

**Bangor University**

## **DOCTOR OF PHILOSOPHY**

**The time-course of attention orienting via observed gaze direction: facilitation, inhibition, and the effects of emotional expression**

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*Award date:*  
2005

*Awarding institution:*  
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**The time-course of attention orienting via  
observed gaze direction: Facilitation,  
inhibition, and the effects of emotional  
expression**

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This thesis is submitted in part fulfilment of the degree of Doctor of Philosophy,  
completed at the Centre for Cognitive Neuroscience, School of Psychology

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## Acknowledgements

I would like to thank Steve Tipper for his supervision, encouragement and eternal optimism that he has provided over the past years. I also want to thank Mark Fenske for his collaboration and advice; Matthew Paul and Klaus Kessler for making working with the EyeLink almost a pleasure. Further thanks go to Andrew Bayliss for many helpful discussions and also for his library that has no limits. I would also like to express my gratitude for the support that my family and friends at home and in the UK have given me. Finally, I want to say thank you to Dan for his immeasurable support, encouragement, inspiration and love.

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## Abstract

Orienting of attention can occur in response to various types of environmental cues, for example, brief sudden onset events in the periphery or symbolic directional cues such as arrows. It is now well established that observing another person's direction of eye gaze also results in attention shifts in the corresponding direction. Such gaze-evoked attention shifts share many properties with those evoked by peripheral cues: they occur rapidly and even counter to the observer's intention. These properties are hallmarks of reflexive orienting of attention. However, gaze cueing effects differ from peripheral cueing in one central aspect. Whereas with peripheral cues, responses to targets at the cued location are inhibited at longer cue-target intervals (the *inhibition of return* phenomenon), no such costs have ever been observed in response to gaze cues. Instead, the early facilitation effect seems to decay.

The present series of experiments challenge this established view by demonstrating that cueing effects can be obtained over longer intervals than previously observed. Most importantly, these longer-term cueing effects are inhibitory. An investigation into the form of memory mediating these longer-term gaze cueing effects suggests that they are not contingent on long-term retrieval associated with a particular face identity. Instead, information regarding the inhibited location appears to be maintained online in visual spatial working memory.

Given that another person's gaze conveys a wealth of social information, one would expect that the emotional expression of a face should affect the orienting response in the observer. However, previous research has failed to observe such an impact of emotion on gaze cueing. The final experiments in this thesis demonstrate emotion-specific modulations of gaze cueing at longer cue-target intervals than previously probed.

Taken together, the present investigation is an attempt to reconcile some conflicting views in the literature. It shows that peripheral cues and gaze cues trigger very similar behavioural effects, not only in terms of automaticity but also in terms of the basic components of orienting of attention: facilitation and inhibition. The results of these experiments also emphasise the importance of time-course as a variable in the study of attention processes. Finally, they highlight the social significance of observed gaze direction and its impact on orienting of attention in the observer.



## **Chapter One**

### *Introduction*

How do we achieve meaningful interactions with our environment? We have to search for and select pertinent information from a vast array of sensory input, most of which is irrelevant for the current behavioural goal or may even distract from the task at hand. Imagine you are looking for your friend in a busy pub; you will have to search through many groups of people until you find her. Such visual search requires the allocation of attention to potential target locations until the required person or object is found. How is our attention directed to candidate locations? Orienting of attention can occur in response to various types of environmental cues. For instance, while searching the pub for your friend, someone near you may be taking a picture. The sudden bright flash will “grab” your attention away from the group of people you were just examining. Later on, you may be looking for the toilets. If you encounter a sign pointing towards a corner of the room, you will be able to find your target more quickly by turning your attention to the door that is in that direction than if you have to investigate every single door in the bar. Our direction of attention is, however, not only influenced by events or objects in the environment but can also be affected by interpersonal interactions.

We spend the majority of our time in the company of other people. Clearly, in order to successfully interact with those around us, we have to be able not only to understand their behaviour but also who or what that behaviour is directed at. For example, if a person near you starts talking, your response to this event will certainly depend on what is being said but even more so on whether that person is talking to you or somebody else. Any such ambiguity can easily be

resolved by monitoring the other person's eye gaze; if your counterpart is looking at you while talking, he will be, without a doubt, addressing you. Another person's direction of eye gaze can also convey important information about events in the environment. Let's return to our example of being in the pub with a friend: imagine you are in a conversation with your friend, when suddenly she breaks eye contact with you and looks towards the entry. You will almost invariably find yourself turning towards the door as well in order to see what attracted her attention, for example, whether someone you know has just entered the bar.

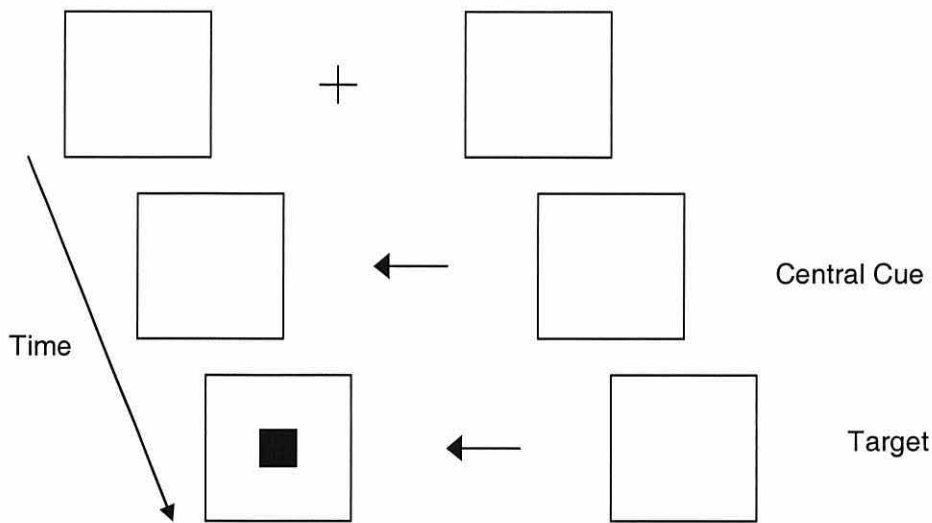
The effects of environmental cues such as sudden onset events and symbolic directional cues on orienting of attention have been investigated extensively over the past decades. Knowledge about issues such as the time-course of orienting; facilitatory and inhibitory processes; perceptual properties of cues and targets; and interactions between attentional and other cognitive systems, has accumulated steadily. In contrast, relatively little is known about the attentional properties of social cues such as the perceived direction of other people's eye gaze.

## Orienting of attention

The central theme of this dissertation is orienting of visual attention. We receive an abundance of visual information whenever our eyes are open, but not all of this input may be relevant for our current behavioural goals. Therefore, our cognitive system must be able to select pertinent input for further processing by attending selectively to relevant aspects of the environment. *Orienting* refers to the alignment of some internal mechanism with an external (visual) input source which results in the preferential processing of that input. Influential work on this topic was carried out by Posner and his colleagues (Posner, 1980; Posner & Cohen, 1984; Posner, Nissen, & Ogden, 1978). Posner (1980) distinguished between two types of attention shifts, *overt* and *covert* orienting. Overt orienting involves the observable orientation of sensory receptors and/or body parts towards a spatial location or object to enable better processing of the target stimulus. Thus, you may move your eyes and head towards an object of interest which will allow the visual input to be foveated and receive optimal processing. Covert orienting refers to alignment of an internal mechanism with some sensory input in the absence of overt responses. Such "invisible" shifts of attention can be detected by using response accuracy or reaction times (RTs) as a measure of processing efficiency of a visual target.

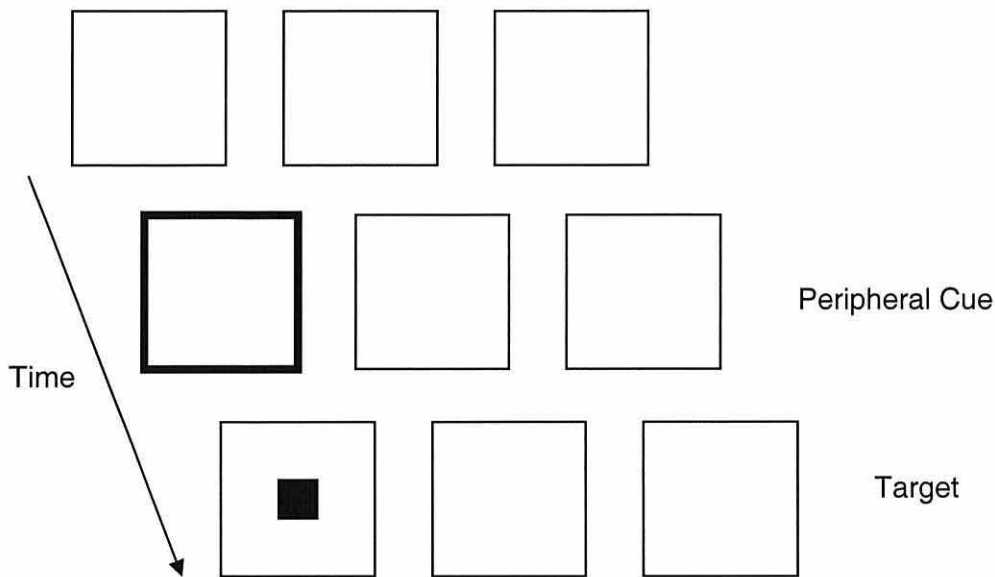
Posner et al. (1978) measured participants' response times to luminance detection stimuli that could occur to the left or right of a central fixation cross. On some trials, the most likely target location was indicated by an arrow presented at fixation (see Figure 1). When the target then appeared in this (the

cued) location, reaction times were faster compared to trials on which the target appeared in the opposite (uncued) location. In order to ensure that this RT difference was not due to facilitated visual processing as a consequence of saccades towards the cued location, eye movements were monitored and only trials in which the eyes remained fixated were included in the analyses. The result of this experiment indicates that participants were able to use the knowledge of the most likely target position to prepare for the subsequent target detection and/or execution of a motor response without having to make an overt orienting response prior to target occurrence. Thus, overt and covert orienting seem to be independent processes. However, there is evidence for a relation between attention shifts and eye movements. Single-cell recording studies with alert monkeys showed that cells in the superior colliculus (SC) have enhanced firing rates if a target that is to be saccaded to is within their receptive fields (Goldberg & Wurtz, 1972). This increased firing occurs even before the actual execution of an eye movement. The SC is a key structure of the neural system to control eye movements and is also implicated in the attention phenomenon of inhibition of return, to be discussed later. This implies that although attention shifts may not depend on eye movements, they can be linked to saccadic motor programs.



**Figure 1. Illustration of the paradigm employed by Posner and his colleagues (1978) to measure covert shifts of attention. An arrow presented at the centre of the display indicates the likely target location. The target then appears in either the same or the opposite location. Adapted from Posner (1980).**

Another way of distinguishing between different forms of orienting is to examine the effects of different types of attention cues, in other words, how attention is controlled. Such control is commonly assumed to manifest itself in two major types: (a) bottom-up (*exogenous*, or stimulus-driven), and (b) top-down (*endogenous*, or goal-driven). Exogenous control is achieved by the capture and guidance of attention by events in the visual field, often in the periphery (Eriksen & Hoffman, 1974). In the basic peripheral cueing paradigm (e.g., Posner & Cohen, 1984), three empty boxes marking the possible target location are aligned horizontally on the screen (see Figure 2). The participant is instructed to fixate on the central box. The outline of one of the peripheral boxes is briefly brightened before a target appears randomly in either box after variable cue-target stimulus onset asynchronies (SOAs). As soon as the target is detected, the participant responds by pressing a key.



**Figure 2. Basic peripheral cueing paradigm. Three boxes are aligned horizontally. One of the outer boxes is illuminated briefly. After variable intervals (SOAs), a target appears in the cued box (valid trial) or the opposite, uncued box (invalid trial). Adapted from Posner and Cohen (1984).**

The abrupt increase in luminance of the peripheral box is assumed to trigger a reflexive attention shift to the cued location which should facilitate target detection at that point in space. Indeed, reaction times are faster when the target occurs in the box that had been brightened (i.e., cued) compared to targets in the opposite (uncued) box. This kind of orienting appears to be automatic as it occurs rapidly and even though the cue is not predictive of the actual target location. Furthermore, instructions to ignore the cue fail to disrupt the cueing effect which is observed even if the target is more likely to appear in the uncued location (Jonides, 1981; Remington, Johnston, & Yantis, 1992).

In contrast to this automatic control of attention, endogenous orienting appears to be, at least partly, under voluntary control. Endogenous orienting is usually triggered by symbolic cues presented at the centre of the display. Such cues may be an arrow pointing to one direction (see Figure 1), or other semantic cues such as a word indicating the likely target location (e.g., “LEFT”). In many studies, the cue correctly predicts the target location on most trials to provide an incentive for the participant to orient in the direction of the cue. What these central cues have in common is that unlike exogenous cues, they do not directly indicate a spatial location, but rather require interpretation. As opposed to peripheral cueing, orienting evoked by the directional information of central cues can be suppressed if that information conflicts with task demands, indicating that endogenous orienting is less automatic than exogenous orienting (Jonides, 1981; but see Friesen, Ristic, & Kingstone, 2004; Tipples, 2002). Also, unlike exogenous orienting, attention shifts incited by central cues are susceptible to interference arising from processing demands of concurrent secondary tasks or orienting reflexes triggered by task-irrelevant peripheral events (Jonides, 1981; Müller & Rabbitt, 1989).

Exogenous and endogenous orienting are mediated by, at least partly, different neural systems. Exogenous orienting is assumed to be subserved primarily by a posterior attention system involving subcortical structures such as the pulvinar and the superior colliculus (Posner, Cohen, & Rafal, 1982; Rafal, Calabresi, Brennan, & Sciolto, 1989). For example, patients with supranuclear palsy which lesions the SC show slowed orienting to peripherally cued locations (Posner, Cohen, & Rafal, 1982; Posner, Rafal, Choate, & Vaughan, 1985).



Single-cell recordings in alert monkeys show that the firing rate of cells in the SC is affected by sudden onset cues but not predictive probabilities (Robinson & Kertzman, 1995). The SC contains both visual cells (located in the superficial layers; Wurtz & Mohler, 1976) and oculomotor cells (in intermediate layers; Mohler & Wurtz, 1976), suggesting that exogenous orienting may be linked to saccadic eye movements. Endogenous orienting is presumably supported more strongly by cortical areas in anterior (e.g., the cingulate gyrus and the supplementary motor area, which are involved in executive functions such as developing and maintaining expectancies; Carr, 1992; see also Corbetta, Miezin, Shulman, & Petersen, 1993) and posterior regions of the brain (e.g., intraparietal sulcus; Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000).

Thus, there is ample support for the notion that exogenous and endogenous forms of attention are mediated by separate neural systems (e.g., Kingstone, Grabowecky, Mangun, Valsangkar, & Gazzaniga, 1997; Rafal & Henik, 1994). However, there is some evidence to suggest that both types of orienting can interact. For example, Müller and Rabbitt (1989) showed that the effect of an endogenous cue is enhanced when it is accompanied by a compatible exogenous cue, while cueing is attenuated if the latter is incompatible. This suggests that both mechanisms can be active simultaneously and their joint influence determines overt performance. In a similar vein, Posner, Cohen and Rafal (1982) manipulated the predictability of peripheral cues such that the target was more likely (on 80% of the trials) to appear in the uncued hemifield than on the same side as the cue. While target detection was initially quicker at the cued location, reaction times were faster at the predicted location after a cue-target

interval of more than 200 ms, indicating that participants were able to voluntarily override the early exogenous capture of attention by the peripheral cue at later SOAs (see also Rafal & Henik, 1994; but see below for an alternative interpretation of these data).

The time-courses of the attentional effects produced by peripheral and central cues, respectively, appear to be characteristic and different. Orienting in response to symbolic cues may arise more slowly than exogenous orienting (Müller & Rabbitt, 1989); while peripheral cues produce their maximum effects at cue-target intervals of approximately 100 ms, the effects of central cues build up more gradually and achieve their largest effects at SOAs of circa 300 ms (Cheal & Lyon, 1991). This difference in orienting latency is also reflected in cortical activation: event-related potential (ERP) recordings show delayed ERP modulations for central cueing compared to peripheral cueing conditions (Eimer, 2000). Another distinction between the two forms of orienting is apparent in the maintenance of cueing effects across time. Facilitation effects triggered by central cues are sustained at optimum level beyond their peak activation at 300 ms. Facilitation in response to peripheral cues, however, declines between 150-300 ms after cue onset (Müller & Findlay, 1988). Even more striking, this initial facilitation is replaced by inhibitory effects at longer cue-target intervals. That is, reaction times to targets on valid trials (i.e., when the target appears in the cued location) are now *slower* than responses on invalid trials (Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984).

## Inhibition of return

This biphasic pattern of reaction times was first discovered by Posner and Cohen (1984) who employed a peripheral cueing paradigm as illustrated in Figure 2. Instead of focussing attention on the location of an uninformative peripheral cue, their participants were encouraged to keep attention to the centre of the display where the majority of targets would occur. In some experiments, attention was automatically drawn away from the cued location by a brief brightening of the central box prior to the presentation of the target. This way, attention shifts could be examined without manipulating the probability of the target location. In both cases, the pattern of reaction times was as follows: for the first 150 ms, RTs on the cued side were quicker than those at the uncued location. After about 300 ms, RTs on the cued side were slower compared to the uncued side. This inhibition effect was observed at SOAs ranging from 300 ms to about 1500 ms.<sup>1</sup> No such reversal of RT patterns was obtained when central arrow cues were used to trigger attention shifts.

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<sup>1</sup> Given that a cued location is inhibited at around 300 ms following the occurrence of the cue, the results of Posner et al. (1982; see above) can be interpreted in a slightly different light: rather than arising from voluntary overriding of exogenous orienting effects, the RT difference between cued (slow) and predicted (fast) locations may reflect inhibition at the cued location.

Posner and Cohen (1984) reasoned that their results reflect the operation of two distinct components of orienting. A sudden event in the environment triggers both facilitatory and inhibitory processes whose joint effect influences responses to targets in the environment (see also Maylor, 1985). If a target occurs in close temporal proximity to a peripheral event, facilitation dominates at the cued location resulting in speeded detection of the target. Once attention is drawn to new locations, inhibition becomes evident at the previously cued location, expressed in elevated RTs. They argued that such a two-fold orienting mechanism would aid the detection of new events in the environment by preventing attention from repeatedly returning to a location that has already been examined. Such perseveration would have potentially devastating consequences for an animal or human searching the environment for desired objects such as food, or potential dangers such as predators, because attention would become trapped at locations that have been (possibly unsuccessfully) monitored while the remainder of the organism's surrounding would be neglected. Hence, this phenomenon has been coined *inhibition of return* (IOR) in reference to the presumed purpose of the inhibitory orienting mechanism (Posner et al., 1985).

This hypothesis was supported by the results of a visual search study by Klein (1988). In visual search tasks, a target is embedded among distractor items. If the target is characterised by unique features, search of the items in the array may proceed in a parallel, effortless fashion so that the target "pops out" from the display. In cases where the target and distractor items share critical features, detection requires a more difficult serial search of each item in turn (e.g., Treisman & Gelade, 1980). If IOR serves to facilitate such serial search by

inhibiting locations or items that have been examined, delayed reaction times should be observed to a detection stimulus that subsequently appears in the location of a search array item, compared to stimuli in other locations. In contrast, no inhibition should emerge for popout searches that do not proceed in such serial fashion. The results of Klein's study supported these predictions, suggesting that IOR serves to bias attention away from previously attended locations, thereby facilitating visual search. A subsequent study by Wolfe and Pokorny (1990) failed to replicate these results when the search array was terminated before presentation of the probe item. When the search objects remain on the screen, however, similar effects to Klein's original study are observed, suggesting that inhibition in this situation may be object-based rather than location-based (Klein & MacInnes, 1999; Müller & von Mühlenen, 2000; see Tipper, Driver, & Weaver, 1991; Tipper, Weaver, Jerreat, & Burak, 1994).

Although IOR is commonly assumed to arise from inhibition of attentional orienting affecting sensory perceptual processing of stimuli (e.g., Reuter-Lorenz, Jha, & Rosenquist, 1996), an alternative (though not mutually exclusive) view postulates that the locus of IOR is at the level of motor response. According to this account, IOR is the manifestation of a motor bias against responding in the direction of the cued location. Initial evidence for this conception came from experiments conducted by Rafal and his colleagues (Posner et al., 1985; Rafal et al., 1989). Rafal et al. (1989, Exp. 4) compared cueing effects in response to peripheral and central cues while manipulating eye movement responses to the cue: participants were instructed to either keep fixated at the centre; to execute a saccade in the direction of the cue; or to

prepare a saccade to the cued location which was to be executed only if a target appeared subsequently (a brightening of the central fixation box otherwise signalled that the saccade should be cancelled). Manual response times to a target following the central brightening were recorded to measure IOR. Inhibition at the cued location was observed in all peripheral cue conditions. Peripheral visual signals have been shown to prime the oculomotor system to prepare a saccade (Rafal et al., 1989). IOR also emerged in the central cue conditions that required direct activation of the oculomotor system (i.e., saccade execution and preparation). Previous studies had failed to obtain IOR in response to central cues when saccadic programming was not required (e.g., Posner & Cohen, 1984). Furthermore, IOR can bias saccadic eye movements away from a previously cued location (Posner et al., 1985). Thus, it appears that IOR and saccadic motor programming are interrelated.

The strongest proponents of a motor account of IOR are Klein and Taylor (Klein & Taylor, 1994; Taylor & Klein, 1998) who argue that if IOR reflects impaired attentional orienting, speed and/or efficiency of target processing at the inhibited location should be impaired. However, the evidence for this is ambiguous (e.g., Maylor, 1985; Gibson & Egeth, 1994; Posner et al., 1985; Pratt, Kingstone, & Khoe, 1997; Reuter-Lorenz et al., 1996; Schmidt, 1996; see Taylor & Klein, 1998, for a review). To account for the equivocal findings in the literature, Klein and Taylor (1994) suggested that a necessary condition for IOR to be observed at a cued location is that an eye movement towards it had previously been programmed. Subsequently, Taylor and Klein (2000) conducted an exhaustive examination of 24 stimulus-response combinations (factorial

combinations of peripheral and arrow stimuli; manual, saccadic or no responses) to test their hypothesis. Apparently consistent with their view, they found IOR in conditions that engaged the saccadic system but, unexpectedly, also in conditions that required peripheral visual processing in the absence of oculomotor responses. Therefore, both attention and motor control seem to be involved in generating and measuring IOR (see also Kingstone & Pratt, 1999). This suggests that covert attention and motor control are interrelated (Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Rizzolatti, Riggio & Sheliga, 1994), and that IOR may serve to separate action programs from associated stimuli (Riggio, Scaramuzza, & Umiltà, 2000; see also Vivas & Fuentes, 2001). Most importantly, it appears that IOR is a multifaceted phenomenon that can be elicited by different types of cue and affects various stages of processing, probably depending on the demands of the task at hand (e.g., Cheal, Chastain, & Lyon, 1998; Ivanoff & Klein, 2001).

### Issues of time-course

IOR is usually observed from about 200-300 ms after the onset of a peripheral cue, until about 1000-1500 ms (e.g., Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Posner & Cohen, 1984), but has also been demonstrated at even longer SOAs (e.g., 3000 ms; Samuel & Kat, 2003). As noted earlier, the inhibition effect is typically preceded by shortlasting facilitation at the cued location. Does this mean that inhibition succeeds facilitation once attention has been withdrawn, or do both effects occur in parallel? According to Posner and Cohen (1984), "a

peripheral visual stimulus both summons attention and serves to inhibit the processing of further information at that position in space. These two effects appear to be independent and may cancel each other out... Immediately after a cue there is usually net facilitation, and no net inhibition appears to occur unless attention is summoned away from the cue" (p. 541). Thus, although they assumed that an active withdrawal of attention from the cued location was necessary for inhibition to be observed, they acknowledged that facilitation and inhibition may be separable phenomena that can co-exist and influence overt performance in an additive manner.

Danziger and Kingstone (1999) devised an elegant procedure that allowed for dissociation between endogenous and exogenous orienting, and hence, facilitation and inhibition effects at a cued location. They presented their participants with four boxes positioned at 12, 3, 6, and 9 o'clock positions around a central fixation cross. There were three perceptually identical cue conditions involving the brief appearance of a peripheral cue (i.e., the brightening of a box), followed by a target at SOAs of 50 or 950 ms. In one condition, the cue was uninformative regarding the target location. It was expected that exogenous orienting to the cued location should initially facilitate target detection at the cued relative to uncued locations, followed by inhibition at the long SOA. In the second condition, the target was most likely to appear in the cued location. Facilitation at the cued location was predicted for the short SOA, while at the long SOA, inhibition might be obscured by endogenous maintenance of attention. Finally, the third type of cue predicted that the target would occur at the location clockwise from the location of the cue on the majority of trials. In



this scenario, exogenous orienting should result in the typical biphasic RT pattern at the cued location, while endogenous shifts of attention should facilitate performance at the predicted location. The results confirmed the predictions regarding the first two cue conditions. Surprisingly, when both types of orienting did not confound each other in the third condition, inhibition emerged at the cued location at both SOAs. This implies that IOR does exist at the cued location even at very short cue-target intervals, but is typically masked by simultaneous facilitation (see also Tipper, Rafal, Reuter-Lorenz, Starrveldt, Ro, Egly, Danziger, & Weaver, 1997). Thus, facilitation and inhibition reflect separate processes that can co-occur at a given location.

In support of this notion, several studies have failed to find facilitatory effects at short SOAs, suggesting that the biphasic RT pattern of facilitation followed by inhibition is not an inevitable consequence of peripheral cueing (e.g., Berlucchi et al., 1989; Danziger, Kingstone, & Snyder, 1998; Tassinari, Agliotti, Chelazzi, Peru, & Berlucchi, 1994; Tassinari & Berlucchi, 1993). One factor contributing to the equivocal results regarding the time-course of facilitation and inhibition may be the effects of the physical characteristics of cue and target. For example, Maruff, Yucel, Danckert, Stuart, and Currie (1999), demonstrated that for facilitation to occur at short SOAs, a temporal overlap between cue and target, as well as visibility of the target until response execution were required. Interestingly, no inhibition was observed at later SOAs when there was a temporal overlap between cue and target. Thus, the continued presence of the cue may have cause facilitatory processes to remain active at the

cued location, thereby either preventing the generation of inhibition or masking its effects.

Collie, Maruff, Yucel, Danckert, and Currie (2000) extended their finding by investigating the spatial as well as the temporal distribution of facilitation and inhibition. They presented a central landmark circle and two peripheral landmark circles aligned horizontally at eccentricities of  $9^\circ$  (near) and  $18^\circ$  (far) on either side. One of the peripheral circles was brightened for either 50 ms or until the end of the trial. After variable cue-target SOAs (ranging from 50 to 850 ms) a target appeared in one of the peripheral circles. Whereas facilitation extended from fixation to the cue but not beyond it, inhibition was observed at both target angles in the cued hemispace, regardless of the eccentricity of the cue. Critically, when the cue duration overlapped with target onset, significant IOR was obtained at late SOAs, but only for far target positions when the cue had appeared at the near location. Note that the null-effect pattern corresponds with the spatial distribution of the facilitation effect. Thus, although IOR is triggered even when there is a temporal overlap between cue and target, its emergence is masked by continuous facilitation at the cued location (see also Wascher & Tipper, in press).

This finding supports Posner and Cohen's (1984) original assumption that attention needs to be withdrawn from the cued location for inhibition to be observable (though this is not necessary to *activate* the inhibition). It is unclear, however, how such withdrawal is achieved. Note that in their original task, attention was actively encouraged not to remain focussed on the cued location,

either endogenously by manipulating the probability of target occurrence at non-cued locations or exogenously by summoning attention to other locations via a second sudden-onset cue. Such active aid may not be necessary for attention to disengage from the cued location. Indeed, several studies have obtained IOR without employing manipulations to re-orient attention to fixation (e.g., Maylor, 1985; Maylor & Hockey, 1985; Pratt, Hillis, & Gold, 2001; Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987). Pratt, O'Donnell, and Morgan (2000) even showed that the magnitude of IOR is reduced when the second cue (which draws attention from the location of the first cue) is presented at the location of fixation, compared to conditions in which the second cue appears at a peripheral location other than the first cue. However, they did not include a control condition where the second cue was absent. Thus, it is still possible that the presentation of a second cue, regardless of its location, aids the withdrawal of attention from the original cue location. Therefore, a re-cueing manipulation is often employed to ensure that IOR is observed (e.g., Abrams & Dobkin, 1994a; 1994b; Rafal et al., 1989; Terry, Valdes, & Neill, 1994). This may be especially important when the task at hand is attentionally demanding. Klein (2000) suggests that when a high level of attention is required to perform the target task, this attentional set is also applied to the cue, resulting in difficulties to disengage from the cued location.

According to Klein (in press), this may explain why the time-course of IOR varies with task demands when attention is not summoned away from the cued location. IOR has been demonstrated with a wide variety of target tasks. It is obtained when the target requires simple detection of its onset (e.g., Maylor, 1985; Reuter-Lorenz et al., 1996; Terry et al., 1994); a manual choice response

based on target location (e.g., Maylor, 1985; Ro, Farné, & Chang, 2003; Tanaka & Shimojo, 1996); and saccadic eye movements to the target location (e.g., Abrams & Dobkin, 1994; Maylor, 1985; Rafal, Egly, & Rhodes, 1994; Reuter-Lorenz et al., 1996; Ro, Pratt, & Rafal, 2000). The evidence for IOR in tasks that require responses based on non-spatial target features, however, is equivocal. Until recently it was assumed that IOR cannot be obtained in target discrimination tasks (e.g., Tanaka & Shimojo, 1996; Terry et al., 1994). However, given that IOR is not only associated with locations but also with specific objects (e.g., Paul & Tipper, 2003; Tipper et al., 1991; 1994), one should expect that IOR emerges when discrimination of stimulus dimensions other than their location is requisite. Indeed, IOR has now been demonstrated with tasks requiring colour, orientation or shape discrimination of the target stimulus (e.g., Chasteen & Pratt, 1999; Cheal et al., 1998; Law, Pratt, & Abrams, 1995; Lupiáñez, Milán, Tornay, Madrid, & Tuleda, 1997; Pratt & Abrams, 1999; Pratt & Castel, 2001; Pratt, Kingstone, & Khoe, 1997).

What factors contributed to the previous failure to observe IOR when target discrimination was required? First, it may be due to the fact that those studies typically employed target-target paradigms (that is, both the cue and the target are responded to; e.g., Tanaka & Shimojo, 1996; Terry et al., 1994; but see Egly et al., 1992). Thus, as attending to non-spatial target features was necessary for executing the first response, this may have prevented inhibition from occurring. This notion was supported by Pratt (1995) who demonstrated IOR with a shape discrimination task using a traditional cue-target paradigm (c.f. Posner & Cohen, 1984). However, Pratt (1995) had his participants respond by

making an eye movement towards the target. Hence, it is possible that the observed inhibition was due to this localisation component of the task.

Second, the temporal interval between cue and target onset has been shown to play a critical role in producing IOR with discrimination tasks. As noted by Lupiáñez et al. (1997), Pratt employed a very long cue-target SOA of 960 ms, whereas researchers who had failed to obtain IOR used shorter SOAs (e.g., 500 ms; Pontefract & Klein, 1988). In order to examine this factor, Lupiáñez and his colleagues compared manual response times in two perceptually identical task conditions. One required the detection of target onset, and the other condition required discrimination of its colour. They employed a wide range of cue-target SOAs (from 100 to 1300 ms) to assess the impact of the task demand on the time-course of inhibition. Whereas IOR was evident at SOAs from 400 ms onwards in the detection task, in the discrimination task it emerged only at substantially longer intervals (from about 700 ms until 1000 ms). This not only demonstrated that IOR can be obtained in detection as well as discrimination tasks, but also suggested that its time-course differs depending on the processing demands of the task.

