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Object-based representations facilitate memory for inhibitory processes

Paul, Matthew Arthur

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OBJECT-BASED REPRESENTATIONS FACILITATE MEMORY FOR INHIBITORY PROCESSES

By

Matthew Arthur Paul

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The data reported in Chapters 2, 3, and 4 has been presented at the following conferences:

Grison, S., Paul, M.A., & Tipper, S.P. (November 2002). *Object-based inhibition as the basis for search over time.* Paper presented at Object Perception and Memory conference, Kansas City, November 21, 2002.

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Summary

Humans have evolved to live within very complex visual environments and in order to act efficiently, need to guide action in a meaningful and productive way. One intractable result of this need for efficient goal-directed action is the need for selection; be if for a mislaid pen in the office, some ripe fruit at the supermarket, or which road to turn into whilst driving. One method of efficient selection is by withholding or suppressing a response to non-task relevant locations and objects. Inhibition is such a mechanism and was inferred and demonstrated by a series of elegant experiments by Posner and Cohen (1984). Posner and Cohen showed that when a person had attended to a location in space, which proved to be irrelevant to task-demands, attention was suppressed or *inhibited* from returning to that location. This effect was termed 'inhibition of return' (IOR) and is believed to be a marker for an underlying inhibitory mechanism.

Initial work demonstrated that inhibition acted in a location-based frame of reference, that is, one where attention is allocated to spatial locations in the environment. However, humans and other complex organisms interact not only with locations, but with objects. Therefore, if our attentional systems were only represented by a location-based frame of reference, search for a moving object would be futile as time would be wasted re-attending to spatial areas that the target object no longer occupies. More recent research has argued therefore that inhibition can also be associated with objects and that such object-based representations are critical for goal-directed behaviour.

The work presented in this thesis examines how object-based representations might influence the maintenance of inhibitory states. As such, two main points are investigated: Firstly, to examine what forms of object-based representations can be associated with inhibitory states, and more specifically, can the *identity* of an object be associated with inhibition? And secondly, when inhibition is associated with an object, is this inhibition more stable over both time and the number of intervening events? A number of new techniques were implemented to answer these questions.

The results from 11 experiments show that object-based frames can indeed be associated with inhibition and that this object-based inhibition appears to be more stable than inhibition merely associated with spatial locations. Furthermore, this object-based inhibition advantage is influenced by two processes: Firstly, objects provide landmarks that support spatial memory; and secondly, evidence suggests that the identity of the object itself can be associated with inhibition. Finally, even though object-based representations appear to facilitate the maintenance of inhibitory states, there is little evidence that this memory capacity will be greater than 6 items.

These findings have important implications for future research both in the development of new procedures and techniques to investigate inhibitory mechanisms and in that they question the traditional interpretation of location- and object-based representations.

Chapter One

The need for, and nature of, selective attention

Abstract

As humans, we act within a complex visual environment and must guide action in a meaningful and salient way. One way of efficiently selecting items of interest is by suppressing responses to recently examined items. There is a strong evolutionary need for such an inhibitory mechanism, without it perseveration of action could lead to starvation and cause the actor to be caught in a never ending loop. Inhibition of Return is believed to be the observable effect of this inhibitory mechanism. Simply put, when an item such as a location or object has been attended to, and proven to be irrelevant to current task demands, there is a slowing of response to that same item. Such an effect would act as an efficient mechanism to aid visual search and thus, direct action.

Of particular relevance is the internal representation or *frame of reference* which subserves this inhibitory attentional mechanism. Traditionally, attention has been believed to operate in a location-based frame of reference where attention is oriented to *locations* in physical space. Humans and other complex organisms have however evolved to interact with *objects* in their environment. As such, the role that object-based representations might play is investigated. It is surmised that the two frames are not mutually exclusive and can operate in tandem depending upon task demands.

Chapter One constitutes an introduction to inhibition as a mechanism of selective attention and reviews the current literature concerning the frame of reference that might mediate such a mechanism.

Furthermore, inhibition is considered to be a mechanism that helps to guide visual search and as such, must have memory for items already searched. How inhibition of return might be integrated with short-term working memory and what its capacity might be is also discussed.

Selection for action

As humans, we are constantly bombarded with sensory information from the world around us. For example, as one sits and reads these words, there is intense visual stimulation as light passes through the eye and is processed by the brain. There may also be background sounds and noises, a surrounding ambient temperature, feelings of ones weight upon the chair and many other sensations acting upon us simultaneously. Much of this information is processed automatically without any conscious awareness – how often are we aware of background noises when we are concentrating or our own body weight, breathing, heart rate or body temperature? As a result, a great deal of this information is irrelevant to our actual behavioural goals and intentions. For example, when searching for a pen on one's desk, the sounds of birds twittering outside the window is not particularly relevant to the search task – the location of the pen is the focus of interest. It is evident then that in order to act efficiently and with purpose we need to be selective in what information we attend to. The process by which we do this is often referred to as 'selective attention' (Neumann & DeSchepper, 1992; Tipper, Bourque, Anderson & Brehaut, 1989).

The need for efficient search mechanisms in visual selection is ubiquitous and fundamental to existence. For example, imagine the aforementioned act of searching your desk for a pen. If attention had been oriented to one area of the desk and the pen was not found, it would be inefficient to spend time searching that same location again. While being time consuming and wasteful for the person searching for the lost pen, such perseveration would be life-threatening to a hungry animal searching for food in the wild. It can be reasoned then that there has been strong evolutionary pressure for efficient search mechanisms to evolve and in particular, a mechanism that prevents the return of attention to already examined locations. Inhibition is such a mechanism and is the focus of interest throughout this thesis.

Inhibition as a mechanism of selection in visual search

Using an elegant yet simple experimental design, Posner and Cohen (1984) demonstrated the existence of an inhibitory mechanism that facilitated visual search and prevented attention from returning to previously attended locations. Specifically, Posner and Cohen found that after attention had been drawn to a cued location and then removed, attention was inhibited from returning to the previously cued location. Figure 1.1 below show an example of the basic cueing paradigm used by Posner and Cohen. Participants were presented with three boxes on a display screen, one box at the centre of the screen and one to either side of centre. Participants were instructed to respond to the appearance of a target in one of the boxes by pressing a response key as quickly as possible. A short-time before the target appeared however, one of the peripheral boxes was cued briefly (by an exogenous flash of the box). Participants were told that this flash was irrelevant and did not predict target location. Posner and Cohen reasoned that this cue served to 'capture' or orient attention and found that when attention had reoriented to the centre of the display, it was impaired from returning to the previously cued location.