This notion was confirmed in a subsequent study by Lupiáñez, Milliken, Solano, Weaver, and Tipper (2001). In their experiment, participants responded to a target with a simple detection response, a two-choice discrimination response, or a go/no-go discrimination response. The latter condition was particularly interesting because it combined the perceptual processing demands of the discrimination task and the response demands of the detection task. Thus,

the researchers could determine whether the delayed onset of IOR in discrimination tasks was related to specific processing requisites associated with the target or to general response selection requirements of the task. The onset of inhibition in the detection task was at an SOA of 400 ms. In the discrimination tasks, IOR was not obtained until 700 ms after cue onset. Importantly, this time-course of cueing effects was the same for both discrimination tasks. Thus, the later emergence of IOR in discrimination than detection tasks is indeed attributable to processing demands of the task.

Although there is now a plethora of evidence regarding the nature of the time-course of IOR, relatively little is known about how inhibition is maintained across time. IOR can not only be observed over a relatively long period of time at a given location, but it can also be associated with multiple successively cued locations (Danziger et al., 1998; Snyder & Kingstone, 2000; Tipper, Weaver, & Watson, 1996). For example, Snyder and Kingstone (2000) reported IOR at five recently cued locations, with the magnitude of the effect decaying with greater delays between cue and target onset. This pattern has led some researchers to advocate that some form of limited capacity working memory is involved in "tagging" inhibition to successive locations (see Shore & Klein, 2000, for a review). This assumption is consistent with the finding that inhibition stays with cued objects, even if they move to novel locations (Tipper et al., 1991; 1994; Tipper, Jordan, & Weaver, 1999), because information regarding the visual and spatial properties of those objects can be updated "online". Precisely this function had been ascribed to working memory by Baddeley and Hitch (1974; Baddeley, 1981; 1986) in their original model.

Recently, the role of visuospatial working memory in maintaining IOR has been probed in a peripheral cueing paradigm (Castel, Pratt, & Craik, 2003). Spatial working memory refers to the ability to encode, transform, and maintain spatial information for perception and action (Corbetta, Kincade, & Shulman, 2002). Castel and his colleagues presented secondary tasks between cue and target onset which involved different types of working memory load. In a spatial task, participants were required to determine the direction in which briefly presented arrows were oriented. In non-spatial tasks, the arrows were present but to be ignored, or a series of digits was to be monitored to identify the number of odd digits. These manipulations were based on the assumption that a stimulus can interfere with the maintenance of information in working memory if they share the same neural representations. Such interference procedures have been used extensively in working memory research (e.g., Baddeley & Lieberman, 1980; Brooks, 1968; Tresch, Sinnamon & Seamon, 1993). These studies have identified at least two separate types of working memory: object and spatial memory. For example, Tresch, Sinnamon & Seamon (1993) instructed their participants to remember the location of a dot in a spatial memory test, and the form of an object in an object memory test. They showed that object memory was selectively disrupted by a colour discrimination object task while spatial memory was selectively impaired by a movement discrimination spatial task. Similarly, Castel et al. (2003) found that IOR was selectively eliminated when the intervening task demanded spatial processing but was maintained in equally demanding non-spatial conditions. They concluded that the inhibited (i.e., previously cued) location is held in visual spatial working memory so that an intervening task requiring the same processes disrupts the trace of the inhibited

location. Similar results were also obtained by Paul (2003) who showed that IOR was disrupted only when a concurrent spatial decision task was introduced but not when the task required lexical decision (i.e., when it was non-spatial).

Another study examining the effects of peripheral cues over long periods of time proposed that a different form of memory may be implicated when the time between cue and target onset is extended considerably. Tipper, Grison, and Kessler (2003) suggested that when encoding a stimulus into long-term memory, the whole processing episode is encoded. This would include the state of attentional networks associated with that stimulus at the time of encoding. When the stimulus is encountered again, retrieval can reinstate the original state of the attentional network. Such a mechanism would be beneficial when searching highly complex scenes where localisation of the desired item might take several minutes, and would enable the observer to smoothly proceed with the search after an interruption.

In their experiments, Tipper et al. (2003) presented pairs of faces, one to the left and one to the right of fixation. These stimuli were contextually rich and colourful so that each face would constitute a distinct processing episode. Coloured patches were briefly superimposed to represent cue (red patch) and target (green patch). Participants were instructed to ignore the red cues and respond to the green flashes only by pressing a left or right button corresponding to the position of the target on the screen. In the first experiment, cue and target were presented within the same trial, with a cue-target SOA of 1800 ms. In two further experiments, the cue display was followed by several other displays (48



and 192, respectively, to generate SOAs of three minutes and 13 minutes) containing different stimuli before the original display was re-presented with a target patch. IOR was observed across each time interval. These long-term effects could not be explained in terms of transient online inhibition, because several stimuli had been cued in between the presentation of a particular cue/target pair. Thus, it appears that inhibitory mechanisms underlying IOR can leave traces in long-term memory that can be reinstated when the processing episode is retrieved after long intervals (see also DeSchepper & Treisman, 1996).

### The neural basis of IOR

Human visual processing is subserved by two major neural pathways from the retina to the brain, the geniculostriate and the retinotectal pathway. The majority of optic fibres project from the retina to the lateral geniculate nucleus of the thalamus. From there, visual information is projected to the cortex. This geniculostriate pathway is implicated in higher visual processing. The remaining fibres of the optic tract terminate in subcortical structures such as the pulvinar of the thalamus and the superior colliculus. This retinotectal pathway is strongly implicated in oculomotor actions and is considered the more primitive visual system as it is also found in lower mammals. Given the evidence linking IOR to saccadic motor programming, it is widely agreed that IOR is mediated by the retinotectal visual pathway, prominently the superior colliculus (e.g., Posner et

al., 1985). This view is supported by a broad range of converging evidence including behavioural, neuropsychological and neurodevelopmental studies.

Although each SC receives monocular input from the contralateral visual field, the projections from the temporal hemifield are greater than those from the nasal hemifield (Lewis, Maurer, & Milewski, 1979; Sherman, 1974). Likewise, IOR is greater for targets presented in the temporal hemifield under monocular viewing conditions (Rafal et al., 1989; see also Rafal, Henik, & Smith, 1991; Simion, Valenza, Umiltà, & Della Barba, 1995). Patients with damage to the SC show impaired IOR. For example, patients with progressive supranuclear palsy which affects the SC (but also other midbrain areas) have deficits in IOR along the same spatial orientation in which eye movements were severely impaired (Posner et al., 1985; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988). In accordance with this, a patient with a rare focal lesion to the right SC exhibited disruption of IOR in the contralesional hemifield. More specifically, this patient showed IOR only in the right temporal and left nasal hemifields, suggesting that it was generated by the intact SC (Sapir, Soroker, Berger, & Henik, 1999).

Furthermore, human infants whose visual processing is subserved primarily by the retinotectal visual pathway (Johnson, 1990) demonstrate IOR effects in overt orienting (Simion et al., 1995; Valenza, Simion, & Umiltà, 1994). Similarly, hemianopic patients with damage to primary visual cortex presumably process information in the blind field via subcortical systems. Indeed, presentation of a cue in the blind field elicits IOR effects (Danziger, Fendrich, & Rafal, 1997).

Also, IOR interacts with a phenomenon known as the *gap effect*. This term refers to speeded responses to a peripheral target when the onset of the target is preceded by the offset of the fixation stimulus, compared with conditions where the fixation point remains visible during presentation of the target (Fischer & Ramsperger, 1984; Saslow, 1967). A temporal gap of about 200 ms produces the biggest RT advantage and affects both saccadic (Fischer & Ramsperger, 1984) and manual responses (Bekkering, Pratt & Abrams, 1996). Like IOR, the gap effect is thought to be mediated by the SC (Dorris & Munoz, 1995; Munoz & Wurtz, 1995a; 1995b; Schiller, Sandell, & Maunsell, 1987; Sparks & Mays, 1983; see also Reuter-Lorenz, Hughes, & Fendrich, 1991). Importantly, larger IOR effects are observed in a gap paradigm, suggesting that IOR and the gap effect influence response times via a shared neural mechanism (Abrams & Dobkin, 1994b).

However, the SC is certainly not the sole mediator of IOR, neither is the neural basis for the effect restricted to subcortical structures. The SC receives input from various areas including cortical areas such as the frontal eye field (FEF) and the parietal lobe, which may be implicated in generating IOR (see Lepsien & Pollman, 2002; Rosen et al., 1999). For example, temporary impairment of the FEF via transcranial magnetic stimulation (TMS), applied after the presentation of a visual cue, has been shown to abolish IOR associated with targets that were ipsilateral to the disabled FEF (Ro, Farné, & Chang, 2003). Similarly, patients with parietal lobe damage show disturbances in IOR for ipsilesional targets (Bartolomeo, Chokron, & Sieroff, 1999; Vivas, Humphreys, & Fuentes, 2003). In line with these findings, it has recently been proposed that

although the SC is coding IOR, the effect is generated in those cortical regions that project to the SC (Dorris, Klein, Everling, & Munoz, 2002). Thus, it seems that activation of the SC may be necessary but not sufficient for producing IOR.

Further support for the notion of cortical involvement in at least some forms of IOR comes from behavioural evidence. It is now well established that IOR operates in various frames of reference. For example, IOR works in retinotopic coordinates where a location on the retina that was cued is inhibited (e.g., Abrams & Pratt, 2000); in environmental coordinates where inhibition is aligned with a location in the environment (e.g., Maylor & Hockey, 1985); and in object-based frames of reference where inhibition is associated with a moving object (e.g., Tipper et al., 1991; 1994; 1999). Tipper et al. (1994) argued that object-based IOR must be dependent on cortical processing because the SC does not process information in object-based coordinates nor does it encode the speed and direction of moving objects. Instead, such computations are achieved by cortical systems such as the medial temporal lobes, inferior temporal lobes, and frontal eye fields (e.g., Gross, 1991; Olson & Gettner, 1995; Priebe, Churchland, & Lisberger, 2001). There is also neuropsychological evidence in line with this view. Tipper et al. (1997) investigated object-based IOR in two split-brain patients. They observed that IOR emerged reliably as long as the object moved within a visual field (and therefore was processed in the same cortical hemisphere). However, when the cued object crossed into the other visual field, a facilitation effect emerged. Control participants showed IOR effects regardless of the visual field in which the object was moving. Thus, in order to transfer object-based inhibition between visual hemifields, intact connections between

the cortical hemispheres are necessary, indicating that object-based IOR is dependent on cortical processing. All this evidence suggests that IOR is generated and/or mediated by a widespread cortico-subcortical network, which supports its status as a flexible and versatile mechanism to aid visual search of objects in complex environments.

### **Gaze cues**

Research on IOR has begun to increase the ecological validity of peripheral cueing paradigms by using moving objects (Tipper et al., 1991; 1994), salient objects (Paul & Tipper, 2003), and faces (Tipper et al., 2003) as target placeholders rather than static boxes. However, the cues in these experiments typically remain artificial and arbitrary (e.g., the brightening of the outlines of shapes or colour patches superimposed onto objects). Recently, researchers have discovered the effects of more naturalistic, social cues on orienting of attention: the perceived direction of another person's eye gaze.

The perception of eye gaze is of special social importance for both humans and non-human primates as it can convey information about another's intentions and emotional states (see Kleinke, 1986, for a review). Thus, human infants spend more time looking at the eye region than other features of the

human face (Maurer, 1985). Similarly, adults tend to look preferentially at the eyes when scanning a picture of a face (Mertens, Siegmund & Grüsser, 1993). There is also a high sensitivity towards changes in the direction of another's gaze (Anstis, Mayhew, & Morley, 1969; Gibson & Pick, 1963; Vecera & Johnson, 1995). For example, in adult-infant interaction situations, 3-month olds smile less when the adult is looking away from them (Hains & Muir, 1996). This shows that they can discriminate changes in an adult's gaze direction, and appear to be able to relate that information to the social bond between themselves and the observed person. Other primate species use such eye gaze information to confer signals of social hierarchy. Eye contact and averted gaze are used as expressions of dominance and submission, respectively (Brothers & Ring, 1993; Mendelson, Haith, & Goldman-Rakic, 1982; Perrett & Mistlin, 1990).

Another's eye gaze direction also communicates information about important events in the environment. Typically, people are looking towards the objects to which they are attending so that the relevant input receives optimal perceptual processing. Therefore, the encoding and interpretation of another person's gaze direction would enable the observer to detect that person's focus of attention. The capacity of gaze following appears to be a fundamental skill. Recently, it has been shown that human infants as young as 3 months can initiate attention shifts in the direction of an adult's gaze (Hood, Willen & Driver, 1998), although other researchers have suggested that this ability does not arise reliably until 12-18 months of age (e.g., Moore & Corkum, 1998; Scaife & Bruner, 1975). Non-human primates also appear to be able to use directional information

conveyed by conspecifics' eye gaze to locate food in the environment (Tomasello, Call, & Hare, 1998; but see Anderson, Montant, & Schmitt, 1996).

The ability to align one's focus of interest with that of another person is known as *joint attention* (e.g., Baron-Cohen, 1994; 1995; Bruner, 1981; Moore & Corkum, 1998). It is considered to be a prerequisite for theory of mind (ToM) which allows a person to interpret other people's intentions and actions and, therefore, is a key for successful social interactions. Both these abilities are markedly impaired in some neuropsychiatric disorders such as autism (e.g., Baron-Cohen, 1989). Baron-Cohen (1995) proposed an attentional mechanism that allows for joint attention where the agent and the observer are both attending to the same object or event, triggered by the agent's shift in eye gaze direction. As one central component of this social attention network, Baron-Cohen suggested an "eye-direction detector", a mechanism which encodes the presence of eyes and whether their gaze is directed at the observer or other objects in the environment. Indeed, there is now copious evidence that certain areas of the brain are specialised in processing gaze-related information.

### The neural basis of joint attention

A central component of the neural system for social perception is the cortical region within and near the superior temporal sulcus (STS). The STS is responsive to movements of the hands and body, as well as the eyes and the

mouth, and therefore supposed to code biological motion (Bonda, Petrides, Ostry, & Evans, 1996; Oram & Perrett, 1994; Puce, Allison, Bentin, Gore, & McCarthy, 1998). However, this region is also activated by static images of different postures of the face and body. Furthermore, cells in the macaque STS are sensitive towards the orientation of another's head and eyes. While many cells are most responsive to the combined direction of head and gaze (i.e., frontal view of the face with eye contact or profile view with averted gaze), others are tuned independently to body, head and gaze information (Perret et al., 1990; 1985; Wachsmuth, Oram & Perrett, 1994). Perrett, Hietanen, Oram, and Benson (1992) suggested that such view selectivity could be used to infer the direction of attention of another individual under a variety of viewing conditions. Jellema, Baker, Wicker, and Perrett (2000) supported this idea with their finding that the response magnitude of a subset of cells in STS that are sensitive to reaching movements of an arm can be influenced by the apparent direction of attention (as indicated by gaze and/or head orientation) of the agent performing the action. They proposed that this brain area, specialised in processing the orientation of faces in general and eye gaze in particular, is part of a distributed network that allows the observer to determine another person's intentions.

In humans, the STS region is similarly responsive to perceived gaze direction in both dynamic (Hooker et al., 2003; Puce et al., 1998) and static face displays (Hoffman & Haxby, 2000). This activation does not appear to depend on the presence of a face *per se*, as averted eyes viewed in isolation are sufficient to modulate brain activity (Puce, Smith, & Allison, 2000). In addition, the STS is more responsive to eye movements that provide meaningful directional



information compared to other gaze shifts (e.g., cross-eyed; Hooker et al., 2003). Interestingly, neural activity in response to faces with deviated gaze is modulated depending on whether the gaze is directed towards an object or empty space (Pelphrey, Singerman, Allison, & McCarthy, 2003). This implies that gaze processing is influenced by the perceived goal of the action. Also, viewing faces with direct and averted gaze compared to eyes closed activates some of the same brain areas that are involved in tasks that require the attribution of other people's intentions and beliefs (Calder et al., 2002; Castelli, Happe, Frith, & Frith, 2002). These findings support Baron-Cohen's (1995) proposal that encoding of another's eye gaze direction is an integral part of a theory of mind.

The STS is part of a wider network for social perception that embodies other aspects of face perception, including the processing of face identity as well as analysis of emotional facial expressions. Haxby and colleagues (Haxby, Hoffman, & Gobbini, 2002; Haxby, Ungerleider, Clark, Schouten, Hoffman, & Martin, 1999; Hoffman & Haxby, 2000) proposed that these different functions (i.e., encoding of face identity, and of face properties that are important for social communication such as gaze perception) are distinct cognitive aspects of face perception that are also anatomically dissociable, taking place in lateral fusiform gyrus and STS, respectively (see also Hasselmo, Rolls, & Baylis, 1989; Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997). For example, when participants are instructed to attend to the identity of face stimuli, a stronger response is evoked in fusiform gyrus than in STS. When the task requires attention to the direction of gaze of a face, the STS region is activated more strongly than the fusiform gyrus (Hoffman and Haxby, 2000).

Nevertheless, this result does not preclude an interaction between both areas, such that one type of information could influence the processing of the other.

For example, activity in the fusiform area is enhanced when the observed face is looking ahead than when its gaze is averted, indicating that it receives preferential processing in the former condition (George, Driver & Dolan, 2001; see also Wojciulik, Kanwisher, & Driver, 1998). This effect of eye contact on face processing has been demonstrated in two behavioural studies by Macrae and colleagues (Hood, Macrae, Cole-Davies, & Dias, 2003; Macrae, Hood, Milne, Rowe, & Mason, 2002). They showed that performances on a gender categorisation task, and during encoding and retrieval of face stimuli were improved when the face was looking at the observer than when its gaze was averted or the eyes were closed.

Furthermore, gaze perception appears to be lateralised to the same hemisphere as the system for face processing. Typically, there is a right hemisphere dominance in face processing (e.g., De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994; Kanwisher et al., 1997; McCarthy et al., 1997). This lateralisation of function is expressed behaviourally in better performances for face stimuli that are presented in the left visual field, and in the dominance of the left side of a face stimulus in the perception of facial attributes (e.g., Burt & Perrett, 1997; Christman & Hackworth, 1993). In line with this evidence, Ricciardelli, Ro and Driver (2002) found a left visual field advantage for the discrimination of gaze direction when the eyes were viewed in isolation. In addition, reflexive orienting of attention in the direction of seen gaze is

lateralised to the same cortical hemisphere as face processing in split brain patients (Kingstone, Friesen, & Gazzaniga, 2000). Kingstone et al. (2000) showed that these effects of gaze direction can be triggered when eyes are presented alone but are absent when the face is inverted, a manipulation known to disrupt face processing (Yin, 1969; see also Langton & Bruce, 1999; Vecera & Johnson, 1995). This indicates that although discerning gaze information can be affected by face processing, it is not dependent on it.

Further input-output connections from the STS project to the amygdala, a structure of the limbic system that is heavily implicated in the processing of the emotional content of stimuli, including facial expressions, and linking this information to emotional responses in the observer (Aggleton, 1993; Aggleton, Burton, & Passingham, 1980; Thomas, Drevets, Whalen, Eccard, Dahl, Ryan, & Casey, 2001). Lesions of the amygdala result in deficits in judgements of both gaze direction and facial expression (Aggleton, 1993; Young, Aggleton, Hellawell, Johnson, Broks & Hanley, 1995), suggesting that it plays a critical role in both tasks. The role of the amygdala in gaze monitoring has been highlighted by several recent functional neuroimaging studies which showed that amygdala activity occurs in response to passive viewing of direct and averted gaze (Wicker, Michel, Henaff, & Decety, 1998) as well as when active detection of eye contact versus deviated gaze is required (Kawashima et al., 1999). A further study by Hooker and colleagues (2003) demonstrated that amygdala response to observed gaze reflects the observer's monitoring for emotional gaze events (e.g., eye contact) since its activity was heightened when detection of direct gaze was required but occurred rarely (see also Whalen, 1998).

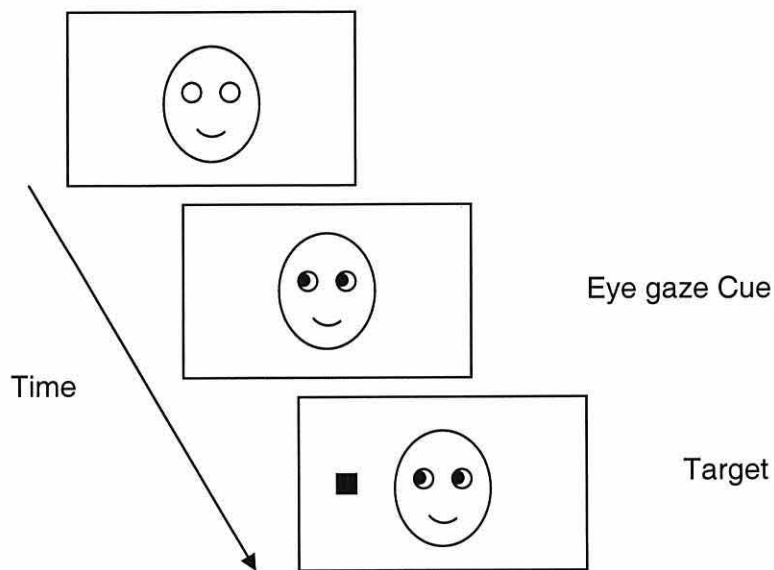
There is also evidence that emotion processing and gaze perception systems can interact. Adams, Gordon, Baird, Ambady, and Kleck (2003) reported that differential sensitivity of the amygdala to faces displaying anger or fear varied as a function of gaze direction. The amygdala has previously been implicated in the brain's response to potential threat (e.g., Adolphs et al., 1999). Adams et al.'s results refine this view by showing that amygdala activity is less pronounced in situations that clearly signal threat to an observer (e.g., an angry face with direct gaze) or clearly signal a threat in the environment (e.g., a fearful face with averted gaze), than in situations where the source of threat requires additional interpretation by the observer (e.g., an angry face with averted gaze or a fearful face with direct gaze). Likewise, anger faces coupled with direct gaze and fear faces coupled with averted gaze are recognised more quickly than either anger faces with averted gaze or fear faces with direct gaze (Adams & Kleck, 2003). Accordingly, Adams and his colleagues argued that the amygdala may play a special role in processing threat-related ambiguity, and that gaze is highly relevant in resolving such ambiguity. Importantly, their findings clearly indicate that the brain's emotional response varies significantly to the same facial expression depending on where the eyes of the observed face are perceived to be looking, which also influences overt performance on behavioural tasks.

The STS is also heavily connected with the parietal cortex, which is implicated in orienting of attention (Harries & Perrett, 1991; Rafal, 1996). Specifically, there are reciprocal connections between STS and the intraparietal sulcus (IPS), an area that is associated with spatial processing and covert shifts of attention (Corbetta et al., 1993; Nobre et al., 1997). Via these connections,

information about eye gaze direction could project to spatial attention systems to initiate orienting of attention in the corresponding direction, as in joint attention. Indeed, passive viewing of a face with averted gaze elicits a stronger response in the IPS than viewing a face with direct gaze (Hoffman & Haxby, 2000). In addition, activity in the STS and fusiform area is correlated with activity in the IPS when a face with deviated gaze is seen (George et al., 2001; Pelphrey et al., 2003; see also Wicker et al., 1998). The relation between gaze perception and spatial attention is apparent in recent behavioural studies that demonstrate that perceived gaze direction can trigger reflexive attention shifts in the corresponding direction in the observer.

### Orienting of attention in response to gaze cues

Only recently have attempts been made to examine the precise cognitive mechanisms of attention shifts in response to eye gaze direction. In these studies, modifications of Posner's cueing paradigm (see Figure 1 and Figure 2) are employed. Instead of fixating on a central box, participants view a face stimulus at the centre of the display. The gaze direction of that face substitutes the peripheral onset or symbolic arrow cues utilised in previous studies of attention orienting. This new paradigm is illustrated in Figure 3.



**Figure 3.** Illustration of the procedure used by Friesen & Kingstone (1998). A schematic face is presented at the centre. The pupils appear in the corners of the eyes, forming a directional eye gaze cue. Then, a target appears in the gazed-at (i.e., cued) or opposite (i.e., uncued) location. Adapted from Friesen & Kingstone (1998).

In one of the first investigations of eye gaze cueing, Friesen and Kingstone (1998) explored whether observed gaze shifts, like traditional attention cues such as peripheral luminance increases or central arrows, produce orienting responses in adults. Participants were asked to respond to target letters that appeared to either the left or the right of a schematic face with varying SOAs after the pupils of the face appeared, constituting a directional gaze cue. The response required was either the mere detection of the target's appearance, or indication of its location or its identity by pressing of appropriate response keys. The eyes of the face looked either left, right, or straight ahead. On valid trials, the target appeared in the gazed-at location while on invalid trials, it occurred in the opposite location. On neutral trials, the face gazed ahead and the target appeared randomly on either side. Participants were informed that the direction

in which the eyes looked was not predictive of the location or the identity of the target, nor when it would appear. Thus, the eye gaze of the face was used as a centrally presented but spatially uninformative cue. The results of the experiment showed that RT was facilitated on valid-cue trials relative to neutral and invalid-cue trials, independent of response type. Furthermore, the cueing effect emerged rapidly at short (105 ms in two response conditions and by 300 ms in all response conditions) cue-target SOAs and disappeared with longer (1005 ms) SOAs. These results reflect the time-course characteristics of automatic, exogenous orienting of attention. However, the data pattern differed from those usually obtained from peripheral cues in an important aspect: no RT cost at longer SOAs was evident, therefore no IOR effect was revealed.

A separate study by Driver, Davis, Ricciardelli, Kidd, Maxwell and Baron-Cohen (1999) used a more realistic computerised face whose eyes were looking to the right or to the left as a central, spatially uninformative cue. Adult participants were required to discriminate a target letter that could appear on either side of the face after 100, 300 or 700 ms. The pattern of results they obtained was comparable to the findings of Friesen and Kingstone (1998). RTs were significantly faster on valid compared to invalid trials at 300 and 700 ms SOAs, even though the direction of gaze was entirely unpredictable of target location or identity. Indeed, in one of their experiments (Exp 3), participants were informed that the target was four times as likely to appear at the uncued side so that they would endogenously orient away from the gazed-at location. Under these circumstances, facilitation was still obtained for the cued location, but only at the 300 ms SOA. At the later interval, a trend towards facilitation at

the expected target side emerged suggesting that participants were able to voluntarily shift their attention in that direction (see also Friesen, Ristic, & Kingstone, 2004). This provides powerful support for the notion that perception of eye gaze direction results in an automatic shift of spatial attention in the fashion of peripheral cueing that cannot be overridden at short SOAs. Again, however, no evidence for IOR was found at the longer SOAs.

Attention can also be cued when gaze and head direction interact.

Hietanen (1999) manipulated head and gaze direction independently to examine which type of cue is more potent in triggering attention shifts. The rationale behind this study was based on work by Perrett and colleagues (1985) who proposed that directional information from gaze, head and body cues is combined hierarchically in a mechanism dedicated to detect another's direction of attention. In Hietanen's study, only short SOAs (up to 220 ms) were used, and frontal views of faces with averted gaze were found to cue attention. If the head was rotated to the side with compatible gaze direction, no cueing effects emerged. In a study by Langton and Bruce (1999), the gaze of the face was always directed in the direction congruent with the orientation of the head. Significant cueing was obtained at a short SOA (100 ms), confirming that social attention cues can trigger reflexive orienting in the observer. Their finding that head orientation cues attention appears to contradict Hietanen's results. However, he had presented heads with only 30° rotation whereas Langton and Bruce had used full profile views. Thus, the directional information conveyed by the cues may not have been as clear with Hietanen's stimuli. In line with previous gaze-cue studies, Langton and Bruce reported no cueing effects at longer SOAs of up to



one second. This finding supports the impression that IOR is not obtained in response to social cues.

Gaze cues also trigger overt orienting responses. Mansfield, Farroni, and Johnson (2003) recorded eye movement latencies to a target presented to the left or right of a face with averted gaze. Reliable facilitation effects were obtained at a fixed SOA of 300 ms. Interestingly, observing averted gaze could elicit saccades in the direction of the cue prior to target onset, even though participants were instructed to fixate on the centre. These involuntary cue-driven saccades did not account for the cueing effects, however, as the results for target-driven saccades were the same when cue-saccade trials were excluded. In a somewhat different task, Ricciardelli, Bricolo, Aglioti, and Chelazzi (2002) investigated whether seen gaze can interfere with goal-driven saccades. In their experiments, potential saccade targets were presented to the left or right of fixation. An instruction cue signalled that a saccade was to be made to one of those targets. A distractor face with averted gaze was then displayed at the centre. Saccadic performance to the target was less accurate when the gaze cue was incongruent with the saccade instruction (i.e., when the face gazed at the non-target). Taken together, these two studies demonstrate that observation of averted gaze can trigger both covert and overt automatic orienting responses (see also Friesen & Kingstone, 2003a).

The studies described above demonstrate that the mere observation of the eye gaze of a face produces a rapid and automatic attentional shift in the direction of the gaze. This orienting occurs when the participants are aware that

the gaze is not predictive of the target location, and even when the target is more likely to appear in the uncued location. Thus, the effect of an attentional cue provided by eye gaze shows similar properties to the effects of traditional peripheral/exogenous cues. This suggests that the encoding of eye gaze direction is an essential aspect of human perception. However, the time-courses of the attentional effects of eye gaze perception differ from those of peripheral cues in one fundamental aspect: eye gaze cueing does not appear to produce IOR at longer SOAs.

### Why do gaze cues fail to produce IOR?

To the best of my knowledge, only two studies directly investigated this lack of IOR in gaze cueing paradigms. With an elegant procedure, Friesen and Kingstone (2003b) compared the attentional effects of gaze cues, which are known to elicit facilitation at the cued location, and of sudden onset cues, which typically trigger IOR at later SOAs. They theorised that the reason why IOR had not been observed in other studies was either that IOR does simply not occur in response to eye gaze shifts, or that IOR is present, but masked by sustained facilitation at the cued location (see Danziger & Kingstone, 1999). In their experiment, four empty circles were placed around a central fixation point. After variable SOAs (105, 555 and 1005 ms), the schematic features of a face (eyes, nose and mouth) appeared abruptly in one of the circles. This occurrence served as a sudden onset cue as well as a directional gaze cue, as the eyes of the face

could look towards one of the other circles. Thus, two separate locations could be cued by two different types of cue with a single event. The offset of one of the circles (which could be at one of the cued or an uncued location) served as the detection target. It was predicted that IOR should appear at the sudden-onset location while facilitation should emerge at the gazed-at location. If IOR was present at the gazed-at location as well but masked, then the amount of inhibition at the sudden onset location should vary depending on whether the onset cue was presented in isolation (with the face gazing ahead) or accompanied by a gaze cue. In the latter condition, the IOR effect should be smaller, because the magnitude of IOR decreases if distributed over several locations (Danziger et al., 1998; Tipper et al., 1996). The researchers concentrated their analyses on the intermediate 555 ms SOA, because traditionally both IOR and reflexive orienting to gaze are observed at such an interval. Indeed, facilitation and IOR did co-occur at separate locations, but critically, the magnitude of IOR was unaffected by the gaze cue. Thus, it appears that IOR and gaze-triggered facilitation effects are separate and independent phenomena, and that gaze perception cannot produce inhibition effects.

In a further study, Friesen and Kingstone (2003a) investigated whether, like IOR, gaze cueing interacts with the gap effect. After presentation of the gaze cue, the face stimulus either remained on the screen or disappeared simultaneously with the onset of the target. The effect of fixation offset (i.e., facilitated saccade latency) was not influenced by the direction of gaze. Friesen and Kingstone took this and the previous finding that both phenomena can co-occur at separate locations as evidence that IOR to abrupt onsets and orienting to

gaze direction are subserved by different neural systems (IOR being confined to subcortical mechanisms and gaze cueing mediated by cortical systems). While this may be true, it is important to remember that IOR is a multifaceted phenomenon which implicates various subcortical and cortical areas, and is not necessarily restricted to one type of cueing. Recall that IOR can occur in response to central arrow cues if saccadic responses are required (Posner et al., 1985). Indeed, inhibition is observed if saccades are prepared but subsequently vetoed (Rafal et al., 1989). Akin to these experiments, gaze studies present the cue at the centre of the display, and saccades are evoked in response to the cue but typically suppressed (Ricciardelli et al., 2002). Hence, the consistent absence of IOR in gaze paradigms is puzzling.

How can the lack of IOR under such circumstances be explained? There are important methodological differences between traditional IOR studies and the gaze cueing studies. In peripheral cueing paradigms, presentation of the cue is brief and transient. Often, this peripheral cue is followed by a second cue at fixation to trigger an attention shift away from the cued location (e.g., Posner & Cohen, 1984). In sharp contrast, the eyes of the face stimulus in gaze paradigms remain oriented to one side until the target appears. Thus, there is a clear temporal overlap between cue and target onset. However, IOR does not occur if the cue remains visible until target onset (Collie et al., 2000; Maruff et al., 1999). Instead, the continuous presence of the gaze information would maintain orienting to the cued location. Such a strategy seems especially likely given that perceived gaze direction provides important social information. Indeed, inhibiting a location that is interesting enough to keep an opponent's attention

focused on it would have had negative consequences for our ancestors, as this prolonged interest of the other person most likely signals an important event such as the approach of an enemy or a potential mating partner. To date, no attempt has been made to match the methodology of gaze-cue paradigms more closely to that employed in studies of IOR. This may be one reason why IOR has never been observed.

Another factor that has not been investigated systematically in the gaze cueing literature is the temporal interval over which facilitatory and inhibitory processes of attentional orienting operate. As we have seen, although the properties of eye gaze cueing are similar to those obtained by peripheral cueing in that they evoke rapid and automatic shifts of attention, there are also differences. Furthermore, there is evidence to suggest that both types of orienting are subserved by different neural systems and proceed in a different manner (Friesen & Kingstone, 2003a; 2003b; Kingstone, Friesen, & Gazzaniga, 2000). Therefore it is possible that although gaze cues do engage both facilitatory and inhibitory processing, the relative time-courses of facilitation and inhibition produced by perceived eye gaze differ from those typically observed in traditional spatial cueing paradigms. All relevant studies have used a limited range of SOAs (from 105 ms to 1005 ms; e.g., Friesen & Kingstone, 1998). Inhibition may simply take longer to develop compared to traditional paradigms so that it is not observed over those intervals.

There are three lines of reasoning to support this view. First, as already pointed out, eye gaze is a very potent cue. Whereas traditional peripheral cues

are often arbitrary and engage attention in a purely exogenous way, gaze cues convey socially meaningful information and can indicate events in the environment that have personal significance for the observer. Thus, it is likely that although observed gaze direction initially triggers automatic attention shifts, there is also an endogenous incentive to maintain attention at the gazed-at location. Due to this prolonged facilitatory processing, IOR would emerge at much later intervals compared to peripheral cueing situations.

Second, the null-results at long SOAs have typically been interpreted as a “decay” of facilitation. However, as noted by Tipper et al. (1997), such null effects must be interpreted with caution, as this does not mean that inhibition is absent. Instead, “it may simply indicate that the underlying excitatory and inhibitory processes are roughly equal in strength” (p. 1529). It has now been shown that facilitation and inhibition can coexist at a given location (e.g., Danziger & Kingstone, 1999). Thus, the null effect at long SOAs could reflect the net effect of both processes that cancel each other out. This implies that the point when inhibition dominates at the cued location lies beyond the range of SOAs that have been probed so far.

Finally, the onset of IOR is delayed with increasing processing demands of the task. Recall that it was originally proposed that IOR was only observed when targets are detected and not when they are identified (e.g., Terry et al., 1994). Subsequent work showed that in fact IOR could be observed when target identification was required, but the inhibition took longer to emerge (Lupiáñez et al., 1997; 2001; see also Khatoon, Briand & Sereno, 2002). This demonstrated

that the time-course of IOR is influenced by the complexity of the task. In traditional peripheral cueing tasks the cue does not pose significant processing demands, therefore inhibitory processes associated with it can proceed smoothly. When the cue is constituted by the presentation of a face which looks in a certain direction, decoding of the cue requires considerably more complex processing. This may delay the onset of IOR in a similar way as demonstrated by Lupiáñez and his colleagues.

A further issue concerning the time-course of inhibition effects has emerged from studies examining the effects of peripheral cues over long periods. Tipper et al. (2003) suggested that the attentional state associated with a stimulus can be encoded into memory and retrieved at later points in time. They had found long-term inhibition using faces as encoding and retrieval stimuli. The use of faces as cue objects in gaze cueing tasks lends itself to investigating this issue further. Specifically, it would be interesting to examine whether inhibition can be obtained with gaze cues but is dependent on such retrieval processes. Thus, if inhibition was observed with extended temporal intervals between cue and target onset, it might be associated with a particular face stimulus that is representing the cue. If one face is looking to one side and later appears along with a target in that location, the face may act as a retrieval cue for the prior encounter of the same stimulus with its associated attentional state. Alternatively, orienting processes in response to gaze cues may act independently of the face stimulus itself. In this case, inhibition of the cued location may be sustained online similarly to the processing proposed by Castel et al. (2003) in their investigation of IOR and working memory.

### Gaze cues and emotion

Given the neurophysiological evidence concerning an interaction between emotion and gaze processing, it is surprising that so few behavioural studies have investigated the impact of the emotional expression of a face on attention shifts in response to its gaze direction. Whereas gaze cues alone can indicate the presence of an important event in the environment, facial expression allows the observer to make inferences about the nature of that event. If, for example, a person looks to one side with a fearful expression, this most likely indicates the presence of danger. It therefore makes sense that gaze-dependent attention effects would vary with the emotion that is being expressed by an observed face. However, the evidence regarding such interactions between emotional expression and gaze-directed orienting of attention is equivocal. Mathews, Fox, Yiend, and Calder (2003) displayed a task-irrelevant photograph of a face with neutral or fearful expressions to represent the gaze-cues. A discrimination target appeared in a cued or uncued location after SOAs of 300 or 700 ms. They found greater facilitation for cued targets when the face was fearful compared to neutral conditions. However, this pattern emerged only for anxious individuals when participants were grouped into high and low levels of anxiety. Another study on gaze cueing and emotion did not differentiate among anxiety levels. Hietanen and Leppänen (2003) used both schematic and realistic faces with neutral, happy, fearful or angry expressions. They too failed to find any evidence that facial affect modulates gaze-dependent attention effects.



However, it is possible that emotional modulation of gaze-dependent attention effects operates across a longer time-course due to the demands of jointly processing facial structure, gaze direction, and emotional expression. Interestingly, the issue of time-course was addressed by Hietanen and Leppänen, who employed a wide range of SOAs across six experiments. After failing to find effects of emotion with 150 and 200 ms SOAs, they extended the interval to 600 ms but obtained similar results. Subsequently, Hietanen and Leppänen reasoned that effects of facial expressions might be short-lived and therefore proceeded to examine very short SOAs of 14-75 ms. Although they did obtain cueing effects at such intervals (providing further support to the notion that orienting to gaze direction is a reflexive process), these were not modulated by the expression of the face. The results of this study clearly demonstrate that the emotional valence of the face stimulus does not affect orienting of attention at short intervals. However, it is possible that such an interaction would be apparent at SOAs beyond the 600-700 ms used by Hietanen and Leppänen (2003) and Mathews et al. (2003).

### **The scope of this thesis**

Orienting of attention can be achieved in response to various types of cue. Eye gaze is an important social cue that elicits reflexive shifts of attention in the

corresponding direction. Although attention shifts triggered by another's direction of eye gaze show similar properties to those attained by sudden peripheral events, both types of orienting differ in one crucial aspect: no inhibition of return is observed when attention is directed by gaze information. Furthermore, gaze-directed orienting effects do not appear to be modulated by the emotional valence of the face stimulus, despite neurophysiological evidence to the contrary. However, it appears that the time-course of facilitation and inhibition and modulations thereof may be a critical factor in resolving these apparent divergences. Nevertheless, this factor has either been neglected in previous research, or addressed insufficiently.

The experiments in this thesis aim to investigate three issues concerned with the time-course of gaze-evoked cueing effects. First, can IOR be observed in response to gaze cues? Second, is the maintenance of cueing effects over time supported by either working memory or long-term retrieval systems? Third, does the emotional expression of a face modulate those effects at longer intervals? Chapter Two investigates the basic (facilitatory) cueing effect and introduces manipulations of the cue in an attempt to assimilate the gaze-cueing paradigm with traditional IOR paradigms. The experiments in Chapter Three examine orienting effects over substantially longer temporal intervals than previously probed. To pre-empt the findings of this chapter, IOR effects were indeed observed at an extended SOA. Chapter Four scrutinises the precise role of time-course and cue manipulations in acquiring this inhibition effect. Chapter Five comprises an investigation of memory involvement in maintaining orienting

across such prolonged intervals. Finally, the effects of emotional expression on gaze-cueing are examined in Chapter Six.<sup>2</sup>

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<sup>2</sup> The experiments in Chapters 2-5 can be found in: Frischen & Tipper (2004), Orienting attention via observed gaze shifts evokes longer-term inhibitory effects: Implications for social interactions, attention and memory, *Journal of Experimental Psychology: General*, 133(4). The experiments in Chapter 6 are currently under review at the *Journal of Experimental Psychology: Human Perception & Performance* (Fenske, Frischen, & Tipper, Faces expressing emotion modulate gaze-evoked shifts of attention). Furthermore, the data from Experiments 2-7 have been presented in form of a poster at the 4<sup>th</sup> Annual Meeting of the Vision Sciences Society, 2004.

## **Chapter Two**

*Properties of attention shifts via observed eye gaze: Effects of  
face identity and central cueing*

The purpose of this chapter was threefold. First, it aimed to establish and replicate the basic effect of eye gaze cueing that had been demonstrated by Friesen and Kingstone (1998) and others (e.g., Driver et al., 1999; Langton & Bruce, 1999), and to lay the methodological foundations for the subsequent experiments of this thesis. Recall that Friesen and Kingstone (1998) had used a schematic face to produce the gaze cues and a relatively wide range of SOAs (from 105 to 1005 ms). They had found reliable cueing from 105 to 600 ms, but no effect of eye gaze at the long 1005 ms SOA. Driver and his colleagues (1999) and Langton and Bruce (1999) had presented more realistic computerised or photographed faces. Like Friesen and Kingstone, these researchers found the most consistent cueing effects at shorter SOAs of 100-700 ms, and again no effect at longer intervals (1000 ms).

Following the procedure of Driver et al., photographs of faces were used in the present experiments to produce the gaze cues. This method provided the basis for all other experiments in this thesis. In this chapter, two cue-target intervals were employed: a short SOA of 200 ms, and a long SOA of 1200 ms, which even exceeds the longest SOA found in the gaze-cueing literature. This interval was chosen to test whether the previous failures to observe IOR had been due to a delayed time-course of inhibition, which therefore may take longer to emerge. It was anticipated that consistent cueing would be found at the short SOA, while at the late interval, either a null-effect as in previous studies should be observed, or inhibition may start to emerge. Experiment 1 closely replicated previous studies by presenting the same face throughout the experiment.

A second aim of this chapter was to examine the effects of the identity of the face on attention cueing. As noted, previous research had presented the same schematic or photographic face throughout the entire experiment. However, some findings suggest that there might be an interaction between gaze direction and face processing. For example, Macrae et al. (2002) suggested a relationship between eye gaze and face identity processing. They investigated whether perceived eye gaze direction can influence face classification. It appeared that performance was improved for stimuli with direct gaze. In a similar vein, Hood et al. (2003) noticed that in a memory task, faces are better encoded and retrieved when their gaze is directed at the observer than when it is averted. Experiment 2 posed the opposite question: can the identity of the face influence orienting to eye gaze? Thus, a different face was presented on each trial to see if the cueing effect increased when habituation to a particular face stimulus was eliminated (see e.g., Gauthier, Tarr, Moylan, Skudlarski, Gore & Anderson, 2000; Jeffrey, 1968; Ravden & Polich, 1998). If participants do not maintain attention with repeated stimuli, then gaze cue orienting effects might decline especially over longer SOAs, which could explain the null-effects that are typically observed. In contrast, when a new face is observed on each trial, then participants may engage attention more with the displays for longer periods, such that significant cueing effects might be observed at the longer 1200 ms SOA condition. Experiment 2 addressed this issue by presenting a different face on each trial. This manipulation was also crucial for later experiments (Experiments 10-13) that investigated whether gaze cueing might be associated with a particular face and retrieved from memory after longer periods of time.

Finally, the lack of IOR that had consistently emerged in previous studies on eye gaze cueing was examined by likening the gaze-cue paradigm to the peripheral cueing paradigm utilised by Posner and Cohen (1984) in their original investigation of IOR. They had presented their participants with a brief peripheral cue which captured attention at that location, followed by a central cue which oriented attention away from the cued location before the target appeared. Despite comparing orienting of attention to eye gaze cues with orienting to peripheral cues, such a re-orienting manipulation has never been employed in eye gaze cueing paradigms in an attempt to observe IOR. In fact, in previous studies, the eye gaze remained directed to one side of space until the target was presented, maintaining orienting to the cued side. This is analogous to the procedure employed by Collie et al. (2000) where the sudden onset peripheral cue remained visible until target onset. Critically, no IOR was obtained under these circumstances. It is therefore important that the cue be transiently presented, and no longer visible when processing the target, for inhibition effects to emerge (see also Wascher & Tipper, in press). Experiment 3 introduced a central cueing manipulation by shifting the eye gaze of the face stimulus back to the centre before the target appeared. Eye contact is known to focus attention on the viewed face (George et al., 2001), so it was hoped that this would summon attention away from the gazed-at location. Thus, inhibition effects may be revealed at the longer SOA when attention is re-oriented to fixation.

### Experiment 1: identical face

This experiment aimed to replicate the basic cueing effect found by previous authors. Typically, the same face has been presented throughout the experiment, and detection or identification of peripheral targets was measured. Likewise, in the present study, the same photograph was presented on each trial, though each participant viewed a different face. The main manipulation was the relationship between eye gaze and the location of the subsequent target. When the eyes gazed at the target location, reaction times were expected to be faster in this validly cued condition, than when gaze direction and target location were incongruent (invalid trials).<sup>3</sup> Furthermore, the SOA between gaze shift onset and target onset was manipulated. It was predicted that facilitation cueing effects would be obtained at SOAs of 200 ms, but no gaze cueing effects at SOAs of 1200 ms, replicating previous findings.

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<sup>3</sup> Some previous studies have also included a neutral (i.e., straight gaze) condition to assess the relative contributions of costs and benefits to the overall cueing effect (e.g., Friesen & Kingstone, 1998). However, finding an appropriate baseline for such cost-benefit analyses is inherently difficult. As Jonides and Mack (1984) point out, the critical assumption is that the “neutral and informative cues must be identical with respect to all their effects except that of information specific to the target” (p. 31). It is reasonable to expect that this assumption would be violated with “neutral” cues such as straight gaze, closed or occluded eyes so that performance on “neutral” trials could not be meaningfully contrasted with valid or invalid trials. For example, straight gaze of the face stimulus establishes eye contact with the observer which in turn evokes emotional arousal and may capture their attention, in contrast to observation of averted eye gaze (Nichols & Champness, 1971; Wicker, Perrett, Baron-Cohen & Decety, 2003). Also, the face-specific N170 ERP wave is delayed when the eyes of a face are closed, suggesting that faces without gaze information are processed differently than when the eyes are visible (Taylor, Itier, Allison, & Edmonds, 2001), an issue that may be critical for the later experiments involving face identity. Therefore, in line with other gaze-cueing studies and traditional IOR studies (e.g., Driver et al., 1999; Taylor & Klein, 2000), only valid versus invalid trials were compared in this as well as the following twelve experiments.



## Methods

### *Participants*

20 undergraduate students (1 male and 19 females; mean age 21.3) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

### *Apparatus*

The experiment was run on a GenuineIntel PC using E-Prime 1.0 software (Schneider, Eshman, & Zuccolotto, 2002). Stimuli were presented on a 17-inch Iiyama VisionMaster 450 monitor set to high colour and a screen resolution of 640 x 480. Participants sat on a comfortable chair with their head position stabilized on a chinrest at a distance of 63 cm from the screen.

### *Stimuli*

A central cross, subtending  $0.7^\circ$ , served as a fixation point. 20 digitised photographs of faces (10 male and 10 female) with their eyes gazing straight ahead were used to produce the cues. The faces, on average subtending  $13.1^\circ$  in height and  $10.4^\circ$  in width, were displayed in 8-bit greyscale. Each face photograph was manipulated to produce the left-gaze and right-gaze cues by cutting out the pupil/iris area of each eye and pasting it into the left and right corner, respectively, of each eye, using Corel Photo Paint 9 software (Corel Corporation, 1999). Thus, only the area within the eyes differed between the cue and straight-gaze stimuli. This ensured that no other asymmetrical properties of

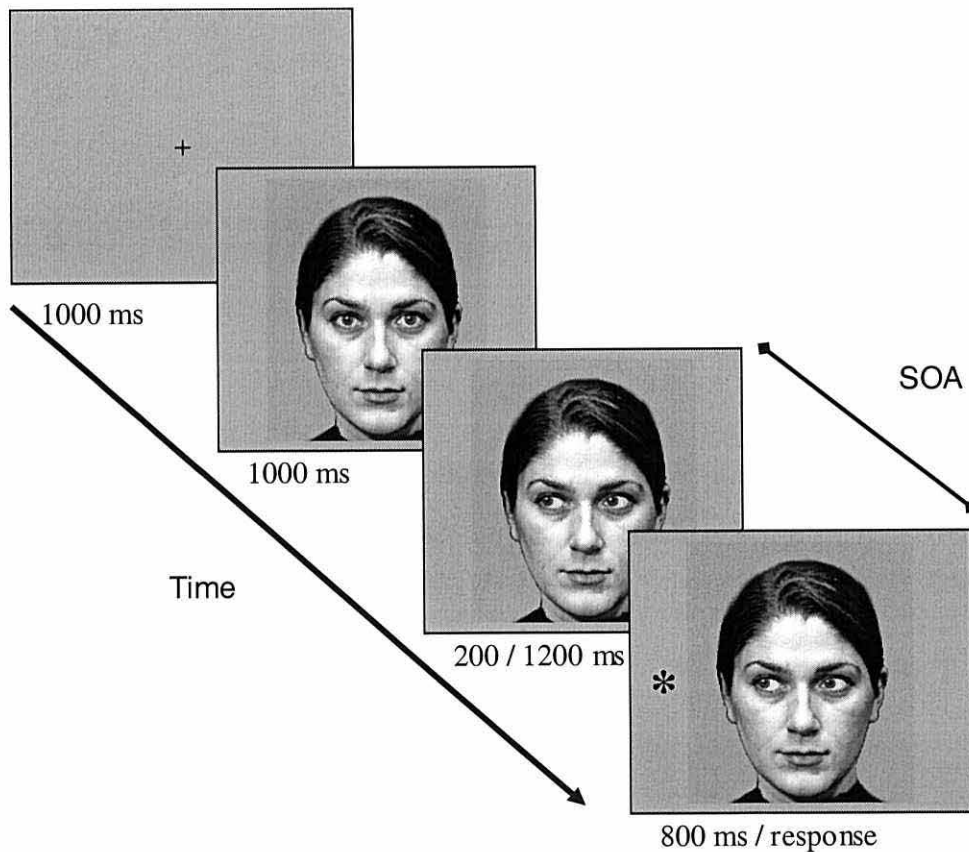
the faces could confound orienting according to the eye gaze cues. The target was an asterisk, subtending  $0.7^\circ$  and presented  $8.6^\circ$  to the left or right of the centre of the screen, approximately on level with the eyes of the face in the vertical plane.

### *Design*

Two within-subjects variables were employed in this study. First, the stimulus onset asynchrony (SOA) between the cue and the target was either 200 ms or 1200 ms. The second variable was the Cue Validity. On validly cued trials, the target appeared at the side the eye gaze of the face was directed to. On invalidly cued trials, the target appeared at the opposite side. Thus, a 2 x 2 design was employed, with the following conditions (SOA - validity): 200-valid; 200-invalid; 1200-valid; 1200-invalid. The dependent measure was the participants' reaction time to the target. Participants performed a short practice block of eight trials representing all four experimental conditions. The face stimulus used in the practice block was the same as that employed in the experimental block. The experimental block consisted of 160 trials randomly drawn from the experimental conditions with equiprobable factorial combinations of the variables. Each participant was presented with a different face stimulus; half the participants viewed a female face, and the other half viewed a male face. This way, possible differential effects of the sex of the stimulus would be balanced out.

*Procedure*

Before the experiment, the participants' vision (i.e., acuity and stereopsis) was tested. The participants sat in front of the monitor, with the keyboard in front of them, under dim lighting conditions. They were instructed to fixate at the centre of the screen throughout the experiment and to respond as quickly and accurately as possible to the target. It was stressed that the target location was completely random and not predicted by the direction of the eye gaze of the face stimuli. They were encouraged to ignore the face. The experimental procedure is illustrated in Figure 4.



**Figure 4.** Schematic representation of the experimental procedure for Experiment 1, depicted here in the validly cued condition.

The participants initiated each trial by pressing the spacebar with their thumb. On each trial, a fixation cross appeared for 1000 ms, which was then replaced by the picture of a face looking straight ahead. After another 1000 ms had elapsed, the pupils of the face appeared to move to either the left or the right corners of the eyes. After an interval of 200 or 1200 ms, depending on the SOA condition, the target appeared to either the left or right of the face. Participants responded by pressing the X-key on the keyboard for a target on the left (using the left index finger), or the M-key for a target on the right (using the right index finger). The response keys were marked with textured stickers to avoid depression of irrelevant keys. The display was terminated with the response, or else after 800 ms had elapsed. Auditory feedback was provided for correct (high beep), incorrect, or missed (low beep) responses.<sup>4</sup>

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<sup>4</sup> In Experiments 1-13, the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) questionnaire was administered to the participants upon completion of the experimental session. The aim was to examine whether participants with high autistic traits would be less responsive to eye gaze cues than those with low scores. However, this was not a central aspect of this thesis, and no consistent results were found. An evaluation of the questionnaire data is presented in the Appendix.

## Results & Discussion

### *Reaction time data*

RT analyses were conducted for correct trials only. The means for each cell were computed. RTs that were below 200 ms or larger than 2.5 standard deviations above the mean were regarded as anticipations and outliers, respectively, and excluded from the analyses. As a result of this trimming, 3.9% of the data were discarded. The means for each cell were recalculated. The resulting data are summarised in Figure 5 (a).

The RT data were entered into a 2 x 2 repeated-measures ANOVA with SOA and Cue Validity as within-subjects variables. There was a main effect for SOA [ $F(1,19) = 67.49$ ,  $MSE = 597.31$ ,  $p < .001$ ], with faster RTs at the long SOA, suggesting that this longer preparation spell facilitated response times (see Bertelson, 1967). Furthermore, the main effect for Cue Validity was significant [ $F(1,19) = 18.34$ ,  $MSE = 190.7$ ,  $p < .001$ ], with faster RTs on validly cued compared to invalidly cued trials. There also was a significant interaction between SOA and Validity [ $F(1,19) = 23.59$ ,  $MSE = 168.01$ ,  $p < .001$ ], which confirms that there was a significant cueing effect [27 ms;  $t(19) = 5.65$ ,  $p < .001$ ] at the 200 ms SOA and no effect ( $< 1$  ms;  $t < 1$ ) at 1200 ms.

### *Error data*

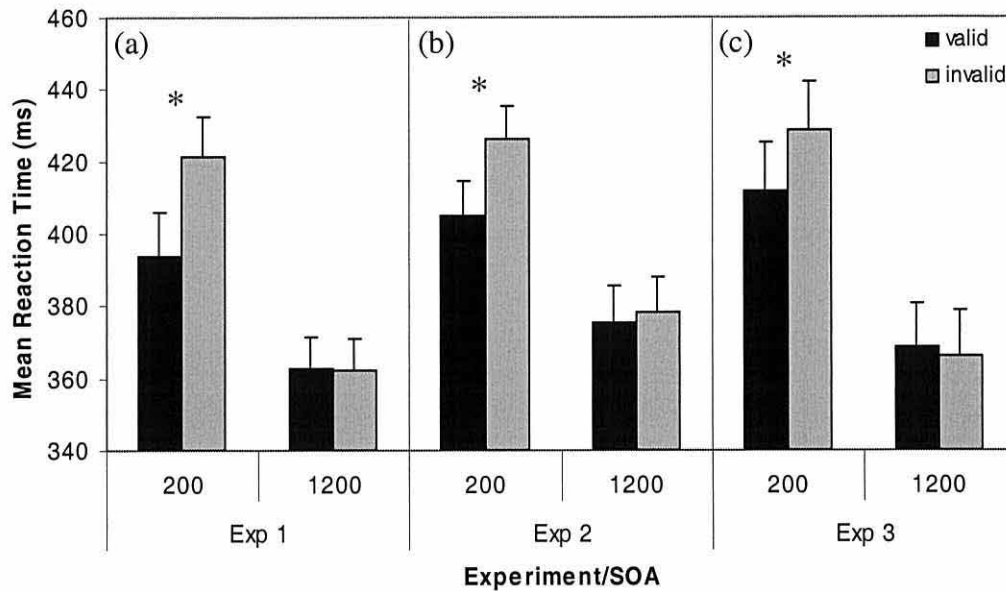
Errors occurred on only 1.6% of the trials (see Table 1). Analysis of the data revealed only a main effect for SOA [ $F(1,19) = 7.19$ ,  $MSE = .39$ ,  $p = .015$ ],

which is in line with the pattern obtained from the RT data. This shows that the RT results were not due to a speed-accuracy trade-off.

**Table 1. Mean error rates in each condition for Experiments 1-3.**

<i>SOA</i>	<i>Experiment 1</i>		<i>Experiment 2</i>		<i>Experiment 3</i>	
	<i>200</i>	<i>1200</i>	<i>200</i>	<i>1200</i>	<i>200</i>	<i>1200</i>
<i>Valid</i>	0.85	0.55	0.55	1.0	0.75	0.6
<i>Invalid</i>	0.8	0.35	0.85	0.6	1.3	0.3

This experiment replicated previous findings (e.g., Friesen & Kingstone, 1998; Driver et al., 1999; Langton & Bruce, 1999) that perceived eye gaze direction induces reflexive orienting to the gazed-at location resulting in facilitated target detection even at a short SOA. In line with Friesen and Kingstone (1998) and others, no evidence of IOR was found at a long SOA. Instead, the facilitation effect seems to have decayed.



**Figure 5.** Results for (a) Experiment 1 (same face), (b) Experiment 2 (different face), and (c) Experiment 3 (central cueing). Mean RTs are displayed in each validity condition for the short (200 ms) and long (1200 ms) SOAs. The asterisk (\*) marks the statistically significant valid/invalid comparisons.

### Experiment 2: different face

Experiment 2 was identical to Experiment 1, except that rather than participants viewing the same face throughout the entire experiment, a different face was seen on every trial. This manipulation should reduce habituation to the face (and gaze) information which, in turn, may lead to stronger and/or prolonged orienting. Thus, if changing the identity of the face from one trial to the next has

such impact on orienting processes, the magnitude of the cueing effect should be larger in this compared to the former experiment. Furthermore, orienting responses may endure for longer, resulting in cueing effects at the long SOA. If, however, this manipulation does not affect gaze cueing, similar RT patterns as in Experiment 1 should emerge.

## Methods

### *Participants*

20 undergraduate students (3 males and 17 females; mean age 20.8) from the School of Psychology, University of Wales, Bangor, participated for course credits.<sup>5</sup> They all had normal or corrected-to-normal vision.

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<sup>5</sup> When examining the data for each participant to check for consistency of the cueing effect across individuals, it was noted that the effect size of two participants was more than 2.5 standard deviations beyond the group mean. Although the effect pattern was in line with the predictions, it was decided to replace these participants as their data were skewing the distribution of scores of the sample (see, e.g., Henik, Friedrich, Tzelgov & Tramer, 1994, for a similar procedure).



*Apparatus, Design, Procedure, and Stimuli* were identical to those in Experiment 1, except that a total of 168 photographs of faces (84 female and 84 male) were used to produce the eye gaze cues. Figure 6 shows some examples of the different faces that were used. The face stimuli employed in the practice block were different from those in the experimental blocks to avoid repeated presentation of a stimulus.



**Figure 6.** A representative selection of the type of face stimuli that were used in Experiment 2.

## Results & Discussion

### *Reaction time data*

The same trimming procedure was applied to the RT data. Consequently, 3.8% of the data were discarded. The trimmed data are summarised in Figure 5 (b). Similar to Experiment 1, there was a cueing effect of 22 ms at the short SOA, but a much smaller effect (5 ms) at the long SOA.

The data were submitted to a repeated-measures ANOVA which revealed main effects for SOA [ $F(1,19) = 118.98, MSE = 271.9, p < .001$ ], with faster RTs at the 1200 ms SOA, as well as for Cue Validity [ $F(1,19) = 13.32, MSE = 247.17, p = .002$ ], with faster RTs on validly cued compared to invalidly cued trials. Both factors interacted [ $F(1,19) = 28.1, MSE = 60.52, p < .001$ ]. Cueing was significant at the short SOA [ $t(19) = 7.48, p < .001$ ], but not at the later interval,  $t < 1$ . In order to investigate the effects of face identity, the data of Experiments 1 and 2 were entered into a mixed ANOVA with SOA and Cue Validity as within-subjects variables and Experiment as a between-subjects variable. There were no significant effects of, or interactions with, Experiment.

### *Error data*

Errors occurred on 1.8% of the trials and are shown in Table 1. There was a significant interaction between SOA and Validity [ $F(1,19) = 5.78, MSE = .42, p = .027$ ], converging with the RT data. No other effects or contrasts were statistically significant.

This experiment replicated the findings of Experiment 1. Whereas a facilitatory cueing effect reliably emerged at the short SOA, no significant effect was obtained at the long SOA. Strikingly, there was no difference in the pattern of results between Experiment 1 (identical face throughout the experiment) and Experiment 2 (different unique face on every trial). Presenting a different face on every trial was a significant change in the experimental procedure, yet it had no impact on gaze cueing over the SOAs tested here.

### **Experiment 3: central cueing**

As has been outlined in the introduction to this chapter, both a transient cue and an active triggering of attention away from the cued location prior to target onset may be critical for IOR to be observed in peripheral cueing paradigms.

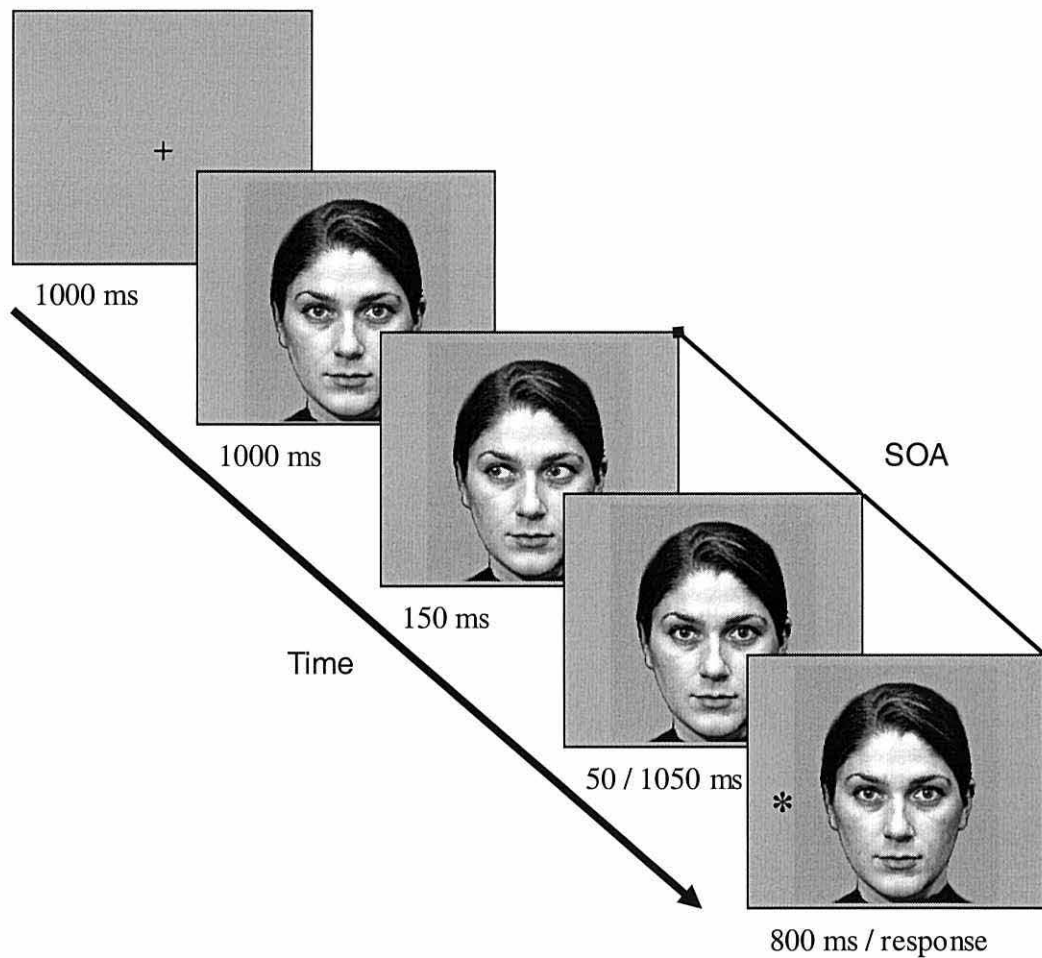
Therefore, it was hypothesised that the observation of IOR in the gaze cueing paradigm would also depend on such manipulations. In this experiment, the gaze cue was presented only briefly, after which the face stimulus was looking straight at the observer again. This re-establishing of perceived eye contact should focus the observer's attention on the face itself rather than the location it had been looking at. It was predicted that the facilitation observed at a short 200 ms SOA would revert to inhibition at the longer 1200 ms SOA.

## Methods

### *Participants*

20 undergraduate students (3 males and 17 females; mean age 21.9) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were the same as those in Experiment 2, except for the following: the eye gaze cue was displayed for only 150 ms, after which the pupil/iris areas moved back to the centre, gazing straight ahead again. After an interval of 50 or 1050 ms, depending on the SOA condition, the target appeared to either the left or right of the face. This procedure is depicted in Figure 7.



**Figure 7.** Illustration of the experimental procedure of Experiment 3. After gazing to one side for 150 ms, the pupils shift back to the centre before the target appears.

## Results & Discussion

### *Reaction time data*

Before RT analyses were conducted on the data for correct trials, the data were trimmed in the same way as previously. As a result, 3.7% of the data were excluded. The means for each cell were recalculated. The resulting data are

plotted in Figure 5 (c). Again, a substantial cueing effect (17 ms) was obtained at the short SOA, but only weak cueing (-3 ms) at the long SOA.

A repeated-measures ANOVA with SOA and Cue Validity as within-subject variables was carried out on the RT data. As in the previous experiments, RTs decreased with increasing SOA,  $F(1,19) = 180.04$ ,  $MSE = 309.26$ ,  $p < .001$ . A main effect for Cue Validity [ $F(1,19) = 8.23$ ,  $MSE = 121.62$ ,  $p = .01$ ] was also found, with faster RTs on validly cued compared to invalidly cued trials. The interaction of SOA and Validity was significant [ $F(1,19) = 21.31$ ,  $MSE = 87.58$ ,  $p < .001$ ], which indicates that the cueing effect was present at the short interval [ $t(19) = 5.88$ ,  $p < .001$ ] but disappeared at the long SOA ( $t < 1$ ).

The data of this experiment were then compared with the data for Experiment 2, which was identical to the present one apart from the central cueing manipulation. The only interaction between the experiments was one with SOA [ $F(1,38) = 4.49$ ,  $MSE = 320.97$ ,  $p = .041$ ]. It appears that the cue-target foreperiod effect was even more pronounced in the latest experiment.

#### *Error data*

Errors, represented in Table 1, occurred on 1.8% of the trials. Analyses revealed a significant main effect for SOA [ $F(1,19) = 6.61$ ,  $MSE = .85$ ,  $p = .012$ ], and an interaction between SOA and Validity [ $F(1,19) = 4.53$ ,  $MSE = .8$ ,  $p = .047$ ]. These patterns were in line with the RT data. No other effects or comparisons were significant.

As examination of Figure 5 makes clear, this experiment found the same effects as Experiments 1 and 2. Again, positive cueing effects emerged rapidly but disappeared at a longer SOA. No evidence of IOR was found despite re-orienting attention back to the centre of the display. These findings are in line with those of previous studies (e.g., Friesen & Kingstone, 1998; Driver et al., 1999; Langton & Bruce, 1999). Although the orienting of attention produced by eye gaze shares many properties with that elicited by peripheral sudden onset cues in that it is automatic and rapidly emerging, it does not seem to trigger IOR at SOAs as long as 1200 ms.

### **Chapter Discussion**

The results of the experiments in this chapter were very similar to each other. In line with previous research (e.g., Driver et al., 1999; Friesen & Kingstone, 1998), facilitatory cueing effects were found at an SOA of 200 ms, while no effect emerged at the considerably longer 1200 ms SOA. This pattern is very robust as it has been obtained across important methodological manipulations.

Presentation of a different face on each trial (Experiment 2) and re-establishing eye contact with the observer before the target appeared (Experiment 3) had no impact on the gaze cueing effects. This shows that these basic properties can be

replicated with the different procedures employed here, which provides a solid methodological basis for the experiments in the following chapters.

The fact that changing the identity of the face stimulus from trial to trial had no effect on attention orienting is consistent with previous findings that have suggested a dissociation between face identity processes and attention shifts via gaze. For example, Campbell, Heywood, Cowey, Regard, and Landis (1990) have shown that there are separate neural mechanisms mediating face identification and gaze following, such that one component can be intact after brain damage, whilst the other is impaired. Similarly, Hoffman and Haxby (2000) showed that when encoding faces in terms of their identities or direction of gaze, different neural structures appear to be involved: inferior occipital and fusiform gyri in the former identification case, and superior temporal sulci and intraparietal sulcus in the latter gaze encoding case. Hence the lack of cross talk between face identity processing and attention orienting via gaze is not an entirely unexpected finding.

In this context, the results of Macrae and colleagues (2002; 2003) that faces with direct gaze are easier to categorise and memorise than faces with averted gaze, can be interpreted in a slightly different light. They had concluded that establishing eye contact with the observed face would facilitate the efficiency of face processing, including categorisation and recognition (cf. George et al., 2001). This advantage for eye contact is probably contributed to by a disadvantage in face processing when the eye gaze is deviated. In this case, the observer's attention is directed away from the actual face stimulus and



towards the location that the face is looking at. It is therefore not surprising that performance on face processing tasks in averted-gaze conditions is worse than in straight-gaze conditions.

However, it would be rash to conclude that because separate neural systems appear to be involved in encoding face identity and direction of eye gaze, there cannot be interactions between these systems. Properties of the face could affect gaze cueing in certain circumstances. Neurophysiological and neuroimaging studies have indeed demonstrated that intentional (Jellema et al., 2000) and emotional (Wicker et al., 2003) states of the observed face can influence eye gaze processing. It is possible that gaze orienting might be associated with a particular face identity, but that this cannot be revealed over the short cue-target intervals examined so far. Therefore, examination of longer-term retrieval processes may be necessary for stronger tests of identity/gaze associations, and these are undertaken in later experiments (see Chapter Five).

Another striking result that has been obtained in this chapter is the lack of IOR at the long SOA, despite crucial manipulations in an attempt to elicit inhibition. Although this seems to suggest that IOR is not triggered by eye gaze cues, it is possible that the present null result at the long SOA reflects inhibition that is counteracted by residual facilitation. For example, Tipper et al. (1997) proposed that facilitation and inhibition are produced by different neural systems and that they can co-exist (see also Danziger & Kingstone, 1999). Thus, it may be that it is not the mechanisms of facilitation and inhibition *per se* that differ from eye gaze cueing paradigms to traditional peripheral cueing, but simply their

respective time-courses. Eye gaze is a very powerful social cue which may result in prolonged facilitation at the cued location. Inhibition, on the other hand, may be slower to develop in this location. This issue is addressed in the following two chapters.

## **Chapter Three**

*Effects of eye gaze cueing at extended SOAs*

The experiments in the previous chapter found no evidence of IOR, despite manipulations of cue duration and central cueing, and although a relatively long cue-target interval had been employed. However, as noted, inhibition might take longer to emerge given the complexity of the task and the potency of the cues (see Klein, 2000; Lupiáñez et al., 1997; 2001). Although Lupiáñez and his colleagues had only examined the processing demands associated with the target, it is conceivable that a complex cue would influence attentional processes in a similar fashion. In the case of gaze cues, the directional information of the cue has to be decoded from a highly complex stimulus, which contrasts with traditional cueing methods where the cue is a simple luminance increase or a simplistic arrow symbol. Furthermore, when a face is encountered whose gaze suddenly shifts to one direction, the observer may be reluctant to withdraw their attention from the gazed-at location. If some event in the periphery was salient enough to attract the opponent's attention away from the observer, it is sensible for the observer to maintain attention at that location for a prolonged period of time. Thus, although inhibition may in fact be present at the gazed-at location, it would be masked by this sustained facilitation (cf. Danziger & Kingstone, 1999).

Therefore, the experiments in this chapter employed a considerably extended cue-target SOA, to test the hypothesis that inhibition takes longer to emerge. In the following experiments, the cue-target interval was twice as long as the 1200 ms SOA of Experiments 1 to 3. Those studies had shown absolutely no cueing effects at 1200 ms SOA. Furthermore, two main unique methodological properties that were developed in the previous chapter were

utilised here. First, a different face was presented on every trial in an effort to evoke retrieval processes if inhibition was associated with a particular face (cf. Tipper et al., 2003). Second, when re-presented, the face was gazing straight ahead, as it was suspected that reorienting attention away from the cued location may be an important aspect of the task, even though Experiment 3 had failed to show any effects at shorter intervals.

Experiment 4 first introduced an extended SOA using a localisation task akin to the task used in Experiments 1-3. Experiment 5 employed a simple detection task while Experiment 6 demanded the execution of saccades to the target instead of an arbitrary key-press response.

#### **Experiment 4: extended SOA**

This experiment aimed to establish whether IOR can be obtained in an eye gaze cueing paradigm with a prolonged SOA. In this and the following experiments, the cue display (in which the eyes of the face stimulus gazed to the left or right) and the target display (in which the face gazing straight ahead appeared along with the target) were intervened by a blank interval of 1700 ms. Hence, the procedure was essentially the same as that of Experiment 3, except for this longer interval of 2400 ms between cue and target onset. It was predicted that responses to validly cued targets would now be slower than those on invalid trials.

## Methods

### *Participants*

20 undergraduate students (16 females and 4 males; mean age 20.7) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

*Apparatus* was identical to that employed in the previous studies. The participants sat at a distance of 57 cm from the screen.

### *Stimuli*

A central cross, subtending  $0.8^\circ$ , served as a fixation point. The same 168 digitised photographs of faces as in the previous experiments were used as the central stimuli, but now subtended on average  $14.5^\circ$  in height and  $11.5^\circ$  in width. The target was an asterisk, subtending  $1^\circ$  and presented  $9.5^\circ$  to the left or right of the centre of the screen, approximately on level with the eyes of the face in the vertical plane.

### *Design & Procedure*

The study comprised 160 trials consisting of a cue and a target display. On 20% of the trials, a target was presented during the cue display. These trials were catch trials to maintain the participants' attention on the display during the cue phase. All trials were randomly presented in the validly and invalidly cued conditions.

Again, participants were instructed to fixate at the centre of the screen throughout the experiment and to respond as quickly and accurately as possible. They were also encouraged to ignore the face and the direction of gaze. A fixation cross appeared for 1000 ms, followed by a face looking straight ahead. After a further 1000 ms, the straight gaze was replaced by averted gaze for 200 ms. During catch trials, a target then appeared to the left or right of the face. The cue display was replaced by a blank screen with a fixation cross at the centre for 1700 ms. The face then re-appeared with the eye gaze directed straight ahead. After 500 ms, the target appeared to either the left or right of the face. This yielded an SOA of 2400 ms; see Figure 8 for an illustration. Participants responded in the same way as in the previous experiments. Auditory feedback was provided as before. Before the experimental block, participants completed a short practice block of eight trials. The stimuli used in the practice block were different from those employed in the experimental session.

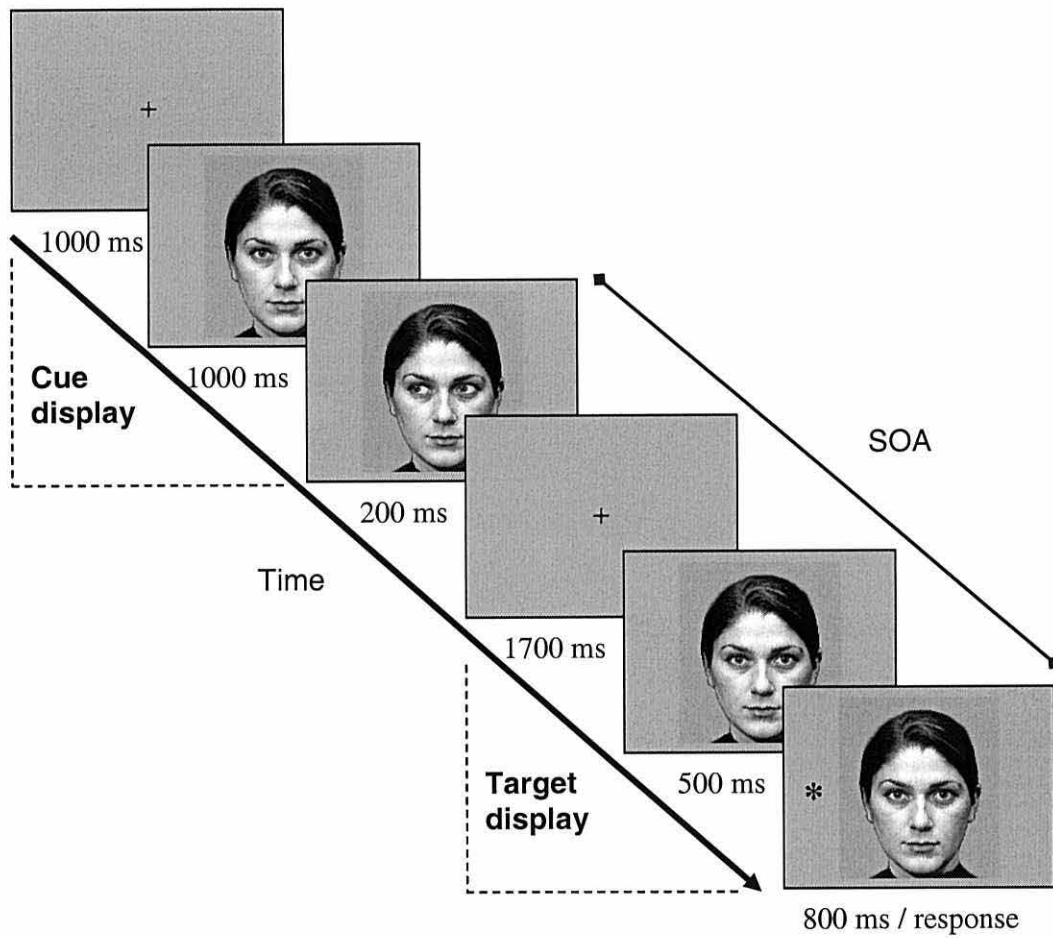


Figure 8. Illustration of the experimental procedure of Experiment 4.

## Results & Discussion

### *Reaction time data*

Data from catch and error trials were excluded from the analyses. The remaining data were treated in the same way as before. As a result of this trimming, 4.3% of the data were discarded. The data are summarised in Figure 9 (a). RTs in the



valid condition were now slower than those in the invalid condition. A paired-samples t-test comparing the valid and invalid conditions showed that this 8 ms difference was statistically significant,  $t(19) = 2.75, p = .013$ , two-tailed.

#### *Error data*

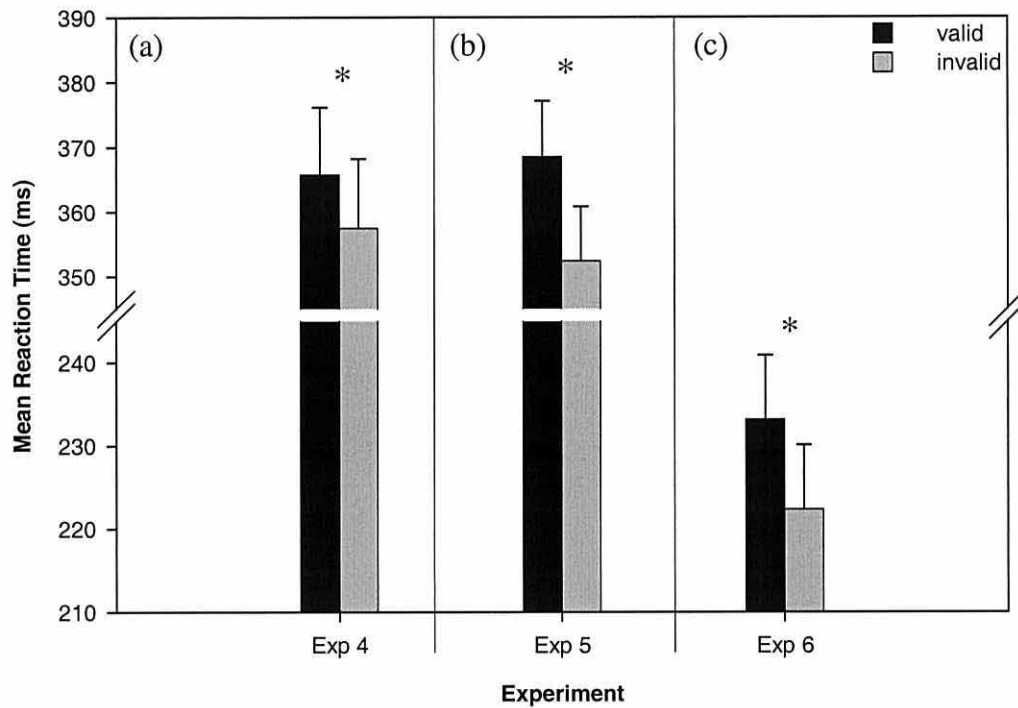
Errors occurred on 1.9% of the trials (see Table 2). No significant effects were obtained from the analysis of these data.

**Table 2. Mean error rates for Experiments 4-6.**

	<i>Experiment 4</i>	<i>Experiment 5</i>	<i>Experiment 6</i>
<i>Valid</i>	0.65	0.55	0.92
<i>Invalid</i>	0.65	0.7	0.25

The results of this experiment showed, for the first time, inhibitory cueing effects triggered by eye gaze cues. This is a striking result. It reveals, first, cueing effects at longer intervals than ever before. Note that there was no hint of a cueing effect at a SOA of 1200 ms in the first three studies, but we see here effects at a SOA of 2400 ms. Second, this is the first evidence that gaze cues can activate inhibitory processes, such that participants are slower to detect targets at

previously gazed-at locations.<sup>6</sup> Because this longer-term inhibition effect is different from anything else in the gaze-cueing literature, it was essential to replicate this finding and extend it to other procedures.



**Figure 9.** The results for (a) Experiment 4 (localisation), (b) Experiment 5 (detection), and (c) Experiment 6 (saccade). Mean RTs are shown for valid and invalid trials. The asterisk (\*) marks the statistically significant differences.

<sup>6</sup> These experiments were purposely designed to match the existing IOR literature (see Klein [2000; in press] for reviews). In the standard IOR procedure, only cued and uncued trials are used, as there are problems concerning baseline conditions (see note 1). In this context, the present data are very much like typical IOR. However, it should be noted that whether the effect is inhibition of cued locations or facilitation of uncued locations remains unclear at this stage. Nevertheless, this mechanism aids search by reducing the likelihood of returning attention to previously attended locations. Indeed, it has been suggested that IOR reflects both inhibition at the cued location and facilitation at uncued locations (Pratt, Spalek, & Bradshaw, 1999). See also Footnote 9.

### **Experiment 5: detection task**

An ongoing debate surrounds the question whether IOR reflects a perceptual or a motor bias against detecting a target at the inhibited location (e.g., Reuter-Lorenz et al., 1996; Klein & Taylor, 1994), although recent evidence suggests that IOR operates on both early, stimulus encoding and late, response selection stages (Taylor & Klein, 2000). Nevertheless, using a target localisation task as in the previous experiments obscures whether the cue directly activates a (left/right) response. Furthermore, IOR is typically observed in a variety of target tasks (detection, localisation, discrimination). Therefore, a simple detection task was introduced in this study to see if the inhibition effect observed in the previous experiment generalises to different task demands.

### Methods

#### *Participants*

20 undergraduate students (15 females and 5 males; mean age 19.7) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were identical to those in Experiment 4, except for the following. Instead of localising the target, the task was now to press the H-key on the keyboard as soon as the target was detected in either

location. Since the same response was required for both left and right targets, there were now two types of catch trial in order to make the target appearance necessitating the response less predictable: on 10% of the total trials, a target was presented on both cue- and target-displays. On a further 10% of trials, a target was presented during the cue but not the target period.

## Results & Discussion

### *Reaction time data*

Data from catch and error trials were excluded from the analyses. The same trimming procedure as in the previous experiments was applied to the RT data. As a result of this trimming, 5.4% of the data were discarded. The trimmed data are represented in Figure 9 (b). A similar data pattern as in the previous experiment was obtained. A paired-samples t-test with the valid and invalid conditions as the variable pair revealed a significant 16 ms cueing effect,  $t(19) = 3.82, p = .001$ , two-tailed, with slower RTs to validly cued targets.

### *Error data*

Errors occurred on 1.7% of the trials. The mean error rates are displayed in Table 2. Analyses revealed no significant effects.

This result replicates the findings of Experiment 4 and shows that, like IOR observed in traditional peripheral cueing paradigms, the inhibition evoked

by eye gaze shifts is not limited to situations in which the responses are in spatial correspondence to the target location.

### **Experiment 6: saccade task**

Saccadic responses have been widely used in IOR paradigms (e.g., Abrams & Dobkin, 1994; Briand, Larrison, & Serreno, 2000; Rafal et al., 1994; Taylor & Klein, 2000). Furthermore, Friesen and Kingstone (2003b) have demonstrated that saccades to targets also reveal the gaze cueing effects, and hence this seems an appropriate method to employ when attempting to confirm the inhibition effect.

### Methods

#### *Participants*

12 undergraduate students (8 males and 4 females; mean age 25.2) of the University of Wales, Bangor, participated for a payment of £8. They all had normal or corrected-to-normal vision.

*Apparatus*

The experiment was run using E-Prime 1.0 software. Stimuli were presented on a 17-inch Samtron 96P monitor set to high colour and a screen resolution of 640 x 480. Eye movements were measured with EyeLink v.1 eye-tracking system (SensoMotoric Instruments / SR research). Measures based on pupil diameter were taken binocularly on horizontal and vertical co-ordinates at a sampling rate of 250 Hz. For the sake of simplicity, only the data for the right eye were used for analyses. Participants sat on a comfortable chair with their head position stabilized on a chinrest at a distance of 57 cm from the screen.

*Stimuli, Design and Procedure* were the same as those in Experiment 4, except that the participants had to perform a saccade towards the target as soon as it was detected, instead of executing a keypress response. The saccadic reaction time to the target was the dependent measure. A drift correction was performed every four trials. During a drift correction, participants were instructed to fixate on a white central fixation cross subtending  $0.7^\circ$  on a black background until their gaze was stable. Thus, the experiment consisted of a total of 200 trials, comprising 128 experimental trials, 32 catch trials, and 40 drift corrections.

## Results & Discussion

### *Reaction time data*

Saccadic RTs were computed with EyeLink Data Viewer (version 1.2.34; SR Research) as the time elapsed between target onset and occurrence of the first saccade with a minimum amplitude of 2.0°. Only saccades in the correct direction were considered for subsequent analyses. Trials in which a saccade of more than 5.0° amplitude (which corresponds to a saccade just beyond the eyes of the face stimulus on the screen) was executed during the cue period were excluded.<sup>7</sup> The means for each cell were computed. RTs that were below 50 ms or larger than 2.5 standard deviations above the mean were regarded as anticipations and outliers, respectively, and not included in the analyses. As a result of this trimming, 3.2% of the data were discarded. Errors occurred on less than 1% of the trials and were not analysed further (see Table 2 for error data). The means for each cell were recalculated. The resulting data are depicted in Figure 9 (c).

Analyses of the RT data showed significant cueing of 11 ms [ $t(11) = 3.61, p = .004$ , two-tailed], with faster RTs to invalidly cued targets compared to validly cued ones. This study replicated the findings of Experiments 4 and 5. In

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<sup>7</sup> Note that there was no fixation cross on the screen when the face was presented. Under such circumstances, it is inherently difficult to maintain accurate fixation. Instead, people tend to fixate on the eye region of the face, which often involves scanning of each eye in turn (see Mertens et al., 1993). Therefore, a relatively generous threshold for fixation errors was chosen.

this case, the onset of a saccade to the subsequent target was delayed after cueing via an observed gaze shift.

### Chapter Discussion

The experiments in this chapter have demonstrated, for the first time, gaze cueing effects at cue-target intervals that were more than twice as long as those reported in the literature thus far. Previously, it was thought that orienting effects via eye gaze cues decayed after about one second following cue onset. The results of the present experiments, however, clearly show cueing effects at an SOA of 2.4 seconds. Most strikingly, these cueing effects were of an inhibitory nature, such that participants were *slower* to detect targets at the gazed-at location. This effect was apparent with the localisation task (Experiment 4) that had been used in the previous experiments, but it was also replicated in two further experiments which required simple detection (Experiment 5) and saccade (Experiment 6) responses. Therefore, this longer-term inhibition effect generalises across very different task demands. This suggests that it is indeed a robust effect that is very much like the IOR effects that are observed in traditional peripheral cueing paradigms. Although the effect sizes that were obtained in the present experiments were considerably smaller than those in the previous chapter (~ 11 ms compared to ~ 22 ms), it should be noted that such small magnitudes are not



uncommon with gaze cueing procedures. Indeed, even smaller but nevertheless significant effects have been reported in the literature (Hietanen & Leppänen, 2003).

Thus, in contrast to the prevailing view in the gaze-cueing literature (e.g., Friesen & Kingstone, 1998; 2003a; 2003b), IOR *can* be obtained in response to observed gaze shifts. The hypotheses outlined in the introduction to this chapter proposed that previous studies failed to observe IOR not because it was not triggered in the first place, but because it was either masked by continuous facilitation at the gazed-at location or because its onset was delayed. Thus, IOR would only be evident when sufficient time had elapsed following the cue onset, to allow the facilitation to decay and/or inhibition to emerge. The critical difference between Experiment 4 and Experiment 3 was the extension of the cue-target SOA. The fact that inhibition was observed in Experiment 4 but not in Experiment 3, which had employed a considerably shorter SOA, supports the notion that a very long time-lag is required for IOR to emerge in a gaze cueing paradigm.

It should be noted that it remains unclear whether the difference in time-course between gaze cueing and peripheral cueing is due to an increased processing difficulty inherent to the gaze cue or to an enhanced salience of the cue. Nevertheless, both these explanations are based on the nature of the cue and therefore apply specifically to orienting effects in response to gaze cues. Furthermore, both accounts postulate that the emergence of IOR in gaze cueing

should be delayed, a view that has received initial support in the present experiments.

However, it is possible that time-course alone is not the critical factor in obtaining IOR. The experiments in this chapter differed from those in the previous chapter in more than one aspect. Not only was the SOA extended in the experiments presented here, but the face stimulus disappeared after the gaze cue had occurred and was only re-presented shortly before the target onset. Thus, the offset of the face could have summoned attention to the centre of the display (cf. Pratt & McAuliffe, 2001). This stimulus offset may have constituted an even stronger incentive for such an attention shift than the eye contact manipulation in Experiment 3. Therefore, the inhibition that was observed in this chapter may have been a result of this central cue rather than the extended time-lag. This effect would have been absent in Experiment 3. These alternatives are probed in the next chapter.

## Chapter Four

*Is time-course the critical factor for the observation of IOR in response to gaze cues?*

Although Experiments 4, 5 and 6 have demonstrated that inhibition can be observed with eye gaze cues with an extended SOA, it remains ambiguous whether this time factor is necessary and sufficient to trigger IOR. In those experiments, a further important manipulation had been introduced: between the cue and target events, the face stimulus disappeared for 1700 ms and re-appeared only shortly before target onset. It is conceivable that this stimulus offset, rather than the longer time-course, is a crucial factor in eliciting inhibitory processes. Indeed, it is well established that the sudden offset of a stimulus can automatically attract attention in a similar fashion as a sudden-onset cue (e.g., Miller, 1989; Pratt & Hirshhorn, 2003; Pratt & McAuliffe, 2001). Thus, the face offset may have summoned attention away from the gazed-at location. This facilitated disengagement from the cued location would have allowed inhibition to emerge, regardless of the cue-target interval. Note that it is also possible that a combination of both factors is necessary to observe IOR. Thus, inhibition may only emerge after a long interval when the face stimulus disappears following cue onset.

Furthermore, the experiments in Chapter Three had a single, fixed SOA, whereas the experiments in Chapter Two employed two variable cue-target onset intervals. This in itself may influence the onset of IOR. Previous research has shown that the time-course of facilitation and inhibition varies with the range of SOAs used (Cheal & Chastain, 2002). More specifically, the delay at which facilitation crosses over to inhibition is inversely related to the width of range of SOAs used in a given block. In Cheal and Chastain's study, participants were

required to identify a target that was presented along with distractor items. An irrelevant peripheral cue appearing near the potential target location preceded the onset of target and distractors. Three levels of SOAs were used within an experimental block. The range of SOAs varied from 100-400 ms, over 100-500 ms, to 100-700 ms. The onset of IOR was consistently earlier the longer the SOA range was. Cheal and Chastain suggested that this pattern was due to the participants' strategy to maintain attention at the cued location when there is little time to disengage attention from that location before the target is expected to appear (i.e., when a short range of SOAs is used).

It is unlikely that such a strategy accounts for the results of Experiments 4-5, because inhibition was only observed with a single late SOA and not when a long range of early SOAs was used (in Experiments 1-3). Furthermore, Cheal and Chastain presented the target along with non-target items, whereas here the target was presented in isolation. Such an onset of a unique event may attract attention in itself so that attention is easily disengaged from the cued location and inhibition emerges. Thus, one should expect a fairly early onset of inhibition when a single target is presented after greatly varying SOAs, as in Experiments 1-3. This, however, was not the case. Nevertheless, Cheal and Chastain's study shows that the range of SOAs used can influence the onset of inhibition. Therefore, the possibility that the difference in cueing effects between Chapter Two and Chapter Three was some kind of artefact of SOA range cannot be ruled out completely.

The experiments in this chapter were designed to address these potential confounds. Experiment 7 was a hybrid version of Experiment 3 and Experiment 4, in that a blank interval was introduced between cue- and target-displays with an SOA of 1200 ms. This way, the sequence of events was the same as in Experiment 4 while the SOA was matched to the long cue-target interval of Experiment 3, for which no cueing effects had been found. This should establish whether the offset of the face stimulus, rather than the duration of the cue-target interval, was responsible for the inhibition in Chapter Three. Experiment 8 dealt with the issue of SOA range. In Chapter Two, the SOA had been variable (200 or 1200 ms), while the experiments in Chapter Three had been fixed (2400 ms). Thus, in Experiment 8, the cueing effects at two SOAs (1200 ms and 2400 ms) were compared with a blank interval between cue and target appearance. Experiment 9 tracked the effects of gaze cues across all three SOAs (200, 1200 and 2400 ms) while the face remained on the screen, to examine whether *both* time-course and the offset of the face stimulus would be necessary to observe inhibition.

### **Experiment 7: face offset**

This experiment combined the methodologies of Experiment 3 and 4, in an effort to eliminate the procedural differences between those experiments that may have

confounded the results in the previous chapter. This experiment was identical to Experiment 4, but the cue-target SOA was 1200 ms, akin to the “null-effect” SOA of Experiment 3. If the offset of the face was responsible for observing inhibition, similar cueing as in Experiments 4-6 should now emerge at this “null-effect” SOA. If, however, inhibition needs time to surface, no effect of cueing should be obtained, replicating the findings of Experiments 1-3.

## Methods

### *Participants*

20 undergraduate students (16 females and 4 males; mean age 20.4) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were identical to those employed in Experiment 3 except for the following. The gaze-cue stimulus was presented for 200 ms. Instead of presenting the face with central gaze immediately, it was replaced by a fixation cross for 500 ms. As in Experiments 4-6, the face was then displayed for 500 ms before target onset.

## Results & Discussion

### *Reaction time data*

Data from catch and error trials were excluded from the analyses. The RT data were treated in the same way as previously. As a result of this trimming, 4.1% of the data were discarded. The trimmed data are represented in Figure 10 (a). The RT difference between valid and invalid trials ( $< 1$  ms) resembles the data pattern at the same SOA in Experiments 1-3 (see Figure 5). Indeed, a paired-samples t-test with the valid and invalid conditions as variable pairs showed no hint of an effect ( $t < 1$ ).

### *Error data*

Errors occurred on 1.4% of the trials and are summarised in Table 3. There were no significant effects.

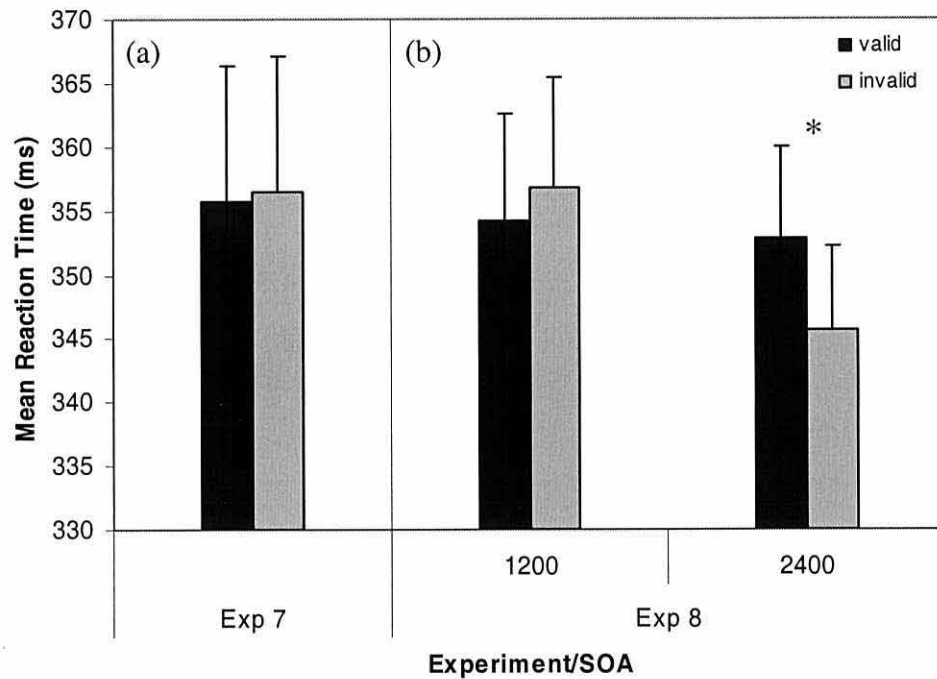
**Table 3. Mean error rates for Experiments 7 and 8.**

<i>SOA</i>	<i>Exp 7</i>		<i>Exp 8</i>	
	<i>1200</i>	<i>1200</i>	<i>1200</i>	<i>2400</i>
<i>Valid</i>	0.95	0.3	0.6	
<i>Invalid</i>	1.3	0.7	0.45	

This result replicates the null-effects of Experiments 1-3. There was no effect of cueing despite the presentation of a blank interval between cue and target displays. This demonstrates that the offset of the face stimulus that was



introduced in Experiments 4-6 was not solely responsible for the inhibition effects in those studies, which supports the hypothesis that time-course is the critical factor.



**Figure 10.** Results for (a) Experiment 7 (face offset, fixed SOA), and (b) Experiment 8 (face offset, variable SOA). Mean RTs are shown for valid and invalid trials. The asterisk (\*) marks the statistically significant difference.

### **Experiment 8: face offset, variable SOA**

In this experiment, the role of variability of SOA was explored. The procedure employed here was identical to the previous experiment, except that the duration of the cue-target interval varied randomly between 1200 ms and 2400 ms. In line with the previous results it was expected that cueing would have no effect at 1200 ms. At 2400 ms, inhibition should again be observed.

#### Methods

##### *Participants*

20 undergraduate students (17 females and 3 males; mean age 19.6) from the School of Psychology, University of Wales, Bangor, participated for course credits.<sup>8</sup> They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were identical to those employed in Experiment 7, except that cue-target SOA was either 1200 ms (to match the late SOA of Experiments 1-3) or 2400 ms (to match Experiments 4-6). This was achieved by varying the duration of the blank interval from 500 ms to 1700 ms.

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<sup>8</sup> Similarly to Experiment 2, the effect size of one participant differed substantially from the rest of the sample (i.e., beyond 2.5 standard deviations from the group mean). This participant's data were dropped and replaced.

## Results & Discussion

### *Reaction time data*

Data from catch and error trials were excluded from the analyses. The same trimming procedure as in the previous experiments was applied to the RT data. As a consequence of this trimming, 4.3% of the data were discarded. The resulting data are represented in Figure 10 (b).

A 2 x 2 repeated-measures ANOVA with SOA and Cue Validity as factors showed a statistically significant interaction between both variables,  $F(1,19) = 6.56$ ,  $MSE = 69.94$ ,  $p = .019$ . Inspection of Figure 10 (b) suggests slight facilitation at the 1200 ms SOA, but a larger inhibition effect at the 2400 ms SOA.<sup>9</sup> Planned contrasts confirmed that the 3 ms facilitation at 1200 ms was not significant ( $t < 1$ ), in contrast to the 7 ms inhibition at 2400 ms,  $t(19) = 2.75$ ,  $p = .013$ .

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<sup>9</sup> As noted, IOR is typically inferred from slower RTs to targets at the previously cued location in comparison with targets appearing at the uncued location (e.g., Maylor, 1985; Maylor & Hockey, 1985; Posner & Cohen, 1984; Tassinari et al., 1987). Addressing the possibility that this RT difference reflects facilitation at the uncued location rather than inhibition at the cued location, Posner & Cohen (1984) pointed out that RTs are usually quicker at later SOAs (Bertelson, 1967). In their IOR experiments, RTs at the cued location failed to show that decline, suggesting that those responses were inhibited. Inspection of Figure 10 (b) similarly reveals that whereas invalid RTs show the typical decline with SOA, valid RTs do not. This suggests that the observed effects indeed reflect inhibition at the gazed-at location.

### *Error data*

Errors were made on 1.4% of the trials (see Table 3). Analysis of the error data revealed no significant effects.

The present experiment replicated both the null results of the long SOA of Experiments 1-3 and Experiment 7 (1200 ms), and the inhibition effect of Experiments 4-6 at 2400 ms, in a within-subjects design. Taken together, these results strongly support the notion that an extended time-course, rather than the offset of the face stimulus, is necessary to produce inhibition at the cued location. However, another possibility is that both an extended time-course and the offset of the face stimulus are critical for inhibition to be observed. It is conceivable that the face offset provides a stronger central cue than the eye contact manipulation in Experiment 3, so that attention is drawn away from the gazed-at location to reveal IOR. The next experiment addressed this issue.

### **Experiment 9: face constant**

In this experiment, the possibility that both face offset and the extended duration of the SOA are necessary to evoke and observe inhibition at the cued location was examined. Instead of displaying a blank screen between cue- and target-displays, the face remained on the screen throughout the trial. If inhibitory

processes are independent of the presence of the face after the cue was given, inhibition should still be observed at the long SOA. If, however, face offset is necessary for cueing attention away from the cued location, no inhibition should emerge. This experiment included all three SOAs (i.e., 200, 1200 and 2400 ms) to investigate the pattern of cueing across the whole range of cue-target intervals that had been employed in the previous experiments.

### Methods

#### *Participants*

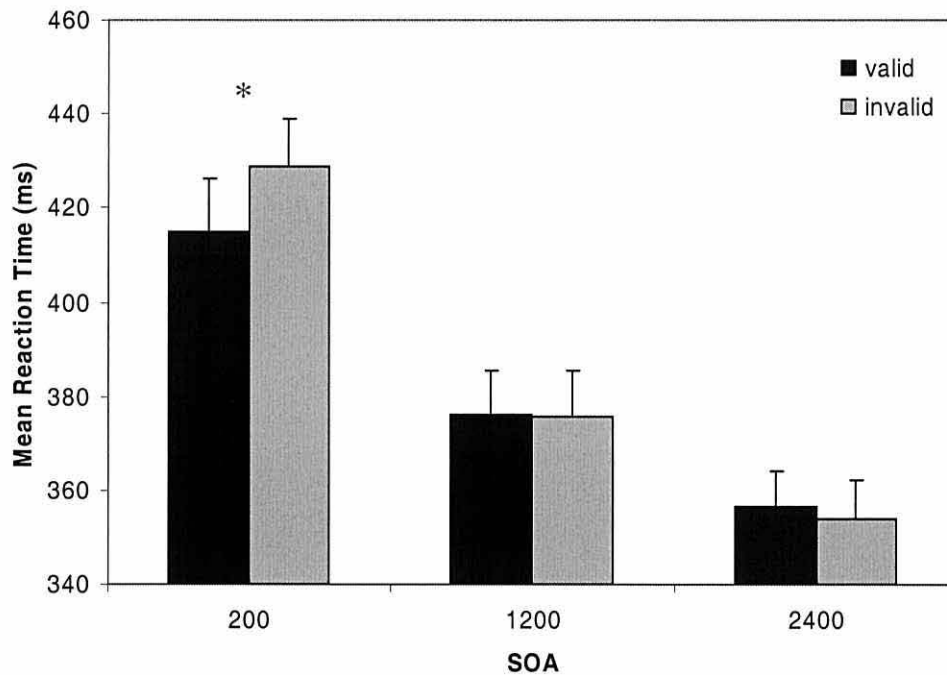
20 undergraduate students (13 females and 7 males; mean age 19.7) from the School of Psychology, University of Wales, Bangor, participated for course credits. They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were identical to those of Experiment 8, except for the following: after the cue display (i.e., face with averted gaze), the face was presented with its eyes gazing ahead until the target appeared. The cue-target SOA was either 200, 1200 or 2400 ms.

## Results & Discussion

### *Reaction time data*

Only the data from experimental trials on which no error had occurred were included in the analyses. The remaining data was trimmed as before. As a consequence, 4% of the data were discarded. The resulting data are displayed in Figure 11.



**Figure 11.** The results for Experiment 9. Mean RTs are displayed for valid and invalid trials at each SOA. The asterisk (\*) marks the statistically significant difference.

The results of a 3 (SOA) x 2 (Validity) repeated-measures ANOVA indicated a main effect for SOA [ $F(2,38) = 109.96$ ,  $MSE = 430.2$ ,  $p < .001$ ], with faster RTs with increasing SOA. There was also a significant interaction

between SOA and Validity,  $F(2,38) = 5.78$ ,  $MSE = 158.24$ ,  $p = .006$ . Inspection of Figure 11 suggests that significant cueing emerged at an SOA of 200 ms only. No difference between valid and invalid trials is apparent at the two longer SOAs. This impression was confirmed by planned contrasts which revealed significant cueing at the short SOA only [ $t(19) = -3.02$ ,  $p = .007$ ; all other  $ps > .2$ ].

#### *Error data*

Errors occurred on 1.6% of the trials, these data are shown in Table 4. No significant effects emerged from the analysis of the error data.

**Table 4. Mean error rates for Experiment 9.**

<i>SOA</i>	<i>Exp 9</i>		
	<i>200</i>	<i>1200</i>	<i>2400</i>
<i>Valid</i>	0.4	0.45	0.2
<i>Invalid</i>	0.6	0.55	0.35

In this experiment, the only significant cueing effect was observed at the shortest SOA, replicating the findings of Experiments 1-3. Surprisingly, no inhibition was obtained at the longest SOA when the face stimulus remained on the display throughout the entire trial. Thus, contrary to the impression conveyed by Experiments 7 and 8, it seems that an extended temporal interval between cue and target is not a sufficient condition to trigger inhibition at the cued location.

## Chapter Discussion

The experiments in this chapter have explored the factors that contributed to the observation of inhibition in the previous chapter. It was hypothesised that in order to obtain IOR, the interval between cue and target onset has to be considerably longer than previously thought. The results of Chapter Three, where inhibition was found with an extended cue-target onset delay, had provided initial support for this hypothesis. The present experiments probed whether time-course was indeed the critical factor, or whether other methodological differences between Chapter Two and Three had contributed to these results.

Experiment 7 showed that inhibition was not obtained at a shorter SOA, even when the face disappeared following the presentation of the cue. Instead, the results matched exactly those of Experiments 1-3, which had found no effects at the same SOA. This demonstrated that the face offset manipulation that had been introduced in Chapter Three was not responsible for triggering IOR. Next, the range of SOA was varied to further match the designs of Experiments 1-3 and 4-6. The results of Experiment 7 and Experiments 4-6 were replicated: whereas no effect was obtained at 1200 ms, inhibition emerged at 2400 ms. Thus, the time-course of cueing effects does not appear to be influenced by the width of the range of SOAs used. Instead, inhibition seems to be observed at very long SOAs only. Finally, the face remained on the screen throughout a trial across all three SOAs in Experiment 9. In line with Experiments 1-3, facilitation was found at the short 200 ms SOA, and no cueing effects were observed at 1200 ms.



Surprisingly, no effect was found at the long 2400 ms SOA either. This outcome is in sharp contrast with the results of four other experiments (Experiments 4-6, and 8) in which IOR had been found consistently at that interval.

It is unlikely that the latter finding is due to the use of three SOAs in this experiment, since the difference in number of SOAs did not have an impact on cueing in Experiments 4-8. The major difference between Experiment 9 and those other studies was the continuous presence of the face. Thus, it seems that the offset of the face does play a critical role, although this is not a sufficient condition to demonstrate IOR. Instead, both a long cue-target SOA *and* the offset of the central face stimulus appear to be necessary for IOR to emerge. This suggests that the observer needs to disengage from the face in order to trigger inhibitory processing at the cued location. Only when the face disappears and summons attention away from the cued location, inhibition emerges.

The straight-gaze manipulation in Experiment 3 was presumably not striking enough to disengage attention from the cued location. Note that in this case, eye contact with the face stimulus was maintained so that the observer remained engaged in the same social interaction situation. It is conceivable that this continuous social context facilitated the observer's engagement with the other party's direction of attention. Indeed, Hietanen (1999) makes a similar point: he found stronger cueing effects of eye gaze when the head was oriented towards the observer than when both head and gaze were laterally averted. This result is counterintuitive, as one would expect combined head and gaze cues to result in stronger orienting responses. Hietanen (1999) argued that when another

person is facing away from the observer, no interaction between both parties is established. As a consequence, the other's behaviour is perceived to be unrelated to the observer, so that changes in gaze direction have less signal value. In this respect, the disappearance of the face stimulus in Experiments 4-6 constituted a disruption of the interpersonal mutual gaze contact state between face and participant, so that attention could be disengaged from the gazed-at location.

It makes sense that this process should take time, as there is a further aspect of social interaction to be considered: the human capability of deception. A stranger's gaze shift to the periphery may signal the presence of a threat to the observer, for example an accomplice to the stranger, ready to attack. For the sake of survival, further processing of the gazed-at location should not be inhibited, even if the gaze shift was only brief and eye contact subsequently re-established. Thus, inhibition can be obtained in response to observed gaze shifts, but only when a very long delay interludes cue and target onset. The next chapter investigates how the orienting effect is maintained across such a long interval.

## **Chapter Five**

*The role of long-term retrieval and working memory systems in  
the maintenance of gaze cueing effects*

The experiments in the previous two chapters have confirmed that longer-term IOR can be activated via gaze cues. The effect generalises across target localisation via key-press and localisation via saccade, as well as simple target detection. Previous research (e.g., Lupiáñez et al., 1997; 2001) has shown that the onset of IOR is not fixed and invariant, but rather is dependent on various task demands such as the complexity of target processing. This prior work had motivated these studies investigating longer cue-target SOAs. However, another motivation for examining cueing effects over longer periods had been recent work suggesting that attentional processes, such as inhibition, can be encoded into memory and retrieved later. Such a process can be observed with peripheral sudden onset cues in some circumstances (Tipper et al., 2003). One aim of this chapter was to investigate whether this can be achieved when faces are used to provide the attention cue.

Tipper et al. (2003) found inhibition effects that were associated with a specific face identity over long periods of time. Note that three important manipulations have been introduced in the previous chapters: first, the interval between cue and target onset has been prolonged considerably. Second, the typical gaze cueing paradigm has been modulated such that, rather than presenting exactly the same face photograph or cartoon figure throughout the entire experiment, a different face photograph was introduced on each trial. Third, during the target display, the face was gazing ahead so that no gaze cue was provided at that point in time. Therefore, the longer-term cueing effects that were observed in Experiments 4-6 might be dependent on exactly the same face

being presented in the cue and target display. That is, attentional processes activated via gaze shift while viewing the face are retrieved when the same face is encountered shortly afterwards. Inhibition in this situation is not continuously present, but returns to resting states until the cue triggers retrieval.

Alternatively, orienting of attention may be sustained online in working memory. The work by Castel and colleagues (2003) has shown that IOR is subject to interference from concurrent spatial processing. This suggests that the inhibition associated with the cued location is coded in a spatial frame of reference and upheld in visual spatial working memory. In this scenario, inhibition remains active between cue and target presentation, and is not dependent on retrieval processes.

The next series of experiments further investigated what type of memory processes may be involved in maintaining IOR, in this case when attention was cued by observed gaze direction. The first two experiments assessed the participation of long-term retrieval processes, while the remaining two studies probed the role of continuous processing in working memory. Experiments 10 and 11 were an attempt to explore whether the inhibition effect is associated with a particular face, or dependent on retrieval associated with faces in general. In Experiment 10, the identity of the face was changed from the cue to the target display in a given trial. This way, no retrieval of the attentional state associated with the cue face was possible at presentation of the target display. Experiment 11 provided a more extreme switch of object category from cue to target display.

Thus, instead of a face a picture of a non-face object was displayed along with the target.

Experiments 12 and 13 utilised an interference technique similar to that employed by Castel et al. (2003). In the present experiments, a simple task intervened the cue and target displays of a trial. The stimuli representing these intervening tasks were identical for both experiments: a simple shape was presented above or below the fixation. In Experiment 12, the shape had to be localised while in Experiment 13, the identity of the shape had to be reported. The pattern of interference from these two types of processing load should allow for inference of the processing system (spatial or identity) that mediates orienting effects over the extended (2400 ms) cue-target interval.

### **Experiment 10: different face**

In Experiment 10, the face during gaze cueing was changed to a different face during subsequent target processing (see Figure 12). This change should disrupt retrieval of prior inhibitory states, as the target face would not retrieve the prior processing of the cue face. However, it would not affect general maintenance of spatial inhibition in visual spatial working memory. When comparing the data in Experiment 4 (identical face in cue and target display) with the current

Experiment 10 (different cue-target faces), the following data patterns are possible:

First, if memory for prior inhibition evoked via gaze is specific to the viewed face, and retrieved *only* when that face is re-encountered, then no inhibition should be observed in Experiment 10 where cue and target face change identity. Second, if inhibition is not associated with specific face identity, but rather spatial inhibition is maintained in visual spatial working memory, then face change between cue and target should not impair gaze cueing effects. Thus, inhibition in Experiment 10 (face change) should be similar to Experiment 4 (identical faces). Third, it is possible that both forms of memory mediate the gaze inhibition effect. In this case, inhibition might be observed in Experiment 10 where cue-target faces change identity because of continuous maintenance in visual spatial working memory. However, the effect in Experiment 4 (identical faces) may be larger because inhibition is supported by continuous inhibition in working memory *and* retrieval of specific memory for attentional states associated with face identity.

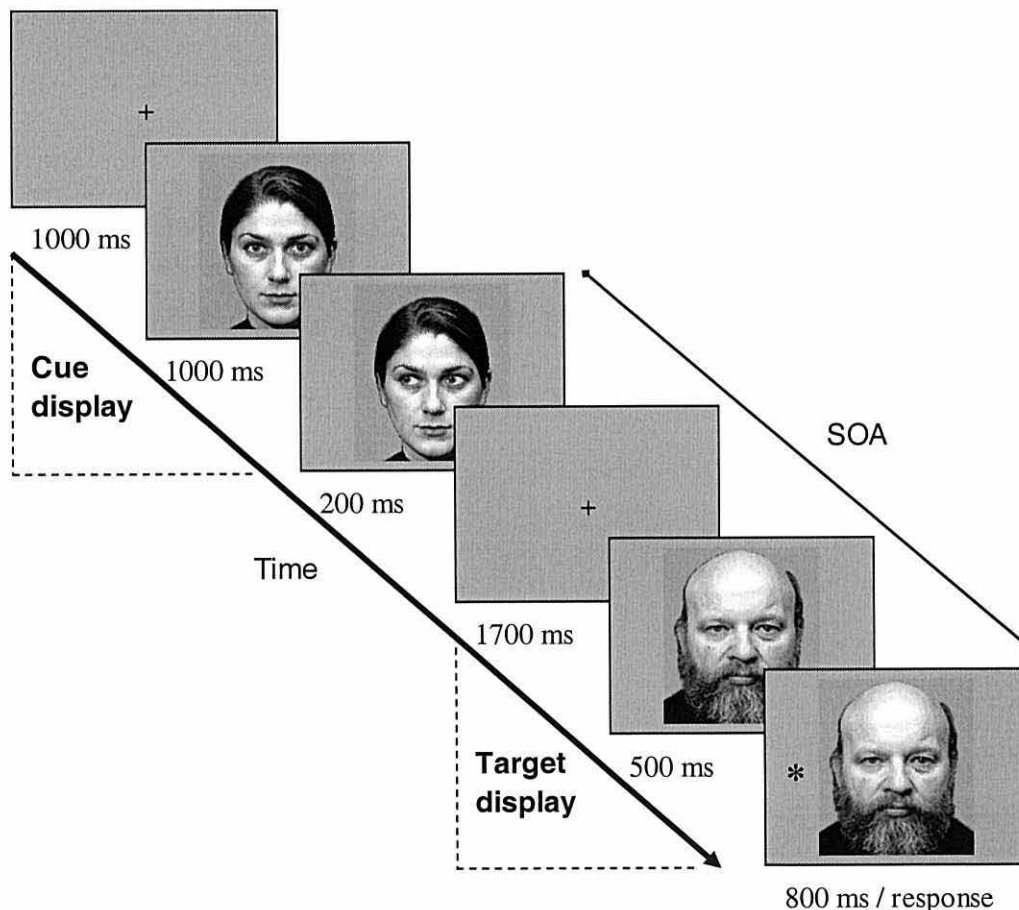
## Methods

### *Participants*

20 students of the University of Wales, Bangor, participated in this study. Three of those participants were dropped and replaced due to high error rates (above

10%). The final sample consisted of 14 females and 6 males (mean age: 22.3) who were recruited via an advertisement on the University intranet and paid £3 for taking part. All had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design and Procedure* were identical to those in Experiment 4, except that a different face was presented in the cue and target displays of a given trial; see Figure 12. As a consequence, the total number of trials was 80 (i.e., half the number of trials in Experiment 4). Furthermore, the order of the face stimuli from cue to target display was counterbalanced for sex of the stimulus and across participants to avoid stimulus-specific confounds.



**Figure 12.** Graphic representation of the experimental procedure employed in Experiment 10. On a given trial, the face that is presented in the cue display is different from that in the target display.



## Results & Discussion

### *Reaction time data*

Data from catch and error trials were excluded from the analyses. The remaining RT data were submitted to the same trimming procedure as in the previous experiments. As a result, 5.2% of the data were discarded.

As can be seen in Figure 13 (a), a similar pattern as in Experiment 4 emerged with faster RTs for invalidly cued targets compared to validly cued ones. This 8 ms effect was significant,  $t(19) = 2.37, p = .02$ , two-tailed. The data for this experiment were then compared with the data for the first half of Experiment 4 in an effort to keep the number of trials for each comparison equal. The results showed that the data pattern did not differ between experiments. More specifically, there was no interaction between cueing (valid/invalid) and Experiment (identical face/different face),  $p = .19$ . It therefore appears that inhibitory effects can be obtained even when a different face stimulus is presented in the cue and target displays of an experimental trial. Table 5 summarises the means that were used for between-experiment comparisons in this chapter.

**Table 5. Means and Standard Deviations (SD) for each validity condition for the first half of Experiment 4, the entire Experiment 10, and the first half of Experiment 11.**

		<i>Experiment 4</i>	<i>Experiment 10</i>	<i>Experiment 11</i>
<i>Valid</i>	<i>Mean</i>	373	375.23	364.71
	<i>SD</i>	48.18	54.29	54.55
<i>Invalid</i>	<i>Mean</i>	358.86	367.46	357.52
	<i>SD</i>	47.92	53.51	51.16

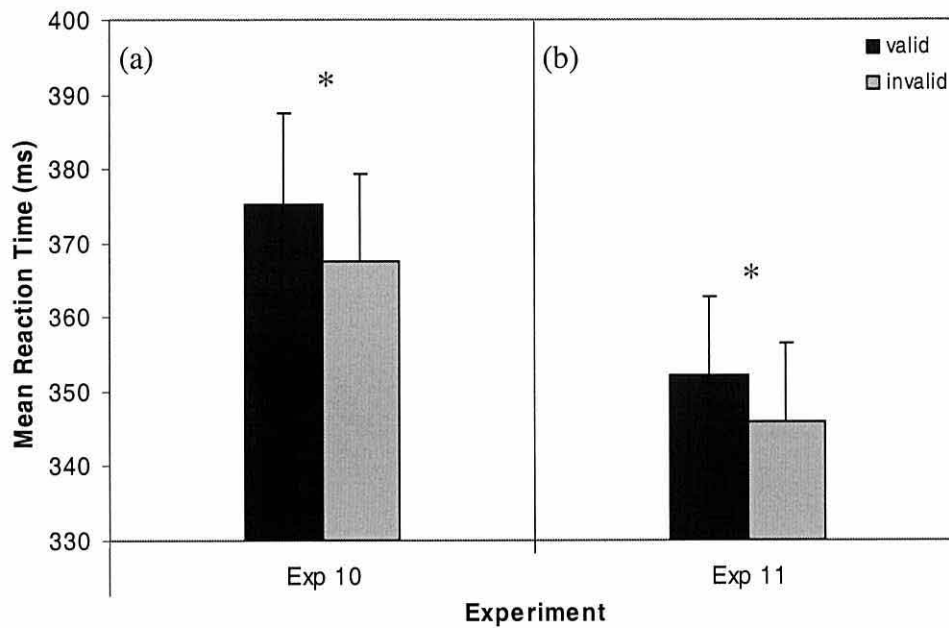
*Error data*

Errors were made on 2.4% of the trials (see Table 6). Analysis of the error data revealed no significant effects.

**Table 6. Mean error rates for Experiments 10-13.**

	<i>Experiment 10</i>	<i>Experiment 11</i>	<i>Experiment 12</i>	<i>Experiment 13</i>
<i>Valid</i>	0.2	0.6	0.45	0.55
<i>Invalid</i>	0.45	0.5	0.4	0.15

The results of this experiment provide initial evidence against a retrieval account. The inhibition was unaffected by the identity change of the face stimulus. An exclusively retrieval-based mechanism cannot account for this result. However, it may be that rather than being associated with a particular token of a category, the attentional state evoked by the gaze cue is encoded in terms of the object category. Retrieval of the category may therefore be affected by retrieval of information associated with exemplars of that category (see e.g., Anderson, Bjork, & Bjork, 1994; Veling & van Knippenberg, 2004). Thus, instead of being tied to a specific face identity, gaze-cued attentional states may be associated with faces in general. The next experiment attempted to resolve this issue.



**Figure 13.** Results of (a) Experiment 10 (different faces in cue and target displays) and (b) Experiment 11 (face in cue display, object in target display). Mean RTs are shown for valid and invalid trials. The asterisk (\*) marks the statistically significant differences.

### Experiment 11: face & object

This study was an attempt to confirm the pattern of data observed in Experiment 10. That is, inhibition evoked by gaze cues can be observed even when cue stimulus and target stimulus are different. In this experiment however, a more extreme difference between cue and target display was employed. A face with gaze shift was the cue display, but the target display contained an image of either

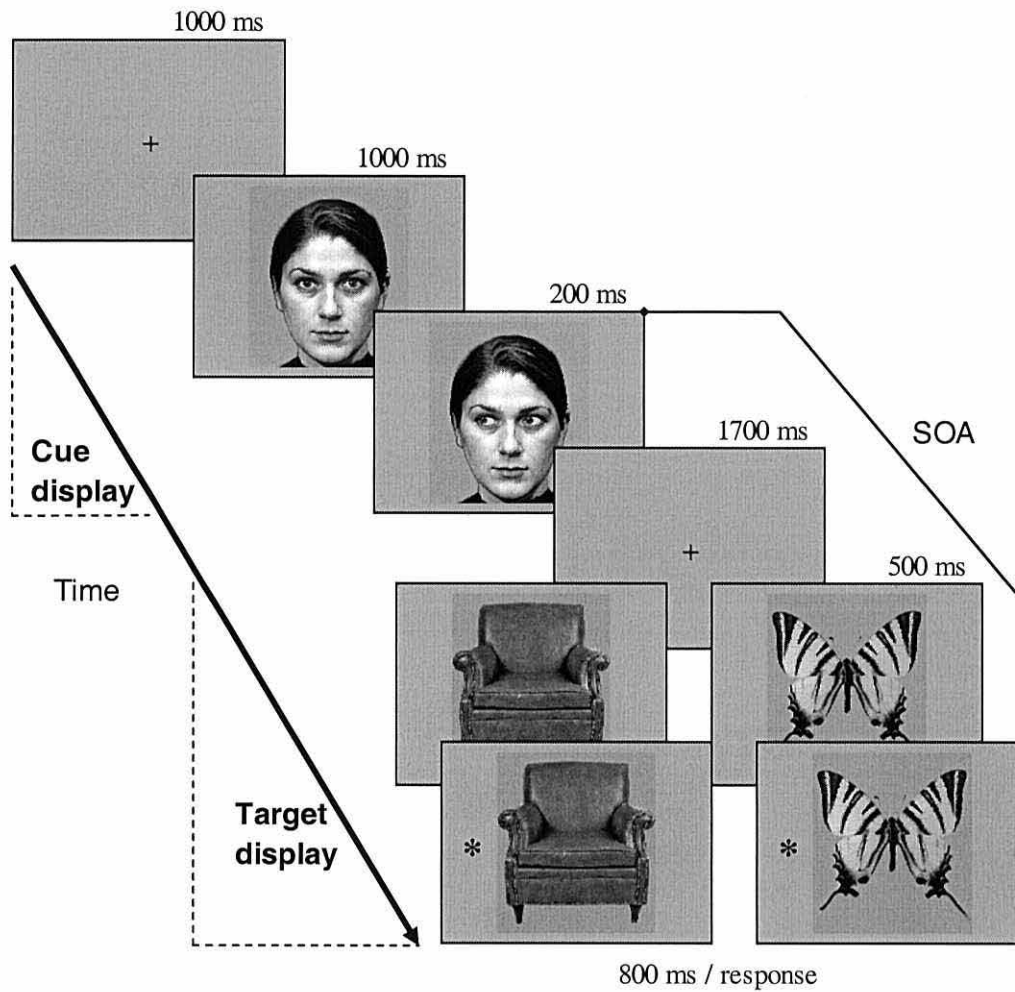
a chair or butterfly. These objects are very different to the face displays, and hence no retrieval of face-associated inhibition should be possible.

## Methods

### *Participants*

20 students of the University of Wales, Bangor, participated in this experiment and were paid £3. They were 16 females and 4 males, with normal or corrected-to-normal vision and a mean age of 21.2.

*Apparatus, Stimuli, Design and Procedure* were the same as those in Experiment 4, except for the following: a picture of an object appeared in the target display as the central stimulus; see Figure 14. The pictures were presented on a light grey background identical to that used for the face stimuli. All pictures were frontal views of the object, keeping the shapes symmetrical. The objects were instances of a single category in order to keep processing demands as equal as possible across face and object stimuli. Furthermore, both animate (butterflies) and inanimate (chairs) categories of objects were employed and presented in separate blocks. Consequently, the experiment was divided into two blocks of 80 trials each. The order of the blocks (butterflies or chairs) was counterbalanced across participants.



**Figure 14.** Illustration of the procedure of Experiment 11. As before, a face is the central stimulus of the target display, but a non-face object is presented in the target display. That object is either a chair or a butterfly.

### Results & Discussion

#### *Reaction time data*

Data from catch as well as error trials were discarded. The remaining RT data were submitted to the same trimming procedure as in the previous experiments.

As a result of this trimming, 3.7% of the data were removed.

Again, significant cueing of 6 ms was obtained [ $t(19) = 3.66, p = .002$ , two-tailed], with faster RTs on invalid trials. In order to assess the effect of the different objects (butterflies versus chairs) on the RT data, a 2 x 2 repeated-measures ANOVA was conducted with Cue Validity and Object Category as factors. Only a main effect for Validity was found,  $F(1,19) = 20.47, MSE = 775.22, p < .001$ ; the object category did not influence the cueing effect,  $F(1,19) = 2.6, MSE = 50.2, p = .12$ . Therefore and for the sake of simplicity, Figure 13 (b) displays the data collapsed across object category. The means for each category are shown in Table 7.

**Table 7. Means and Standard Deviations (SD) for each object category in valid and invalid conditions for Experiment 11.**

	<i>Chair</i>		<i>Butterfly</i>	
	<i>Valid</i>	<i>Invalid</i>	<i>Valid</i>	<i>Invalid</i>
<i>Mean</i>	353.64	344.9	352.19	348.57
<i>SD</i>	50.46	47.47	51.83	52.91

#### *Error data*

Errors occurred on 1.2% of the trials. The mean error rates are displayed in Table 6. No significant effects emerged from the analysis of the error data.

Further analyses compared cueing effects between this study and Experiment 4 (identical cue-target faces). The data from the first halves of Experiments 4 and 11 were used for comparison because of the object category switch in Experiment 11 (switching from chairs to butterfly target displays, or

vice versa) which did not occur in Experiment 4; see Table 5. Furthermore, the number of trials in each condition was kept equal this way. This analysis showed no significant effect of, or interaction with, Experiment,  $p = .103$ .

The results of this experiment again confirmed that the longer-term IOR effect does not require the same face to be presented during gaze cueing and during target presentation. Indeed, equivalent cueing effects emerged regardless of the category of the cue display object. These data are incompatible with reliance on specific retrieval of face identity or category. Instead, they provide initial support for the hypothesis that the inhibition might be maintained continuously over the period from initial gaze to subsequent target presentation in visual spatial working memory systems. However, partial involvement of identity retrieval would predict larger gaze cueing in Experiment 4 where cue and target face are identical. Although non-significant, there are trends towards this pattern in the data, where inhibition is 14 ms in the first half of Experiment 4 compared to 7-8 ms in Experiments 10 and 11 (see Table 5). Therefore, two further studies were conducted which attempted to selectively disrupt online maintenance of inhibition in working memory. Following the work of Castel et al. (2003) and Paul (2003), intervening tasks were presented between the gaze cue display and the subsequent target display.

### **Experiment 12: intervening spatial task**

In this experiment, a task that required spatial processing was presented between cue and target displays. Furthermore, the target display contained either the same face as the cue display, or a non-face object (i.e., a butterfly). The predictions were as follows: if the inhibition required retrieval processes, this intervening task would selectively disrupt the maintained visual spatial working memory component of inhibition, but would not affect the specific retrieval of inhibition associated with face identity. Thus, when comparing conditions where the face in cue and target display is identical (as in Experiment 4) with conditions where cue face is followed by images of butterflies, then inhibition should survive in the former but not the latter condition if it can be mediated by retrieval of prior instances. In contrast, if inhibition was purely maintained in visual spatial working memory, the intervening task should disrupt the effect regardless of the stimulus that is presented in the target display. A further change to the experimental design, in an effort to increase sensitivity, was to examine identical face cue/face target conditions and face cue/butterfly target conditions in a within-subjects design.



## Methods

### *Participants*

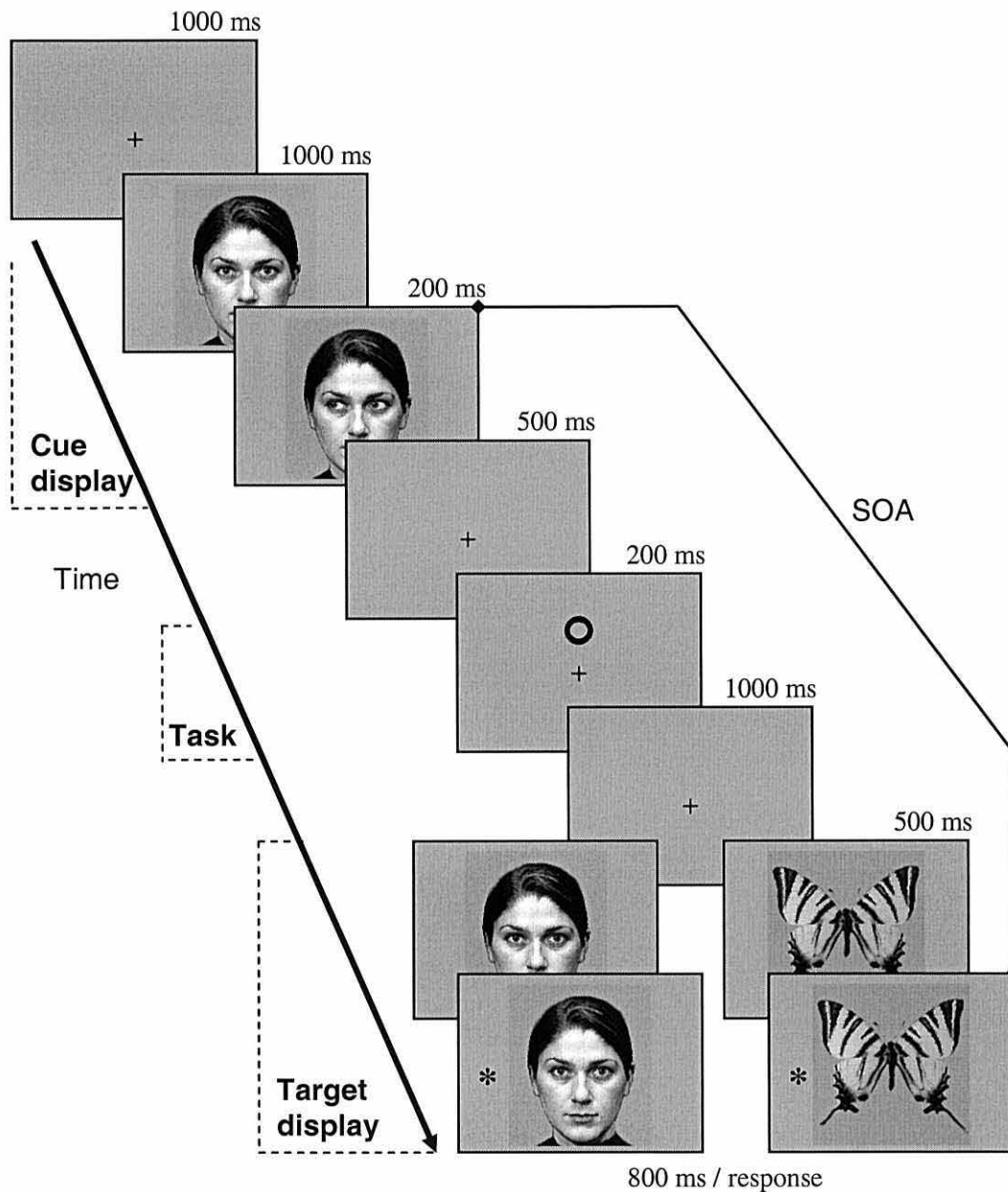
20 students of the University of Wales, Bangor, participated in this experiment and were paid £5. The data of five participants were dropped and replaced due to high error rates (above 10%). The final sample consisted of 10 females and 10 males, with normal or corrected-to-normal vision and a mean age of 25.7.

*Apparatus, Stimuli, Design, and Procedure* were the same as those in Experiment 4, except for the following: on half the trials, the central stimulus of the target display was the same face used in the cue display, while a picture of a butterfly was presented in the target displays of the remaining trials. Face and butterfly trials were presented randomly in a mixed fashion. Moreover, between cue and target displays, a shape subtending  $3^\circ$  appeared  $0.8^\circ$  above or below the central fixation cross for a duration of 200 ms (see Figure 15). On half the trials, the shape was the outline of a square and on the other half it was a circle, though the identity of the shape was irrelevant for this experiment. The participants' task in response to this stimulus was to say out loud and clearly where the shape had appeared ("UP" if it was above the fixation cross or "DOWN" if it was below) as soon as they had detected it.<sup>10</sup> These verbal responses were manually recorded by the experimenter who stayed in the room. The cue-target SOA

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<sup>10</sup> A verbal rather than a manual response was chosen for the intervening task because pilot studies that I conducted had shown that the latter resulted in very high error rates, presumably because the two different keypresses (task versus target) caused competition within the same response system.

remained unaffected by this intervening event and matched the 2400 ms SOA of the previous experiments.



**Figure 15. Experimental procedure of Experiment 12. A shape is presented above or below fixation as a spatial discrimination task before either the same face stimulus as in the cue display or a butterfly appears along with the target.**

## Results & Discussion

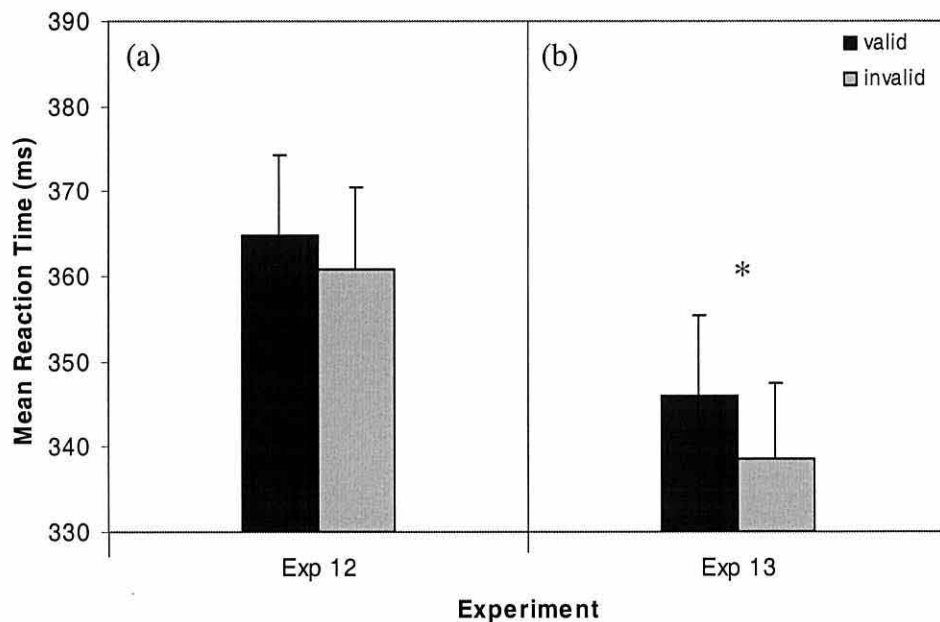
### *Reaction time data*

Data from catch as well as error trials were discarded. The remaining RT data were submitted to the same trimming procedure as in the previous experiments. As a result of this trimming, 4.8% of the data were removed. The participants had no difficulty with the intervening task; their accuracy was 99.4%.

A 2 x 2 (Stimulus Category x Cue Validity) ANOVA confirmed that the overall cueing effect of 4 ms was not significant,  $F(1,19) = 2.73$ ,  $MSE = 130.87$ ,  $p > .1$ . An interaction between both factors did not reach significance either ( $p > .7$ ), suggesting that this null effect was found for both face and butterfly trials. The only significant result was a main effect for Stimulus Category [ $F(1,19) = 26.67$ ,  $MSE = 372.22$ ,  $p < .001$ ], with faster RTs on butterfly trials. For simplicity, Figure 16 (a) presents the data collapsed across stimulus category since no difference in cueing between face and butterfly trials was found. The mean RTs for each category are displayed in Table 8.

### *Error data*

Errors occurred on 2.2% of the trials (see Table 6). No significant effects were obtained from the analysis of these data.



**Figure 16.** Results for (a) Experiment 12 (spatial task), and (b) Experiment 13 (non-spatial task). Mean RTs are shown for valid and invalid trials. The statistically significant difference is marked by an asterisk (\*).

The simple spatial task intervening cue and target presentation abolished the gaze-evoked IOR effect. Strikingly, this was the case when the cue face had been followed by butterfly target displays, as well as when cue and target face had been identical. Therefore, these results confirm the previous conclusions drawn from the comparisons of Experiments 4, 10 and 11. There appears to be no evidence that inhibition is associated with a specific face identity and retrieved/reinstated at a later time. Rather, the results support the notion that attention is inhibited from orienting to a spatial location, and this information or state is maintained in visual spatial working memory over the 2400 ms SOA period (cf., Castel et al., 2003; Paul, 2003). When a further spatial task is

introduced, this disrupts maintenance of this spatial information, hence causing the inhibition to decay.

**Table 8. Means and Standard Deviations (SD) for each stimulus category presented in the target displays of Experiment 12 and 13, for both valid and invalid trials.**

<i>Stimulus</i>			<i>Experiment 12</i>	<i>Experiment 13</i>
<i>Butterfly</i>	<i>Valid</i>	<i>Mean</i>	353.87	336.67
		<i>SD</i>	38.67	38.43
	<i>Invalid</i>	<i>Mean</i>	349.68	331.12
		<i>SD</i>	38.37	39.14
<i>Face</i>	<i>Valid</i>	<i>Mean</i>	376.25	354.9
		<i>SD</i>	50.34	47.54
	<i>Invalid</i>	<i>Mean</i>	371.92	346.19
		<i>SD</i>	50.04	43.44

### **Experiment 13: intervening non-spatial task**

Following the procedure utilised by Castel et al. (2003) and Paul (2003), a virtually identical task was employed in this experiment. The present task, however, did not demand spatial processing. This way it could be assessed whether the IOR disruption apparent in the previous experiment was indeed due to visual spatial working memory load or more general task-switching demands that the intervening task would have posed.

## Methods

### *Participants*

20 students of the University of Wales, Bangor, participated in this experiment and were paid £5. One participants' data were dropped from the analysis and replaced due to high error rates (above 10%); the final sample was 14 females and 6 males, with normal or corrected-to-normal vision and a mean age of 21.1.

*Apparatus, Stimuli, Design, and Procedure* were the same as those in Experiment 8, except that now the participants responded to the intervening task by naming the identity of the shape rather than its location (i.e., "SQUARE" or "CIRCLE").

## Results & Discussion

### *Reaction time data*

Data from catch trials and error trials were excluded from the analyses. The RT data were trimmed, and 4.3% removed prior to further analyses. Similarly to Experiment 11, the intervening task posed no difficulty to the participants as is evident in the accuracy rate of 98.6%. The data are plotted in Figure 16 (b). A 2 x 2 ANOVA revealed, as before, a main effect for Stimulus Category [ $F(1,19) = 20.9$ ,  $MSE = 263.8$ ,  $p < .001$ ], with faster RTs on butterfly trials. In contrast to the previous experiment, the cueing effect (7 ms) was now significant,  $F(1,19) =$

6.93,  $MSE = 145.77$ ,  $p = .016$ . The interaction between Validity and Category did not reach statistical significance ( $p > .5$ ).

#### *Error data*

Errors were made on 1.6% of the trials, the mean rates are shown in Table 6. No significant effects emerged from the analysis of these data.

Whereas the spatial task in Experiment 12 disrupted the inhibition effects, the present non-spatial task did not. The results of this experiment together with the previous one therefore seem to provide some support for the notion that the IOR that was observed in response to eye-gaze cues was maintained in visual spatial working memory.

## **Chapter Discussion**

The experiments in this chapter investigated the role of two forms of memory in sustaining orienting effects over the 2.4 sec cue-target interval: long-term retrieval of attentional states associated with a particular stimulus and online maintenance in working memory. The results of the present experiments support the latter working memory account. Experiments 10 and 11 (and comparisons with Experiment 4) showed that equivalent cueing effects can be obtained

whether the central stimulus in the target display contains the same face, a different face, or a different type of object. This suggests that the inhibition effect was not dependent on retrieval processes. However, although between-experiments comparisons did not yield significant interactions between cueing and experiment, the magnitude of the effect was larger in Experiment 4 (14 ms) than in Experiments 10 and 11 (~ 7 ms; see Table 5) when the number of trials were matched across experiments. This signalled the possibility that both retrieval and online processes might be involved and operate in an additive manner.

Therefore, the next two experiments were conducted to selectively disrupt the working memory component. Based on previous research (Castel et al., 2003; Paul, 2003) that demonstrated that IOR is maintained in visual spatial working memory, intervening tasks were employed that posed spatial and non-spatial demands. The IOR effect was abolished only when the task required spatial processing but was unaffected by concurrent non-spatial processing. Critically, in Experiment 12 (spatial task), the effect was disrupted when a butterfly was presented in the target display as well as when the face from the cue period was re-presented. This evidence indicates that retrieval processes do not underlie the cueing effects at the present cue-target intervals.

The results from the intervening task experiments also suggest that IOR is maintained in a spatial frame of reference since only the spatial task disrupted the effect. In the non-spatial task, the magnitude of IOR was similar to previous experiments that did not employ such an interference technique (~ 7 ms in



Experiments 4 [entire experiment], 10 and 11). The difference in RT pattern obtained in Experiments 12 and 13 was not due to differences in task difficulty, since both tasks posed roughly equivalent processing demands and were performed equally well. When the data for both experiments were entered into a mixed ANOVA to compare the cueing effects, the interaction between experiments did not reach significance ( $p > .4$ ). This failure to observe an interaction between the two tasks despite significant effects in one but not the other may be attributed to the relatively small effect sizes and a lack of power due to the use of a between-subjects rather than within-subjects design. However, using a within-subjects design to contrast the effects of spatial and non-spatial tasks would likely have involved the asymmetric transfer of a strategy that was learned in one (e.g., spatial) condition to the other (e.g., non-spatial) condition (see Poulton, 1982). For this reason, this work can only provide a first cautious insight into the role of working memory in maintaining IOR across time in gaze-cue paradigms.

Nevertheless, the data pattern from both experiments implies that the shape localisation task and the gaze-cue task recruited shared cognitive or neural resources. The fact that the shape identification task did not influence the IOR effect also suggests that the inhibitory mechanisms did not access an object-based frame of reference. This makes sense since the gaze-cue task required target localisation. The detection target was a singular shape that did not change throughout the experiment and therefore would not have posed object-recognition processing demands. Thus, in the present task, IOR was most likely maintained in spatial working memory.

## **Chapter Six**

*The influence of emotional facial expression on gaze cueing  
effects*

The focus of this chapter was the effect of the emotional expression of the face stimulus on orienting of attention. It is now well established that the emotion that a face expresses affects the allocation of selective attention. For example, faces expressing negative emotion have been shown to attract (e.g., Eastwood, Smilek, & Merikle, 2001; Fox, Lester, Russo, Bowles, Pichler, & Dutton, 2000; Öhman, Lundqvist, & Esteves, 2001; Vuilleumier & Schwartz, 2001) and hold (e.g., Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002) attention more strongly than faces expressing positive emotion, possibly by narrowing the focus of attention to reduce the influence of less relevant, peripheral information (Fenske & Eastwood, 2003). This demand for attention by affectively negative faces has even been shown to interfere with other ongoing tasks, presumably by attracting attention away from task-relevant information (Eastwood, Smilek, & Merikle, 2003; Vuilleumier, Armony, Clark, Husain, Driver, & Dolan, 2002; White, 1996), or by affecting the ability to disengage attention from an affective face in order to re-allocate it to another task-relevant location (e.g., Fox et al., 2001; 2002).

An abundance of neurophysiological and neuroimaging evidence demonstrates dense connectivity between cortical and subcortical areas coding attention, emotion and gaze direction perception (e.g., Adams et al., 2003; Aggleton et al., 1980; Hooker et al., 2003). This suggests that perceived gaze direction could influence emotion processing and vice versa. Indeed, there is support for the notion that gaze direction can affect emotion processing of the face stimulus (Adams & Kleck, 2003; Adams et al., 2003). In particular,

amygdala activity is less marked when gaze direction and facial expression convey unambiguous information whether a threat is directed at the observer (e.g., an angry face with direct gaze) or present in the environment (e.g., a fearful face with averted gaze). These findings are in line with the idea that there are distinct patterns of neural activity involved in basic approach and avoidance categories of emotion, motivation, and affective response (e.g., Cacioppo & Gardener, 1999; Davidson, 1995; Davidson & Irwin, 1999). According to this view, an *approach* system operates through emotions that motivate social interactions (e.g., happiness), while an *avoidance* system operates to facilitate withdrawal from aversive situations (e.g., fear, disgust). However, not all negative emotions elicit avoidance. Anger, for example, is often associated with approach behaviour. Thus, the effect of gaze direction may be quite different depending on whether an observed face is displaying anger or fear.

However, a relationship between emotional expression and orienting to gaze direction has not been successfully demonstrated in the general population (Mathews et al., 2003; Hietanen & Leppänen, 2003). It is possible that this failure is due to a lack or insufficient consideration of the time-course of orienting effects. Lupiáñez et al., (1997; 2001) had demonstrated that inhibition effects take longer to emerge with increasing task complexity. Similarly, the emergence of emotional modulation of gaze-dependent attention effects may be delayed because of the processing demands posed by the complex face stimuli comprising gaze and affect information. A cue-target SOA beyond a second may therefore be needed to observe modulation of gaze-evoked shifts of attention by faces expressing emotion.

In Experiment 14, the effects of three emotional expressions were compared: fear, happiness, and anger. The fearful expression represents an avoidance-type emotion while happy and angry faces embody approach-type emotions. The same SOAs as in Chapter Two were utilised (200 ms and 1200 ms). The duration of the latter SOA is almost twice as long as the intervals used by previous studies investigating the combined effects of facial expression and gaze direction on orienting. It was expected that the emotional content of the faces would influence the time-course of the gaze cueing effect. Thus, significant cueing effects may be observed at the 1200 ms SOA, at which point only null results had been obtained in previous experiments (see Chapters Two and Four). Furthermore, the pattern of these cueing effects should differ depending on the specific emotion of the face.

In addition to the longer SOA, an animated morphing procedure was incorporated that provided one initial second of exposure to a forward-looking, affectively neutral face that subsequently changed its emotional expression and gaze direction in a relatively smooth fashion prior to the onset of a target. Activity in brain regions implicated in processing facial affect is greater with dynamic compared to static emotional expressions, and activity patterns in the STS, and amygdala clearly discriminate between facial expressions of anger and fear when presented in dynamic morphs (LaBar, Crupain, Voyvodic, & McCarthy, 2003; see also Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004). Thus, employing a dynamic morphing procedure maximised the temporal overlap of gaze-related and emotional influences on attention, while allowing

direct comparisons of gaze-evoked effects that accompany fearful, happy, and angry facial expressions across a substantially broad time-course.

Experiment 15 served as a baseline comparison. In this study, only affectively neutral faces were presented while maintaining the dynamic morphing procedure of Experiment 14.

#### **Experiment 14: emotional face**

Experiment 14 examined whether cueing effects vary according to the specific facial emotion that is expressed at the time that gaze information is encoded. Participants viewed a face displaying an affectively neutral expression that gazed straight ahead. This face then morphed into an emotional face (with fearful, happy, or angry emotional expressions) that either retained a direct gaze or looked to the left or right. As in previous chapters, participants had to localise a target that was subsequently presented to the left or right of the face.

In line with the framework distinguishing facial emotions on an approach versus avoid dimension (e.g., Cacioppo & Gardner, 1999; Davidson, 1995; Davidson & Irwin, 1999), it was predicted that a face displaying an approach-type emotion (i.e., anger or happiness) would engage observers more than a face displaying an avoidance-type emotional expression (i.e., fear). On the

presumption that such engagement requires time, angry and happy faces were expected to show pronounced effects of gaze direction on reaction times (RTs), but only at the longer SOA. For the avoidance-type emotion (i.e., the fearful face), typical gaze-related attention effects at the short SOA were expected that should decay by the longer SOA.

In accordance with evidence on the effect of negative affect on attention allocation (e.g., Eastwood, Smilek, & Merikle, 2001; Fenske & Eastwood, 2003; Vuilleumier & Schwartz, 2001), it was expected that a face expressing anger with direct gaze might capture and hold attention more than the same direct-gaze face expressing fear or happiness. A disengagement difficulty in this case would result in slower RTs when a direct-gaze face displayed anger compared to when it displayed fear or happiness, or slower RTs when a face displaying anger had direct gaze than when it had averted gaze. In contrast, if the approach/avoid dimension alone determined disengagement difficulties related to observed facial emotion, then direct-gaze should slow RTs equally for expressions of anger and happiness compared to those for fear.

## Methods

### *Participants*

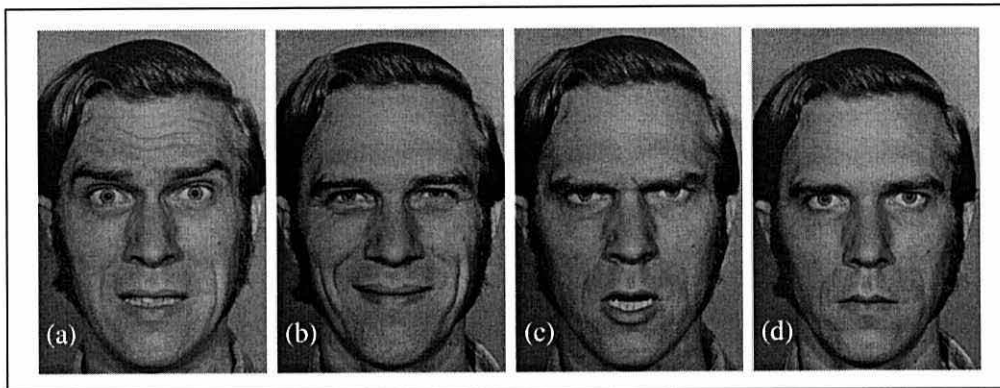
Twenty undergraduate students (6 males and 14 females) from the University of Wales, Bangor, participated in this study for course credits or a payment of £5. They all had normal or corrected-to-normal vision.

### *Stimuli*

Four grey-scale photographs of a single male face from the Ekman and Friesen (1976) series were used to produce the face stimuli and are depicted in Figure 17. Images of this individual were selected on a basis of the distinctiveness and clarity of the fearful, happy, threatening and neutral expressions displayed in each. Each face image was manipulated to produce the left-gaze and right-gaze cues by cutting out the pupil/iris area of each eye and pasting it into the left and right corner, respectively, of each eye, using Corel Photo Paint 9 software. The transitions between the neutral starting face with its gaze straight ahead and the three emotional expressions with the eyes directed to the left, right, and centre were accomplished by producing nine additional 'mid-expression' face stimuli using Morph 1.1 software (Gryphon Software Corporation, 1992). The initial neutral face subtended  $16^\circ$  in height and  $11^\circ$  in width, with a vertical distance of  $5^\circ$  between eyes and mouth. The emotional faces were made to be slightly larger, subtending  $16.6^\circ$  in height with a vertical distance of  $5.5^\circ$  between eyes and mouth, to enhance the aspects of social interaction with the emotional faces by giving the impression that the face was slightly approaching the observer



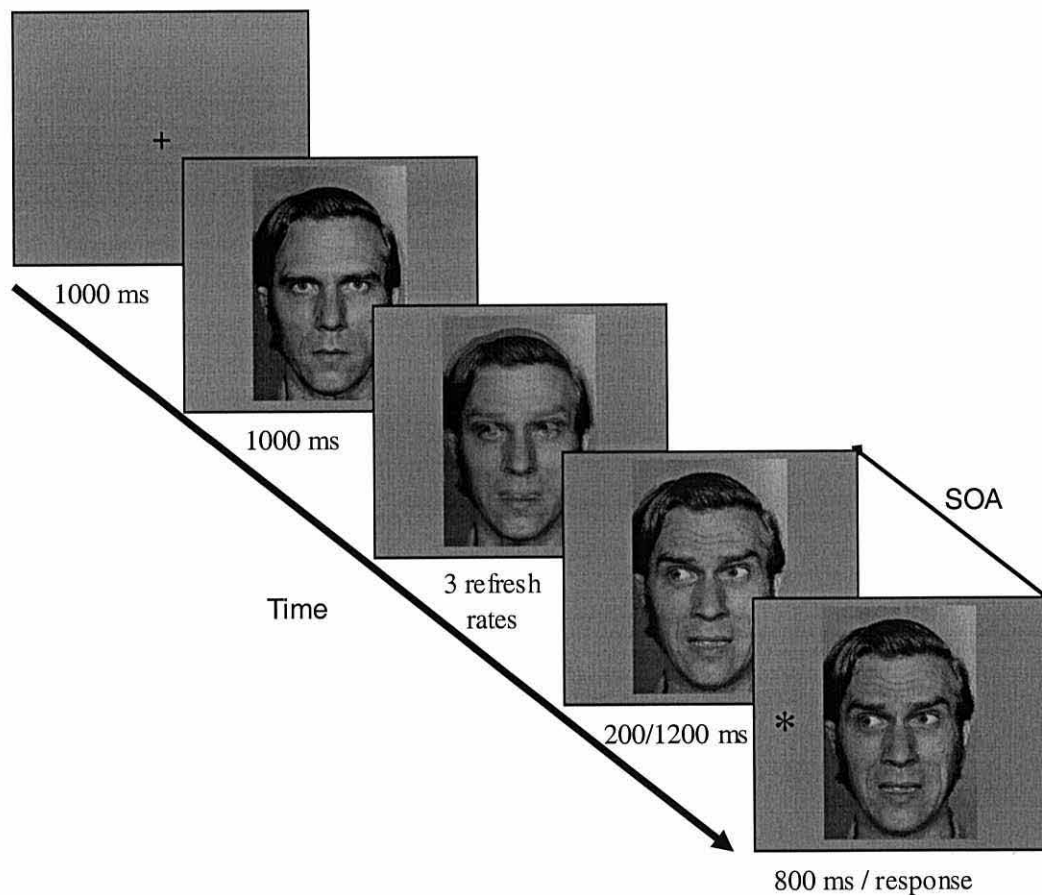
while the gaze and/or emotional expression was changing. A central cross, subtending  $0.7^\circ$ , served as a fixation point. The target itself was an asterisk, subtending  $0.7^\circ$ , and was presented  $8.6^\circ$  to the left or right of the centre of the screen, on level vertically with the eyes of the face.



**Figure 17.** Face stimuli (direct-gaze) displaying the different emotional expressions used in Experiment 1. From left to right: (a) fear, (b) happy, (c) anger, and (d) neutral.

*Apparatus, Design & Procedure* were identical to those of Experiment 1, except for the following: a face with neutral expression was presented for 1000 ms. Following this, the morph-stimulus was presented for 30 ms, followed by the appearance of the cue display. Each cue display contained a fearful, happy, or angry face that looked straight ahead, to the left, or to the right. The cue display remained visible throughout the remainder of the trial. On valid-cue trials, the target appeared on the same side of the display that the face was gazing at, and on invalid-cue trials, the target appeared on the opposite side to that gazed at by the face. Finally, on direct-gaze trials, the face continued to gaze ahead while the target appeared equally often to the left or right. This procedure is depicted in

Figure 18. Participants performed a short practice block of eighteen trials before the experimental block of 360 randomly intermixed trials formed by the factorial combination of cue-target SOA (200 ms vs. 1200 ms), emotional expression of the face in the cue display (fear vs. happiness vs. anger), and cue validity (valid vs. invalid vs. direct-gaze).

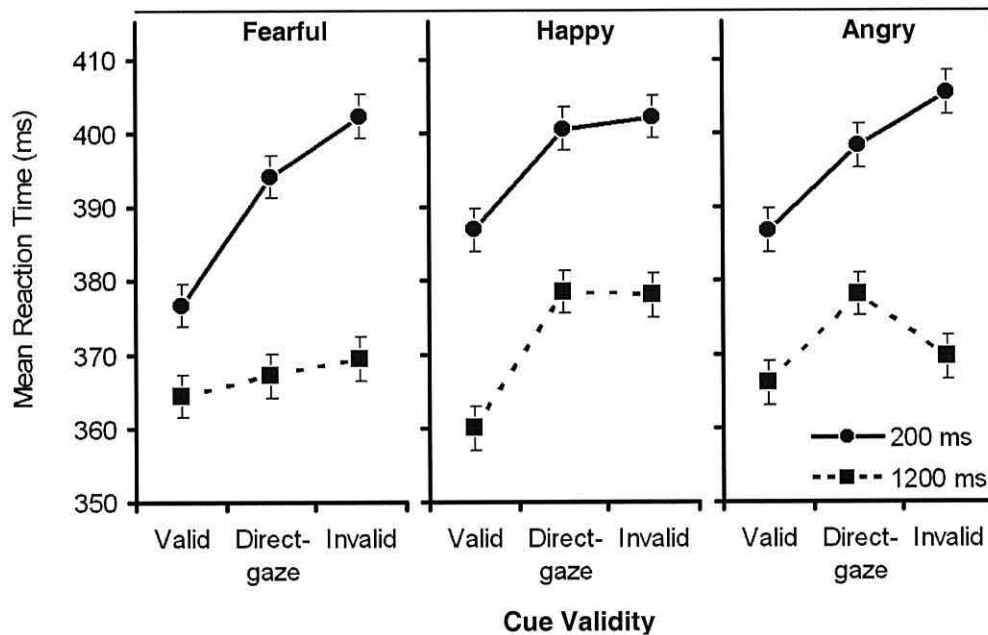


**Figure 18. Illustration of the experimental procedure of Experiment 14, depicted here in the fearful/valid condition.**

### Results & Discussion

#### *Reaction time data*

Data from catch trials and error trials were excluded from the analyses. The RT data were trimmed, and 4% removed prior to further analyses. The resulting data are shown in Figure 19.



**Figure 19.** Mean reaction times (RT) for each cue condition and cue-target SOA used in Experiment 14. Data are displayed separately for each emotion (fearful, happy and angry). The solid line represents the short SOA and the dashed line the long SOA.

A 2 (SOA) x 3 (Emotion) x 3 (Cue Validity) repeated-measures ANOVA revealed a significant main effect for Cue Validity, [ $F(2, 38) = 35.76$ ,  $MSE = 206.64$ ,  $p < .001$ ], with faster RTs on valid than neutral or invalid trials.

Furthermore, RTs for fear-face trials were faster, overall, compared to those for anger- or happy-face trials. The analysis confirmed that this main effect for Emotion was significant,  $F(2, 38) = 5.68$ ,  $MSE = 187.32$ ,  $p = .007$ . There was also a significant main effect for SOA, [ $F(1, 19) = 17.17$ ,  $MSE = 3183.78$ ,  $p = .001$ ], with faster RTs at the long SOA.

There was also a significant SOA x Validity interaction [ $F(2, 38) = 3.32$ ,  $MSE = 292.64$ ,  $p = .04$ ], which was qualified by a three-way interaction between SOA, Emotion and Validity,  $F(4, 76) = 2.92$ ,  $MSE = 173.63$ ,  $p = .02$ . Figure 19 indicates that there were robust facilitatory cueing effects for each emotion at the short SOA. At the long SOA, cueing effects seemed to emerge for anger and happy emotions only. When the RT effects for each SOA were assessed separately, the following patterns emerged: the main effect for Validity was significant at both SOAs [short:  $F(2, 38) = 20.87$ ,  $MSE = 302.23$ ,  $p < .001$ ; long:  $F(2, 38) = 10.41$ ,  $MSE = 197.06$ ,  $p < .001$ ]. However, the Emotion x Validity interaction was significant only at the long SOA [ $F(4, 76) = 2.56$ ,  $MSE = 204.02$ ,  $p = .04$ ], but not at the short SOA ( $F < 1$ ). These results show that facilitatory cueing effects can occur well beyond the cue-target SOAs used previously (e.g., Friesen & Kingstone, 1998; Langton & Bruce, 1999), and that gaze-evoked attention effects can be modulated, given sufficient time, by the emotion expressed by an observed face.

As predicted, Figure 19 shows that the patterns of gaze-related effects were highly similar for all emotion conditions at the short SOA, but were unique for each emotion condition at the long SOA. To examine this further, the RT

data for each emotion condition were submitted to separate repeated-measures ANOVAs. For Fear trials, a significant interaction between Validity and SOA emerged [ $F(2, 38) = 4.44, MSE = 254.94, p = .01$ ], with significant cueing effects at the short SOA [ $F(2, 38) = 14.95, MSE = 229.34, p < .001$ ], but not at the long SOA ( $F < 1$ ). In contrast, the analyses for Happy-face trials revealed no reliable interaction between Validity and SOA,  $p > .7$ . As can be seen in Figure 19, the magnitude of the cueing effect did not diminish with increasing SOA, and even increased slightly. The interaction was significant for the Anger data,  $F(2, 38) = 3.76, MSE = 211.93, p = .03$ . Despite this interaction, cueing was significant at both the short SOA [ $F(2, 38) = 8.97, MSE = 199.56, p = .001$ ] and the long SOA,  $F(2, 38) = 4.53, MSE = 166.41, p = .017$ . At the 1200 ms SOA, there was little difference in invalid- versus valid-trial RTs (3.4 ms). However, direct-gaze RTs were slower than RTs in either averted-gaze condition (direct-gaze – valid-trial RTs, 11.9 ms; direct-gaze – invalid-trial RTs, 8.5 ms). Thus, observing an angry face with direct gaze resulted in slower detection of peripheral targets at the long SOA than when gaze was averted. This pattern, as predicted, implies difficulties in attentional disengagement from the threatening face stimulus. A further analysis of long SOA trials showed that perceived eye contact led to significantly slower RTs on both happy- and angry-face trials compared to those on fear-face trials,  $F(2, 38) = 4.94, MSE = 165.14, p = .012$ . This suggests that face-related attentional disengagement effects may be specific to facial expressions associated with an *approach* system of emotion and social interactions.

*Error data*

Errors occurred on 2.3% of trials, the error rates are shown in Table 9. Analyses revealed significant main effects for Validity [ $F(2, 38) = 3.35$ ,  $MSE = .001$ ,  $p = .045$ ]. There was also a main effect for SOA [ $F(1, 19) = 5.43$ ,  $MSE = .001$ ,  $p = .03$ ]. These results converge with the RT results to suggest that interpretation of RT data is not compromised by a speed-accuracy trade-off.

**Table 9. Mean error rates in each experimental condition for Fearful, Happy and Angry emotions of Experiment 14.**

<i>SOA</i>	<i>Validity</i>	<i>Emotion</i>		
		<i>Fearful</i>	<i>Happy</i>	<i>Angry</i>
<i>200</i>	<i>Valid</i>	0.7	0.4	0.45
	<i>Direct-gaze</i>	0.3	0.35	0.6
	<i>Invalid</i>	0.45	0.8	0.85
<i>1200</i>	<i>Valid</i>	0.3	0.25	0.15
	<i>Direct-gaze</i>	0.55	0.2	0.4
	<i>Invalid</i>	0.4	0.25	0.7

The results of this experiment clearly show that gaze-elicited shifts of attention are modulated by the emotion that is expressed in an observed face, even in individuals that have not been identified as being highly anxious (cf. Mathews et al., 2003). In particular, emotion-specific cueing effects emerged at the 1200 ms SOA, at which previous experiments (see Chapters Two and Four) had found no gaze cueing effects. Whereas fearful faces elicited no cueing effects at this SOA, both happy and angry faces triggered reliable effects. This

supports the distinction between approach- and avoidance-type emotions. The specific RT pattern differed for happy- compared to angry-face trials. On Happy trials, strong facilitation emerged. In the Anger condition, no facilitation was observed but RTs were delayed on direct-gaze trials. This confirms previous observations that threatening emotions capture attention and narrow its focus (e.g., Eastwood et al., 2001; Fenske & Eastwood, 2003). Nevertheless, it is possible that these results were not due to the use of different facial expressions per se, but were caused by other methodological changes that were introduced in the present experiment. The next experiment aimed to clarify this issue.

### **Experiment 15: neutral face**

The purpose of Experiment 15 was to determine whether the lasting gaze-related attention effects observed in Experiment 14 were indeed due to the emotional content of the face displays, and not simply an artefact of other manipulations such as the morphing procedure. This dynamic mode of presentation was employed to enhance the effect of the facial expressions (see LaBar et al., 2003). However, it is possible that the morphing procedure enhances gaze-cueing effects more generally. Therefore, Experiment 15 utilised the same procedures as Experiment 14, except that the expression of the central face was always neutral. If the morphing procedure itself was responsible for the prolonged gaze-cueing

effects, a basic cue-validity effect should be observed at the long cue-target SOA. If the effects in the previous experiment were due to the emotional content of the face, the results of this experiment should resemble the basic findings of Experiments 1-3, with facilitation at the short SOA that would be absent at the long SOA.

In contrast to the previous experiments in this thesis, the present studies used a direct-gaze condition. Although the face stimulus in this experiment has a neutral expression (see Figure 17 d), eye contact itself can be perceived as challenging or otherwise threatening. This is a basic phenomenon that occurs in a wide variety of animals. Indeed, simple eye contact is thought to evoke physiological and emotional arousal in humans (Gale, Spratt, Chapman, & Smallbone, 1975; Nichols & Champness, 1971), and prolonged eye contact with humans or non-human conspecifics elicits escape or submissive behaviours in animals ranging from macaque monkeys (Coss, Marks, & Ramakrishnan, 2002; Perret & Mistlin, 1990) to black iguanas (Burger, Gochfeld, & Murray, 1992) and snakes (Burghardt & Greene, 1990). Accordingly, it may not be reasonable to expect the direct-gaze condition in Experiment 15 to act in a truly 'neutral' manner. If direct-gaze in the absence of other overt emotional expression is sufficient to elicit perceptions of threat, then the pattern of RTs on direct-gaze trials in this experiment may resemble that seen with anger-face displays in Experiment 14.



## Methods

### *Participants*

Twenty undergraduate students (6 males and 14 females) from the University of Wales, Bangor, participated in this study for course credits or a payment of £5.

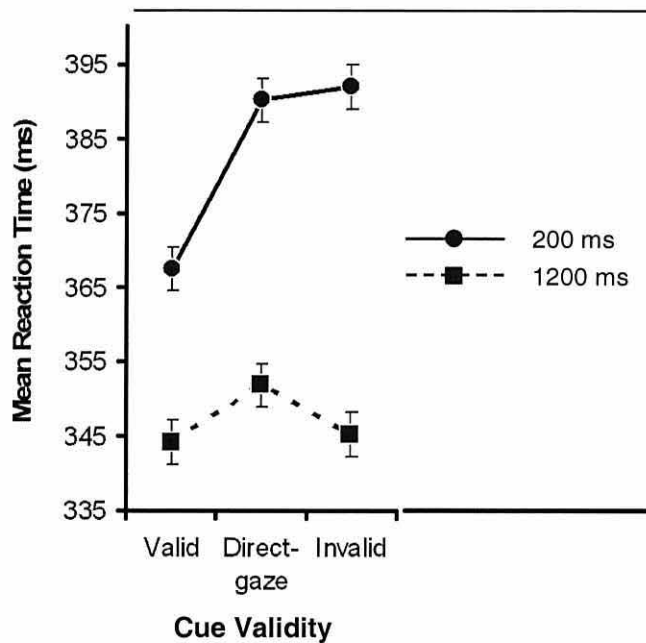
They all had normal or corrected-to-normal vision.

*Apparatus, Stimuli, Design, and Procedure* were identical to that used in Experiment 14, with the exception that the central face stimulus always displayed an affectively neutral expression. In order to match the physical aspects of the previous experiment as closely as possible, the direct-gaze neutral face morphed into a slightly larger face with variable gaze while maintaining its neutral expression. The sizes of the initial, morphed, and final face displays were matched to that for the neutral face, morphs, and emotional face displays, respectively, of Experiment 14.

## Results & Discussion

### *Reaction time data*

Correct RT data were treated in the same manner as before. As a result of this trimming, 3.3% of the data were discarded. The means for each cell were recalculated and are summarised in Figure 20.



**Figure 20.** Mean reaction times (RT) for each cue condition and cue-target SOA used in Experiment 15. The expression of the face stimulus in this experiment remained neutral. The solid line represents the short SOA and the dashed line the long SOA.

A 2 x 3 repeated-measures ANOVA with SOA and Cue Validity as within-subjects factors revealed a significant main effect for Validity [ $F(2,38) = 22.72$ ,  $MSE = 117.35$ ,  $p < .001$ ], with faster RTs on valid than on invalid or direct-gaze trials (see Figure 20). There was also a significant main effect for SOA [ $F(1,19) = 46.60$ ,  $MSE = 840.69$ ,  $p < .001$ ], with faster RTs at the long than at the short SOA. A similar RT pattern as in Experiments 1-3 emerged, in that there was a robust cue-validity effect at the short SOA, but not at the long SOA (invalid minus valid RT difference: 24.6 ms versus 1.0 ms, respectively). The difference in the magnitude of cuing effects was reflected in a highly significant SOA x Cue-validity interaction,  $F(2,38) = 16.3$ ,  $MSE = 87.2$ ,  $p < .001$ .

Moreover, while there was little difference in invalid- versus valid-trial RTs at the long SOA, direct-gaze RTs for these trials were slower than either averted-gaze condition. Separate ANOVAs for each SOA confirmed that gaze direction had significant effects at both the short [ $F(2,38) = 30.18, MSE = 124.04, p < .001$ ] and the long SOA,  $F(1,38) = 4.28, MSE = 80.52, p = .021$ . Thus, observing direct gaze in an otherwise affectively neutral face resulted in slower detection of peripheral targets at the long SOA than when gaze was averted.

#### *Error data*

Errors occurred on 1.6 % of the trials (see Table 10). There was only a main effect for SOA [ $F(1, 19) = 15.55, MSE = .7, p = .001$ ].

**Table 10. Mean error rates for Experiment 15.**

<i>Validity</i>	<i>SOA</i>	
	<i>200</i>	<i>1200</i>
<i>Valid</i>	0.8	0.65
<i>Direct-gaze</i>	1.45	0.8
<i>Invalid</i>	1.6	0.6

The results of this experiment generally resembled the pattern observed in Experiments 1-3: whereas reliable facilitation emerged at the short SOA, no difference between valid and invalid trials was evident at the long SOA. However, there was a significant effect of gaze direction at the long SOA which closely resembled the RT pattern observed for angry-face trials in Experiment

14: RTs were delayed on trials with perceived eye contact. This supports the hypothesis that direct-gaze in the absence of other overt emotional expression may be sufficient to elicit threat-type responses (see Panel d of Figure 17).

### **Chapter Discussion**

The experiments in this chapter investigated whether the emotional expression of a face modulates the effects of observed gaze direction on orienting of attention. The results clearly showed that different emotions produce distinctive cueing effects. Face displays that expressed fear produced early but short-lived facilitation in RTs for gazed-at target locations. In contrast, both happy- and anger-face displays produced strong but unique effects of gaze direction on responses across both cue-target intervals. Taken together with the fact that the cueing effects did not differ for the different emotional expressions by 200 ms from cue onset, these results suggest that interactions between gaze-direction and facial emotion take time to fully develop.

At the long SOA, targets appearing next to faces with direct gaze took longer to localise when the faces expressed happiness or anger than when they expressed fear. This finding suggests that faces with emotional expressions associated with an approach system of motivation preferentially engage the observer when eye contact is established. For faces expressing anger,

localisation responses with direct-gaze were even slower than those on invalid-gaze trials, suggesting that disengagement difficulties in attentional orienting may be greater in anger- than happy-face displays. Accordingly, slower target detection with straight-ahead gaze, especially with expressions of anger, may reflect relatively enhanced engagement of attention with a viewed person during such social interactions. This result is in line with previous demonstrations that faces displaying threat can capture and hold attention, and confirms the prediction that such effects are enhanced when eye contact with the observer is established.

For happy-face displays, a prolonged facilitatory effect of gaze-cueing emerged. While relatively little is known about the attentional effects of emotionally positive stimuli (in comparison with the effects of negative stimuli), there is some evidence to suggest that positive facial affect modulates attentional processes. Fenske and Eastwood (2003), for example, found that the impact of irrelevant flanking stimuli on the time to discriminate the emotion expressed by a central schematic face was greatest for affectively positive targets, compared to the smaller yet robust effect for neutral targets, and the complete absence of any effect for negative targets. From these results, they argued that focused attention is modulated by faces expressing emotion and that positive facial expressions of emotion may dilate the focus of attention, just as negative facial expressions reduce peripheral distractibility by constricting the focus of attention.

Derryberry and Tucker (1994) have also argued that positive affect can expand the scope of cognitive processing. In the context of gaze-cueing, an enhanced

scope of attentional operations associated with expressions of happiness may entail a prolonged response to gaze information.

The avoidance system, which is implicated when viewing fearful faces, seems to have two stages of attentional orienting. Initially, there is a relatively large cueing effect at short SOAs. This might reflect a rapid orienting of attention to a gazed-at location when a fear evoking stimulus might be present. Subsequently, attention is no longer specifically focused at the gazed-at location. Rather, there appears to be a general overall alerting which facilitates detection of targets wherever they appear. Furthermore, responses were generally faster than those for happy- or anger-face trials, regardless of SOA or gaze direction. This may indicate a hyper-arousal state in response to fear displays. Similar alerting or vigilance responses are seen in participants with anxious mood states who show enhanced attention to visual stimuli in the periphery (Shapiro & Lim, 1989). Thus, in the absence of a threat detected at the gazed-at location, a general alerting influence may enable rapid orienting to possible danger at any location, and without advance knowledge of what a potential source of danger is, or where it may appear, it may be maladaptive for such a monitoring state to be selectively directed and maintained at just one location in the environment.

Experiment 15 utilised only faces with neutral expressions. The basic cueing effects resembled those found in Chapter One: facilitation at the short SOA, and no RT difference between valid and invalid trials at the long SOA. This demonstrates that the morphing procedure introduced in the current chapter was not solely responsible for the emotion-specific prolonged cueing effects

observed in Experiment 14. However, the pattern of the direct-gaze neutral-face trials in Experiment 15 closely resembled the direct-gaze results in Experiment 14 for angry-face trials, although the mean direct- versus averted-gaze RT difference was larger for the angry-face trials (7.1 ms and 10.2 ms, respectively). While the direct-gaze results were not of primary interest here, they are nevertheless noteworthy, as they support the idea that direct-gaze in the absence of other overt emotional expression is sufficient to elicit perceptions of threat. This also highlights the difficulty of finding an appropriate baseline in spatial cueing paradigms (see Footnote 3). Furthermore, in the absence of contrasting emotional expressions, the “neutral” expression may in fact be perceived as threatening (see Figure 17 d). Incidentally, at an SOA of 1005 ms, affectively neutral schematic faces produced slower direct- than averted-gaze RTs in two out of the three response conditions (i.e., localisation and identification) reported by Friesen and Kingstone (1998). Importantly, the similarity between their findings and the present results suggests that the gaze-cuing effects that were obtained in Experiment 14 were in fact due to the emotion expressed by the face displays and the relatively long SOA rather than a low-level artefact of the morphing procedure per se.

## **Chapter Seven**

### *General Discussion*



The experiments in this thesis have explored some important properties of the effects of observed eye gaze direction on orienting of attention. Previous studies had found attention shifts in response to such gaze cues which occurred rapidly (by 14 ms; Hietanen & Leppänen, 2003), automatically (Driver et al., 1999; Friesen & Kingstone, 1998) and counter to intention (Driver et al., 1999; Friesen et al., 2004). Therefore it was suggested that gaze cues act in a similar fashion to sudden onset events in the visual periphery, as both these types of cue trigger reflexive orienting of attention. However, the maintenance of this new effect across time differed from peripheral cueing in an important aspect: the effect appeared to decay at longer SOAs, such that no RT difference between valid and invalid trials was obtained. In sharp contrast, with peripheral cues, the initial facilitation typically turns into an RT disadvantage for cued locations at longer cue-target intervals. This inhibition of return phenomenon seemed completely absent in gaze cueing paradigms. Therefore, it was suggested that orienting to gaze cues and peripheral cues, respectively, were different phenomena that are mediated by separate neural systems (Friesen & Kingstone, 2003a; 2003b). Furthermore, although neuroimaging evidence suggested that gaze direction perception and emotion perception processes interact, behavioural studies failed to find influences of emotional facial expressions on gaze cueing.

The present series of experiments challenge these established views. It was demonstrated that (a) cueing effects can be obtained at far longer cue-target intervals than previously thought, (b) that these longer-term cueing effects are

inhibitory, and (c) that cueing effects can be modulated by the emotional expression of the face stimulus at longer intervals.

Experiment 1 was a replication of previous gaze studies (e.g., Driver et al., 1999). A photograph of a face was presented with direct gaze that would then look to the left or right. A to-be-localised target then appeared at the gazed-at or the opposite location. The basic gaze cueing effect of facilitation at a short (200 ms) SOA and no RT difference between valid and invalid trials at a longer (1200 ms) SOA was replicated. In Experiment 2, a different face was presented at each trial in order to examine whether face identity interacts with gaze cueing. Exactly the same pattern as in the first experiment emerged, suggesting that changing the identity of the face stimulus does not influence the cueing effect, at least at the SOAs probed here. Experiment 3 introduced a central cueing manipulation in an attempt to summon attention away from the cued location and thereby revealing IOR. Such a procedure matched traditional IOR paradigms more closely than previous gaze studies which had presented the gaze cue continuously until target onset. Indeed, under such circumstances no IOR is observed (Collie et al., 2000; Maruff et al., 1999). Thus, in this experiment, the gaze of the face returned to the centre before target onset, re-establishing eye contact with the participant. However, no inhibition emerged at the 1200 ms SOA. Instead, the same RT pattern as before was obtained.

In Experiment 4, an extended SOA was utilised to test the hypothesis that inhibition takes longer to emerge when attention shifts are triggered by gaze direction. The duration of the SOA in this experiment was 2400 ms, which was

double the duration of the long SOA in the first three experiments. This was achieved by inserting a blank interval between cue and target displays such that the face disappeared following the gaze cue (i.e., eyes looking to the left or right). Shortly before target onset, the face would re-appear with direct gaze. This procedure therefore closely matched that of Experiment 3 except for the blank interval and SOA duration. The results of this experiment showed slower RTs at the cued compared with the uncued location. Thus, inhibition was observed for the first time in response to eye gaze cues. This effect was replicated in Experiments 5 and 6 with simple go/no-go detection and saccadic response tasks, respectively. Hence, the effect is robust and occurs reliably. Moreover, it shows very similar properties to “traditional” IOR obtained in response to peripheral cues as it generalises across different response tasks. The fact that this effect was observed at such a long SOA but not at shorter cue-target intervals (see Experiments 1-3) suggested that the onset of IOR is delayed in gaze-cue paradigms. However, it was also possible that the offset of the face stimulus between cue and target displays acted as a potent second cue to trigger attention away from the cued location, thereby allowing IOR to be observed.

This hypothesis was tested in the next series of experiments. Experiment 7 used an identical face-offset manipulation with a shorter (1200 ms) SOA. Recall that no cueing effects had been obtained at this interval previously. If observation of IOR was enabled by the offset of the face rather than the extended time-course, inhibition should now emerge at this SOA. However, no hint of a cueing effect was obtained. In Experiment 8, the SOA was varied from 1200 ms (previously no effect) to 2400 ms (previously inhibition). The outcome of this

study confirmed the earlier results: no cueing effect emerged at 1200 ms, but reliable inhibition was observed at 2400 ms. These results supported the hypothesis that IOR takes time to manifest itself in response to gaze cues. Experiment 9 probed whether both time and the offset of the face are necessary to produce IOR. Therefore, similarly to Experiment 3, the face remained visible throughout the trial. Under these circumstances, the only significant cueing effect was the basic facilitation at the short (200 ms) SOA. At both 1200 ms and 2400 ms, no difference between valid and invalid RTs was obtained. This suggested that although an extended time-course is necessary for IOR to be observed in response to gaze cues, it is not a sufficient condition. In addition, the offset of the face stimulus is required as this presumably cues attention away from the gazed-at location.

The following experiments investigated how those cueing effects are maintained across the 2400 ms interval utilised here. Previous research had indicated the role of two forms of memory mediating such maintenance. First, Tipper et al. (2003) demonstrated that an attentional state can be encoded into long-term memory along with its associated episode and retrieved at a later time. Thus, in the present paradigm, when a face was presented with averted gaze, this episode would have been encoded into memory. When the face was re-encountered at a later point (i.e., after the blank interval in Experiments 4-6), the attentional state that had been associated with this stimulus (e.g., if the face had been looking to the left, attention would have been oriented to the left) could have been retrieved which may have accounted for the cueing effects that were observed at that point. Thus, inhibition may depend on the presentation of an

identical face in cue and target displays. Second, Castel and colleagues (2003) suggested that inhibition is sustained in visuospatial working memory. They reported that in a spatial cueing paradigm, IOR was disrupted by concurrent spatial processing demands posed by a secondary task. In this situation, inhibition associated with the cued location would be maintained continuously across the cue-target interval and not be dependent on the repeated presentation of an identical stimulus in cue and target displays. The results of the present studies were inconsistent with a retrieval account and therefore supported the alternative working memory hypothesis. Experiments 10 and 11 showed that equivalent cueing effects were obtained whether the central stimulus in the cue and target displays were the same face, a different face, or even an entirely different class of object. Experiments 12 and 13 introduced a secondary task akin to the Castel et al. (2003) procedure. The inhibition effect was disrupted only when the secondary task demanded spatial processing and not when it required shape identification. However, the overall cueing effects for spatial and non-spatial task conditions were not statistically significantly different from each other.

The final two experiments examined the effects of emotional facial expressions on gaze cueing. Evidence from neuroimaging studies suggested that emotional expression and gaze direction interact to influence neural activity (e.g., Adams et al., 2003). However, previous research had failed to find behavioural evidence for such a modification in a normal population. Even though these studies employed an extensive range of SOAs, they never exceeded 700 ms (Hietanen & Leppänen, 2003; Mathews et al., 2003). In the present experiments,

the effects of fearful, happy and angry faces were compared across our established range of SOAs (200 ms and 1200 ms). It was reasoned that rather than impacting reaction times at very short intervals, emotion-related modulation might take time to emerge. Indeed, whereas equivalent cueing effects for all emotions were obtained at 200 ms, emotion-specific cueing effects emerged at a 1200 ms SOA.

### **Implications of IOR evoked by gaze cues**

The present series of experiments have demonstrated that inhibitory cueing effects can be obtained in response to gaze cues. This provides further support for the notion that gaze cueing effects are very much like peripheral cueing effects: first, gaze-evoked cueing effects emerge rapidly even at very short SOAs (Friesen & Kingstone, 1998; Hietanen & Leppänen, 2003; Langton & Bruce, 1999). Second, those cueing effects arise at short cue-target intervals even if the cue is counterpredictive (Driver et al., 1999; Friesen et al., 2004). Third, it is now apparent that inhibition is obtained at longer SOAs. All these criteria are hallmarks for reflexive attention shifts like those obtained in response to peripheral sudden onset cues (Jonides, 1981; Maylor, 1985; Posner, 1980; Posner & Cohen, 1984).

However, the fact that such automatic shifts of attention could be triggered by centrally presented, nonpredictive cues has led some researchers to suggest that eye gaze is a “special” attentional cue due to its biological significance (e.g., Friesen & Kingstone, 1998; 2003b; Langton & Bruce, 1999). Orienting of attention via other symbolic central cues such as arrows have in the past been regarded as non-reflexive, as orienting responses in the corresponding direction were slower to emerge and could be suppressed if the cue was misleading (Jonides, 1981; Müller & Rabbitt, 1989). The prevailing lack of IOR with gaze cues further distinguished gaze cueing from peripheral cueing effects (see Friesen & Kingstone, 2003b). However, recently it has emerged that centrally presented arrow cues can also induce rapid shifts of attention, even if they are uninformative with regards to the likely target location (Ristic, Friesen, & Kingstone, 2002; Tipples, 2002). Thus, it appears that biologically relevant (gaze) and biologically irrelevant (arrow) central cues trigger very similar attention shifts. The present studies further demonstrate that, like peripheral cueing, inhibition can also be obtained in response to gaze cues, which makes these two types of cueing effects very similar. Thus, eye gaze may not be as different from other types of cues as previously suggested, at least in terms of their basic behavioural effects.

Nevertheless, there are more subtle differences between gaze, arrow and peripheral cueing. For example, it appears that although arrow cues elicit reflexive attention shifts, gaze cues do so more strongly. When the target is more likely to appear in the uncued location (i.e., the cue is counterpredictive), gaze cues nevertheless trigger attention shifts in the gazed-at, but unpredicted,

direction at short cue-target intervals (Driver et al., 1999). The directional incentive of arrow cues, on the other hand, can easily be overridden so that orienting occurs to the predicted location only (Friesen et al., 2004). Moreover, the onset of IOR is relatively delayed with gaze cues compared to peripheral cues. With peripheral cues, inhibition is observed reliably within about a second following cue onset (see Samuel & Kat, 2003). The present studies, together with previous findings of null effects at such SOAs, demonstrate that inhibition emerges at much later intervals when evoked by observed gaze direction.

Although the present experiments clearly show that the onset of IOR is delayed with eye gaze cues, they were not designed to investigate the exact basis of this time-lag. There are at least three alternative explanations. First, IOR may be delayed because the gaze cue itself demands complex processing. Second, the time-course of facilitation may be prolonged and therefore mask inhibition because of the social importance of another's gaze direction which would encourage facilitation and discourage inhibition of the gazed-at location. Third, the time-course of inhibition may be delayed independently of the time-course of facilitation.

The first explanation would be in line with Lupiáñez et al. (1997; 2001) who demonstrated that the time-course of IOR is influenced by processing demands of the target task. Similarly, processing demands associated with the cue may cause a delay of inhibition. Since equivalently complex photographs of faces were used to produce the gaze cues in the current experiments, it is not possible to differentiate between processing demands posed by these cues and



therefore to make inferences on that basis. Future studies may, for example, manipulate the complexity of the gaze cue. If the time-course of IOR was affected by the processing of the cue, one would expect an earlier onset of IOR if the cue was processed easily, and a later onset with increasing processing difficulties. However, at present it is not clear which aspects of a face/gaze stimulus entail higher processing demands. For example, it is conceivable that a detailed photograph is a more complex stimulus than a simplistic line drawing and therefore should pose higher demands. Indeed, there is some evidence that schematic faces produce slightly larger cueing effects than photographs (Hietanen & Leppänen, 2003). However, the human brain is highly efficient at processing faces (e.g., Kanwisher et al., 1997), so that a realistic face might provide greater contextual cues and therefore be processed more fluently than (or at least as well as) a cartoon face. Hence, further research is required before cue complexity can be manipulated adequately.

The second explanation claims that facilitation is sustained at the cued location for longer in response to gaze information. Such prolonged orienting to the gazed-at location could be achieved reflexively or by a, possibly implicit, endogenous process. Langton & Bruce (1999) suggested that gaze cues can elicit both exogenous and endogenous orienting when the cue is informative. Facilitation effects were observed at longer SOAs than usual (1000 ms) when the cue predicted the most likely target location but not when the cue was nonpredictive. The delayed onset of inhibition observed in the present studies may reflect a similar, though less pronounced, endogenous maintenance of facilitation at the gazed-at location, even when the cue is uninformative with

regards to the target appearance. Thus, the null-effect at SOAs of about one second that was obtained here as well as in previous studies would reflect inhibition that is counteracted or masked by this endogenous orienting effect. However, it is unlikely that endogenous orienting alone is responsible for this. Indeed, Friesen et al. (2004) showed that when attention is oriented endogenously away from the cued location, similar null effects emerge at such SOAs for the gazed-at location. In their study, the gaze cue was counterpredictive so that the target appeared in the location opposite to the direction of gaze on the majority of trials. A wide range of SOAs was employed to determine the point at which reflexive orienting to the cued location would give way to voluntary shifts to the predicted target site. At the gazed-at location, facilitation was observed at short SOAs (105-600 ms). At the predicted location, facilitation emerged across the later range of SOAs (600-1800 ms). Thus, both types of orienting exhibited overlapping time-courses, suggesting that both occur relatively independently of one another. Importantly, no cueing effect was evident at those longer SOAs at the cued location. If endogenous orienting to the cued location had been responsible for the null-effect at such SOAs in other studies, one would have expected to see at least a trend for inhibition in the Friesen et al. study since voluntary attention was committed elsewhere. This, however, was not the case. The present experiments have also shown that when attention is triggered away from the cued location exogenously, via perceived eye contact or stimulus offset at fixation, inhibition is not observed at a similar interval (i.e., 1200 ms).

Taken together, these findings suggest that rather than resulting in prolonged facilitation, gaze cues elicit a delayed onset of inhibitory processes at the gazed-at location (as proposed in the third explanation). Nevertheless, it is possible that both explanations apply. Indeed, the results of Experiment 9 imply that this may be the case: in this study, no inhibition was observed at 2400 ms without a stimulus-offset manipulation. This indicates that facilitatory orienting processes have to be directed away from the cued location in order for inhibition to emerge.

Covert performance measures such as ERPs might be more suitable than overt behavioural measures to resolve this issue. With ERPs, it is possible to track the activation of facilitatory and inhibitory components over time, so that inhibition can be revealed even when it is masked behaviourally. Several ERP components have been linked to inhibitory attentional processes. The P1 wave is an early component that reflects modulation of early sensory processes via attention allocation (Eimer, 1994a). Suppression of P1 is assumed to be a marker of inhibitory processes (McDonald, Ward, & Kiehl, 1999). Importantly, it is present even if behavioural IOR is not observed. At later stages in IOR tasks, two negative difference (Nd; referring to increased negativity in valid cue conditions; see Eimer, 1994b) components emerge: Nd250 which presumably reflects sustained facilitation that masks behavioural IOR, and Nd310 which seems closely related to overt inhibition performance (Wascher & Tipper, in press). Applied to the present experiments, the following scenarios would be expected at the critical (null-effect) 1200 ms SOA: if the onset of behavioural IOR was delayed because it was masked by sustained facilitation at the cued

location, one would expect suppression of P1 and Nd250 at this SOA. At later (i.e., 2400 ms) SOAs, when inhibition emerges in overt performance, suppression of P1 would still be observed, but no Nd250. Instead, Nd310 would now be obtained in parietal areas. If, however, the onset of inhibitory processes *per se* was delayed, one might fail to obtain either P1 suppression or Nd250 at the 1200 ms SOA. This is certainly an issue worthy of future investigation.

Although inhibition effects are obtained in response to gaze cues, one cannot assume that these are the same processes relying on the same neural systems as the inhibition evoked by sudden onset peripheral cues. The subcortical SC has been implicated in orienting processes triggered by peripheral stimuli (e.g., Rafal, et al., 1988; Sapir et al., 1999). In contrast, encoding of gaze direction appears to require cortical processing, especially in STS (e.g., Perrett et al., 1985; see also Hoffman & Haxby, 2000; Kingstone et al., 2000). Several studies have confirmed dissociations between peripheral cueing and gaze cueing effects, supporting the notion of separate systems. For example, Friesen and Kingstone (2003b) demonstrated that facilitation in response to gaze cues and inhibition evoked by a sudden onset peripheral stimulus could be observed simultaneously. In their study, the same stimulus served as the gaze cue and sudden onset peripheral cue. The fact that one stimulus could evoke two attentional states (excitation and inhibition) in two separate locations simultaneously is impressive evidence that gaze and sudden onset attention cues can be processed in parallel, probably by separate neural systems. Similarly, Friesen and Kingstone (2003a) showed that orienting via saccades is not influenced by the offset of a fixation stimulus, whereas peripheral cueing of

attention does interact with fixation offset (Abrams & Dobkin, 1994b). Because the offset of a fixation stimulus is assumed to disinhibit the SC, the lack of interaction with gaze cue orienting suggests that orienting attention via gaze is not mediated by the SC.

However, given that Friesen and Kingstone (2003b) argue that inhibition is absent in response to gaze cues (at least at shorter SOAs of around 555 ms), it is not surprising that there is no interaction between gaze cueing and the gap effect at such intervals. It would be interesting to see whether such an interaction would be evident at later intervals such as the 2400 ms SOA utilised here, where inhibition does occur.

As has been outlined in the introduction, even though the SC appears to play an important role in evoking inhibition of return of attention after orienting to a location, this does not mean that it is the sole neural structure mediating IOR. Indeed, there is increasing evidence that the range of inhibition effects now observed must be mediated by a more extensive network of neural systems involving both subcortical and cortical components. For example, Dorris, Taylor, Klein & Munoz (1999) noted that while the SC plays a role in IOR, the inhibitory effects are actually due to inputs from neural regions upstream from the SC, probably the parietal lobe. Similarly, neuropsychological evidence also suggests that IOR might be associated with processing in cortical regions, as patients with unilateral or bilateral inferior parietal damage fail to produce IOR effects (e.g., Bartolomeo et al., 1999; Vivas et al., 2003). Furthermore, it has

been suggested that object-based inhibition is dependent on cortical processing (Tipper et al., 1997).

Thus, a range of neural systems will be activated during search and selective action determined by behavioural goals (e.g., Tipper, Weaver & Houghton, 1994), perceptual input signals (e.g., Spence, Lloyd, McGlone, Nicholls, & Driver, 2000), and response outputs (Howard, Lupiáñez, & Tipper, 1999; Briand et al., 2000). The inhibition will be mediated by different neural systems in different circumstances, but nevertheless its function remains the same: to prevent re-processing of information at locations previously found to lack any useful information. As noted by Klein (in press), IOR thus cannot be viewed as a simple invariant mechanism, but is a multifaceted phenomenon, an inhibition process evoked in the service of a range of behavioural demands. Therefore, just as IOR can be evoked by peripheral sudden onset cues (Posner & Cohen, 1984) and central symbolic cues (e.g., Rafal et al., 1989), then the present data reveal that it can also be elicited by observed gaze direction.

### **The relationship between attention and memory processes**

Studies of attention and memory cannot be viewed as two separate disciplines (e.g., Tipper, 2001). In all cueing and priming studies, the effects of one stimulus are examined via the processing of a subsequent stimulus at a later point

in time. Therefore, there are critical issues concerning the form of neural representation that enables the first stimulus to affect processing of the later stimulus. In this dissertation, the inhibitory processes activated by an eye gaze cue were examined, and two possible forms of memory system subserving the inhibition across time were tested specifically.

### Memory retrieval

The first account suggests that inhibition can be associated with a particular object identity. Thus, after initial encoding, when an object is re-encountered at a later time, the prior processing episode is retrieved, including the original attentional state of the network. Reinstating inhibitory states will therefore impair processing of information at the previously inhibited location. Long-term retrieval of inhibitory states or traces has been demonstrated with the paradigms investigating negative priming (DeSchepper & Treisman, 1996) and inhibition of return (Tipper et al., 2003).

Here, this idea was extended to orienting of attention via gaze cueing. When the gaze orienting face and the subsequent target detection face were identical, it was predicted that inhibition would be retrieved. In contrast, when the cue face was unrelated to the subsequent target display (different face or different object category), then there was no possibility for identity-based retrieval of inhibition. A central feature of such an account is that inhibition is

not necessarily maintained over time. Rather, in some circumstance it can be reinstated. This reinstatement of inhibition is only possible when the retrieval stimulus can access prior processes: that is, when it is an identical face. The results of the present experiments show that inhibition is obtained regardless of the identity of the central stimulus.

Furthermore, according to a retrieval account, inhibition should be able to survive intervening events when cue and target face are identical, because it needs not be maintained over time. However, the results of Experiment 12 clearly show that inhibition is not observed when a stimulus requiring spatial processing intervenes between gaze cue and subsequent target. Therefore, this appears to be another contrast between the inhibition evoked by gaze cues and that evoked by sudden onset peripheral cues: the latter peripheral-cue inhibition seems to be associated with face identity and can be retrieved from memory at a later time; the gaze-cue inhibition does not appear to be associated with a face identity, and it cannot be retrieved at a later time. This is in line with the notion that face recognition and gaze perception systems operate independently (e.g., Haxby et al., 1999).

However, the procedure utilised here and that by Tipper et al. (2003) differ in a potentially important aspect. In the Tipper et al. experiments that obtained retrieval effects, the cue face was followed by several other faces before it was re-encountered in the target display. In the present experiments, cue and target face were always presented within the same trial. This procedure may not have encouraged retrieval processes, so that identity-specific cueing effects



would not be observed. I conducted a pilot study in which the gaze cue was followed by 40 intervening items (other cue and target displays) before the original face was presented again with a target at the previously gazed-at side (valid trial) or the opposite side (invalid trial), to match the Tipper et al. procedure. In order to make the stimuli more distinctive and hence more likely to leave a long-term trace that can be retrieved, the faces in this experiment were colourful (as opposed to uniform grey-scale) novel and famous faces. The results showed indeed significant long-term cueing effects, but only for famous faces and left targets. This left-right asymmetry is in accordance with Tipper et al. (2003) who also found stronger long-term inhibition effects for the left side. They attributed this finding to the lateralisation of face processing to the right cortical hemisphere, where the memory representation of the face along with the associated attentional state would be encoded more strongly. Furthermore, a stronger cueing effect for the left hemifield is in line with Ricciardelli, Ro and Driver (2002) who found a left visual field advantage and dominance for judgements of gaze direction. The fact that long-term cueing in the gaze pilot study was associated with famous faces only could be due to the higher level of familiarity with those stimuli which would also result in stronger memory representations. Thus, it seems that identity-specific long-term gaze cueing effects may be obtained, but the circumstances under which this occurs need to be investigated further. For example, it is possible that when encoding of the face stimulus is made explicit by being part of the task requirement (for example, a face recognition test is employed), long-term cueing effects would be observed for non-famous faces as well.

### Visual spatial working memory

The other memory account suggests that inhibition is associated with a spatial location, and that this inhibitory state is maintained in visual spatial working memory (Baddeley & Hitch, 1974). Previous work has investigated the working memory properties of sudden onset-cue IOR, and shown that inhibition can be maintained simultaneously for four, or more, objects in working memory (e.g., Danziger et al., 1998; Paul & Tipper, 2003; Snyder & Kingstone, 2000; Tipper et al., 1996). Most closely related to the studies here, Castel et al. (2003) and Paul (2003) showed that stimuli requiring concurrent encoding of spatial information disrupted the maintenance of IOR. When, however, processing of the stimulus is non-spatial, IOR is not disrupted.

This latter finding is exactly the result that was obtained here. A stimulus requiring a spatial response disrupted IOR. This was the case even when the cue and target face were identical, a situation where identity-based inhibition retrieval should have supported IOR. A virtually identical but non-spatial task that required shape identification failed to disrupt IOR, which suggests that the disruption in the spatial task is not due to a general working memory load but specifically to visual spatial processing demands. However, the lack of an interaction between both types of tasks limits the strength of this argument. Therefore, any conclusions regarding the exact working memory mechanisms involved in maintaining the effects that were observed have to remain tentative. Nevertheless, the pattern of data obtained in the present experiments supports the conclusion that gaze-evoked inhibition is not dependent upon retrieval processes

but rather is at least partly mediated by working memory processes, and is therefore vulnerable to processing interference. Support for the working memory hypothesis could be obtained by manipulating the relation between gaze cue task and intervening task further. For example, if the gaze cue task was target identification requiring shape processing rather than localisation, the inhibition effect might be affected by a concurrent object identification task such as in Experiment 13.

### **Eye gaze and emotion**

The final experiments of this thesis demonstrated that the emotion expressed by a face has a significant impact on the magnitude, and qualitative pattern, of gaze-related attention effects. These results are consistent with recent neuroimaging investigations that show clear interactions, even in non-anxious individuals, between gaze-related neural response and the specific emotion that is expressed by an observed face (e.g., Adams et al., 2003; Hooker et al., 2003). The cue-target interval at which the present modulations emerged was longer than those used in other behavioural studies (Hietanen and Leppänen, 2003; Matthews et al., 2003). This once again shows the critical importance of time-course in studying gaze-related (and other) attention effects. At present, it is not clear why these effects take time to emerge. Little is known about the time-course of the

combined processing of facial expressions and gaze direction. Several ERP studies indicate that emotional expressions are analysed rapidly and affect cortical processing at very short latencies (within 120-230 ms of stimulus presentation; Balconi & Pozzoli, 2003; Eimer & Holmes, 2002). Nevertheless, emotional processing may influence attention systems at later stages. Therefore, further research is required to highlight the time-course of interactions between emotion and gaze processing and attention systems.

Another important factor in obtaining the present emotion-specific cueing effects may have been the use of an animated morphing procedure that provided a dynamic and synchronized change from affectively neutral face with direct gaze to emotional expression with averted gaze. The primary effect of this procedure was to produce face displays that conveyed the sense of an observed face 'getting fearful', 'getting angry', or 'getting happy'. Although the morphing procedure as such was not responsible for the unique cueing effects obtained with the emotional displays (see Experiment 15), the dynamic presentation may have boosted emotion-related effects. The fact that dynamic information contributes to face recognition abilities (Christie & Bruce, 1998; Lander, Christie, & Bruce, 1999) and judgements of expressed emotion (Bassili, 1978; 1979; Kamachi et al., 2001), and that brain regions implicated in processing facial identity and emotional content are more active with dynamic compared to static presentations of changes in face displays (LaBar et al., 2003; Sato et al., in press) converges with this notion. Therefore, employing dynamic presentations of cues may be a promising direction for future research on attentional processes. Indeed, Kingstone and his colleagues have recently stressed the importance of

ecological validity for attention research (Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003). The use of dynamic gaze and/or emotion displays as they were used here certainly constitutes a more naturalistic cue than static displays that have been used in the past (e.g., a static face with occluded or empty eyes where subsequently pupils appear abruptly in the left or right corners of the eyes).

The present findings also resonate with the idea that there are distinct operating characteristics for the basic approach and avoidance categories of emotion (e.g., Cacioppo & Gardner, 1999; Davidson, 1995; Davidson & Irwin, 1999). It was predicted that the approach-type emotions (anger and joy), which motivate social interactions, would be more likely to show prolonged gaze-related attention effects than the avoidance emotion (fear), which is thought to facilitate withdrawal from aversive situations. This is precisely what was found. In addition, trials in which the central face maintained a direct gaze with the observer produced significantly longer response times for the happy-face and anger-face displays compared to that for fear-face displays, providing additional support for the idea that emotional expressions associated with an approach system of motivation preferentially engage the observer with the observed face when eye contact is established. Nevertheless, the specific pattern of gaze-related effects on localisation performance was unique for each of the displayed emotions, clearly differentiating even the longer-term effects of the approach-type emotion. Such contrasts in data patterns reveal the different consequences of another's emotional state for an observer, and reflect the attentional states that are best suited to deal with each situation.

The most striking difference separating the two approach-type emotions was the prolonged facilitation for happy face displays which was absent in the anger condition. Considering that interpreting the internal mental state of another person (theory of mind) includes inferences about an external stimulus that may have activated that state, then a face that transforms its expression from being affectively neutral to overtly positive may signal the impending arrival of a positive stimulus in the environment (food, potential sexual partner, etc.). Maintaining the direction of attention towards a gazed-at location in this situation may therefore be a useful strategy to facilitate competition for the positively reinforcing stimulus. Support for this view comes from primate research showing that the direction of conspecifics' eye-gaze is actively used to locate food (Tomasello et al., 1998), and can even be used to derive what another individual can or cannot see in order to “deceive” the opponent in food competition tasks (Hare, Call, Agnetta, & Tomasello, 2000; Fujita, Kuroshima, & Masuda, 2002). Finding a prolonged gaze-evoked attention effect in happy-face displays, together with the present speculation about the specific impact that observing happy or other positive expressions may have on both gaze-related and more general attention effects, highlights the need for further research into the effects of positively valenced stimuli on the allocation of attention.

Obviously, given that the present emotion-specific modulations of attention effects have not been observed before, it is necessary for future research to replicate these findings. Furthermore, it would be interesting to determine more precisely the underlying neural mechanisms that mediate these modulations. One obvious candidate for this role is the amygdala, as this

structure is considered crucial in analysing emotional facial expressions (e.g., Thomas et al., 2001). Individuals with amygdala damage are severely impaired in recognising emotion from facial expressions, especially negative emotions such as fear and anger (Adolphs et al., 1999; Adolphs & Tranel, 2003). Hence, this patient group should show no modulation of gaze cueing effects in response to angry and fearful faces, compared to those with neutral expression. The specific RT pattern for happy emotions, on the other hand, should not be affected since those patients exhibit normal recognition of happy expressions (Adolphs et al., 1999). Analysis of emotional content may also be supported by cortical brain areas. For example, the neuropsychological condition of frontotemporal dementia is characterised by marked atrophy in ventromedial and dorsolateral frontal cortex, the anterior cingulate cortex and the insula, whereas the amygdala is spared (Rosen et al., 2002). These patients show impaired emotion recognition from facial expression, but also have difficulties recognising vocal emotion (Keane, Calder, Hodges, & Young, 2002). Since this patient group's deficit appears to be multimodal, it is difficult to generate specific predictions. Nevertheless, differences in RT pattern between the distinct emotion conditions should be reduced or even abolished.

### **Implications for social interactions**

Another person's eyes provide subtle signals about their mental states and intentions as well as their perception of their environment. Indeed, the sophisticated social systems of primates rely on extracting information from visual signals such as gaze direction. Gaze direction provides signals for dominance and submission (Brothers & Ring, 1993; Perrett & Mistlin, 1990), and can be used to deceive conspecifics (Hare et al., 2000). As noted by Baron-Cohen (1995), eyes convey clues for empathy, deception and intention. Gaze is also critical for learning, ranging from the young monkey learning that a snake is dangerous because adult animals look at it while producing expressions of fear (Mineka, Davidson, Cook, & Keir, 1984), to the human infant associating a word with an object that is looked at by an adult (Dunham, Dunham, & Curwin, 1993).

Therefore the current studies of attention shifts via observation of gaze have some implications for issues such as theory of mind and joint attention. Interpersonal interactions require the ability for rapid and fluent access to the state of mind of another person. This applies to various social situations that may entail competition or collaboration with another person, as well as constellations that the observer is apparently unrelated to. For example, if a person is encountered who carries a knife in their hand, it could obviously be of vital importance to understand not only the intention and emotional state of that person, but also what or who his impending actions may be directed at. The future actions of a person will often be signalled by their focus of attention. Humans seem to have evolved a system that can produce joint attention between



two people extremely quickly and which emerges relatively early (in 3 month old infants: Hood et al., 1998). Furthermore, it is automatically activated independent of the viewer's intentions (e.g., Driver et al., 1999), and appears to be lacking in some clinical populations such as individuals with autism (Baron-Cohen 1989; Leekam, Hunnisett, and Moore, 1998). Thus, orienting of attention in response to observed gaze direction appears to be a fundamental process.

At first glance, the very slow emergence of inhibition effects after observing gaze shifts is a curious finding. Clearly, like peripheral sudden onset cues, observed gaze direction triggers automatic and rapid orienting of attention. Inhibition emerges only when the interval between cue and target is extended for longer periods. This delay may be a property of social interactions. That is, when another person suddenly breaks eye contact to look towards another location, an assumption is that something of interest has happened at that viewed location, or more importantly, something is expected to happen in the near future. The importance of the possible peripheral event may be considered to be high because the viewed face and focus of attention is initially directed towards the observer. On the one hand, if an event in the environment is important enough to not only attract your opponent's attention but also to interrupt his interaction with you, this event is probably important for yourself as this gaze shift may indicate the presence of danger or of some positive reward. Thus, it would pay off not to inhibit the gazed-at location immediately. On the other hand, when interacting with other people, one must consider the possibility of deception and attack, and hence maintain a suspicious stance. Therefore there may be a reluctance to inhibit further processing of the gazed-at location, as this

may contain a threat stimulus, such as an out of view accomplice to your opponent.

At present, it is unclear whether the delayed onset of inhibition is indeed due to the social significance of the cue. A nice test of this hypothesis would be to use non-social symbolic cues such as arrows. Recently it was demonstrated that arrow cues trigger reflexive orienting of attention in the observer (e.g., Friesen et al., 2004). Previous research suggested that IOR is not evoked by arrow cues unless the oculomotor system is activated (Rafal et al., 1989). It would be intriguing to see whether inhibition can be obtained in response to arrow cues in the absence of such activation, but at very much extended intervals such as the one utilised here with gaze cues.

The notion of social significance is supported by Hietanen's (1999) finding that gaze-related cueing effects are stronger when the observed head is oriented towards the observer than when both head and gaze are averted. He speculated that in the latter situation, interest in the observer is minimal because the head is oriented away, and hence the attention shift to the periphery is less dramatic than when eye contact is broken to make the sudden saccade. The present finding that inhibition is observed at long intervals only when the face stimulus disappears following the gaze cue is in line with this notion. It may be that the continuous presence of the face (as in Experiment 9) encouraged the observer to sustain engagement with the face and its associated attentional state whereas the offset of the face (as in Experiment 4) disrupted this mutual social contact so that attention could be disengaged from the gazed-at location.

Otherwise, as was suggested earlier, the offset of the face may have served as an exogenous cue to summon attention away from the gazed-at location. Note that this second explanation does not entail any social interaction component. If the face in the cue display morphed into a different face in the target display, one could determine whether the social context of the interaction with a particular person was preventing inhibition to emerge, without employing an exogenous offset cue. Alternatively, this hypothesis could be tested if a different exogenous cue was presented at fixation while displaying the same face continuously, for example by briefly superimposing a coloured patch onto the face instead of offsetting the face.

At present, it appears that the social context of gaze cues may influence the time-course of attention orienting processes. Clearly, peripheral sudden onset cues do not have any of this social meaning, and hence attention withdraws rapidly from a location when no stimulus is presented. Thus, it seems that social interactions must be considered when interpreting the cueing effects in typical gaze cueing experiments.

## Summary

The experiments in this thesis have demonstrated some important properties of attention shifts in response to eye gaze cues that have so far been missing in the literature. First, it was shown that cueing effects can be obtained over substantially longer periods of time than previously thought. Second, those longer-term effects are inhibitory in nature. The lack of inhibition in previous studies has been used as an argument to distinguish between peripheral cueing and eye gaze cueing as fundamentally different forms of orienting of attention. The present findings suggest that, in fact, both types of cues elicit very similar responses, at least in terms of their behavioural effects. The longer-term cueing effects that were observed here are not contingent on long-term retrieval associated with a particular stimulus identity. Instead, information regarding the inhibited location appears to be sustained online in working memory. Finally, it was shown that the emotional expression of the face that provides the gaze cue can influence orienting responses in the direction of gaze. This highlights the social significance of observed gaze direction and its impact on orienting of attention in the observer.

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## Appendix

### *Autism-Spectrum Quotient*

The ability to direct one's attention according to someone else's apparent orientation of attention is known to developmental psychologists as "joint attention". In some developmental disorders, such as autism, this ability is markedly impaired. Baron-Cohen (1995) proposed the existence of specialised brain modules responsible for joint attention: an "eye direction detector" which identifies the presence of eyes as well as the direction of gaze, and a "shared attention mechanism" which is specific to humans and (possibly) other higher primates. These modules are assumed to be selectively impaired in individuals with autism. Recently, Baron-Cohen and his colleagues developed a questionnaire, the Autism-Spectrum Quotient (AQ), to detect traits of autism in normal participants (Baron-Cohen et al., 2001). This was based on the hypothesis that the autistic brain is an extreme version of the male brain in terms of empathising and systemising (the "extreme male brain theory of autism"; Baron-Cohen, 2002). That is, both males and autistic individuals (the latter to an extreme extent) are defined psychometrically as having better abilities in systemising (i.e., the drive to analyse variables in a system and derive the rules underlying its behaviour) than empathising (i.e., the drive to identify another's emotions and thoughts). There is also an association between science and maths skills and autism (Baron-Cohen, Bolton, Wheelwright, Short, Mead, Smith, & Scahill, 1998). Using the AQ, Baron-Cohen et al. (2001) discovered a relationship between those skills and autistic traits in normal individuals. Thus, autistic tendencies are not specific to males but are found in individuals with skills and interests associated with the systemising domain.

Taking the above into account, it is reasonable to assume that individuals with increased autistic traits would have decreased abilities to encode gaze direction, and, as a consequence, to achieve joint attention. When participating in an eye gaze cueing experiment, this deficiency may be apparent in decreased cueing effects. In order to test this hypothesis, the AQ questionnaire was administered to participants in Experiments 1-13. It was predicted that participants with high scores on the AQ would show less cueing than those with low scores.

## Methods

### *Participants, Measures and Procedure*

The Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2001) questionnaire was administered to the following participants: all participants of Experiment 1; Experiments 4-6; Experiment 8; and Experiments 10-13 completed the questionnaire. In Experiments 2 and 3, sixteen and fourteen participants, respectively, received the measure. Finally, nineteen participants answered the AQ in Experiments 7 and 9. Questionnaires were given out after the main experimental sessions. Participants were naïve to its purpose and were instructed to complete the questionnaire quickly and to avoid thinking about their answers too long.



## Results & Discussion

The total AQ score was calculated for each participant (subscales were disregarded in these analyses; see Baron-Cohen et al., 2001, for scoring of the AQ). The mean AQ scores for each experiment are shown in Table A1. These data correspond with those obtained by Baron-Cohen et al. (2001), who report mean scores ranging from 15.4 to 18.6 for their non-patient samples. The mean scores did not vary significantly between experiments ( $F < 1$ ).

**Table A1. Mean AQ scores for Experiments 1-13 (Exp 1: same face; Exp 2: different face; Exp 3: central cueing; Exp 4: extended SOA/localisation; Exp 5: extended SOA/detection; Exp 6: extended SOA/saccade; Exp 7: face offset; Exp 8: face offset/varying SOA; Exp 9: face present/varying SOA; Exp 10: extended SOA/different face; Exp 11: face & object; Exp 12: spatial task; Exp 13: non-spatial task).**

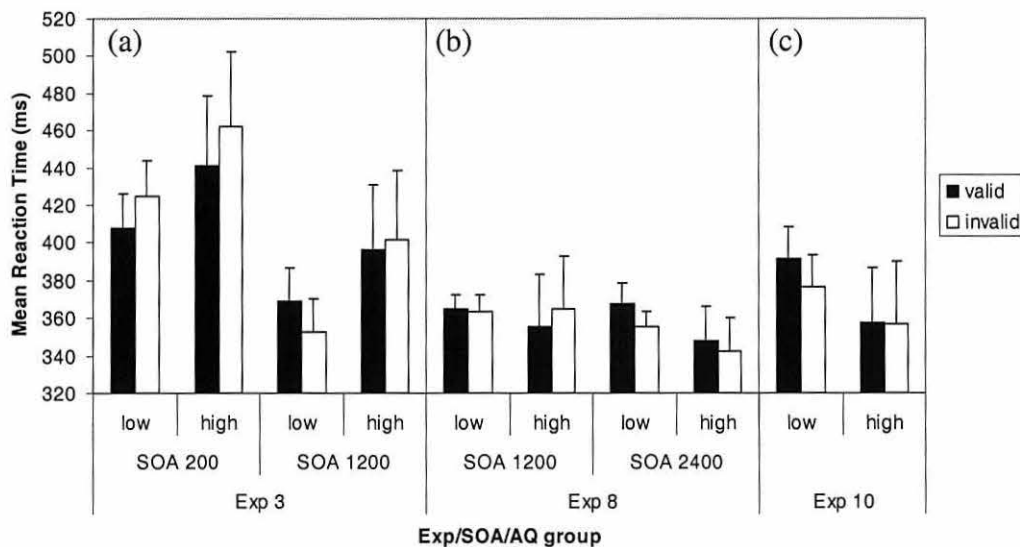
	<i>Experiment</i>												
	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>10</i>	<i>11</i>	<i>12</i>	<i>13</i>
<i>M</i>	16	16.9	17.4	16.2	13.7	15.6	15.6	17.2	15.8	16.5	15.8	18.4	15.9
<i>SD</i>	5.7	5.9	4.7	5.5	4.16	5.2	5.78	4.1	4.9	4.3	2.5	6.7	3.8

Participants who had scores of more than two points above the mean for their respective sample were classified as high scorers (HS), while those with scores of more than two points below the mean were considered low scorers (LS). The data of participants whose scores were clustered around the mean were excluded from the following analyses. This procedure resulted in the following samples: eight LS and six HS in Experiment 1; seven LS and five HS in Experiment 2; six LS and five HS in Experiment 3; seven LS and HS, respectively, in Experiment 4; eight LS and five HS in Experiment 5; six LS and

five HS in Experiment 6; four LS and five HS in Experiment 7; six LS and five HS in Experiment 8; seven LS and five HS in Experiment 9; six LS and five HS in Experiment 10; nine LS and five HS in Experiment 11; seven LS and eight HS in Experiment 12; seven LS and five HS in Experiment 13.

The participants' RT data were entered as within-subjects variables into separate mixed ANOVAs for each experiment (refer to the main text for a detailed description of the RT variables for each experiment). In each ANOVA, AQ group (high or low) was defined as a between-subjects factor. For the majority of experiments, no significant effects of AQ group or interactions with this factor were obtained ( $ps > .1$ ). The only significant results emerged in Experiments 3 (central cueing), and 10 (extended SOA/different face), and a marginally significant result was obtained in Experiment 8 (face offset/varying SOA). In these experiments, the magnitude and/or consistency of the cueing effect varied depending on the AQ group [Experiment 3:  $F(1,9) = 6.32$ ,  $MSE = 71.05$ ,  $p = .033$ ; Experiment 10:  $F(1,10) = 5.52$ ,  $MSE = 60.75$ ,  $p = .041$ ; Experiment 8:  $F(1,9) = 4.93$ ,  $MSE = 41.06$ ,  $p = .053$ ]. As can be seen in Figure A1, slightly stronger and more consistent cueing effects were obtained from low scorers compared to high scorers.

In order to assess whether the failure to obtain effects in the other experiments was due to a lack of statistical power, a meta-analysis was conducted on the LS and HS groups in all experiments, separated by SOA. There was no overall effect of or interaction with AQ group,  $p > .2$ .



**Figure A1.** RT data for (a) Exp 3, (b) Exp 8, and (c) Exp 10 as a function of AQ score (high versus low scoring groups).

The significant results that were obtained in three experiments were in line with the predictions: participants with higher autistic traits showed less cueing effects than those with low scores on the AQ. Presumably, low autistic individuals were either better at decoding the directional information conveyed by the eyes of the face stimulus, or were more inclined to align their own attention in the corresponding direction. The present data do not allow for distinguishing between those alternatives. Future research may address this issue, for example, by assessing low and high scorers' abilities to discriminate which location another person's gaze is directed at.

The difference in cueing between low and high scorers emerged in only three out of thirteen experiments. The failure to obtain differences in AQ group in ten studies may be due to differences intrinsic to the experiments. This, however, is not very likely, because the experiments in which the effects of AQ

group were obtained did not differ dramatically from other experiments in which no hints of such an effect were found. For example, Experiment 3 was virtually identical to Experiment 2 apart from the central cueing manipulation, which, in turn, it had in common with Experiment 9. Differences in the final LS and HS samples are also unlikely to have contributed to the contrast between experiments, since the AQ scores for these three experiments were not significantly different from the other experiments ( $F < 1$ ).

Instead, it may be that either the AQ as a measure of autistic traits or the experimental task as a measure of the effects of those traits on orienting of attention were not sensitive enough to detect those subtle differences. Sensitivity of the AQ may be compromised by its lack of filler items and by its failure to discriminate between “strongly agree/disagree” and “slightly agree/disagree” responses in scoring the items. The experimental tasks did not, apart from use of eye-gaze direction as cues, tap into skills or deficits specific to autism. For example, if the target had required discrimination of local or global features, differences between the groups may have emerged more consistently with high autistic individuals showing a local processing bias (see Happé, 1999, for a review). This is an issue that may be worth investigating in the future.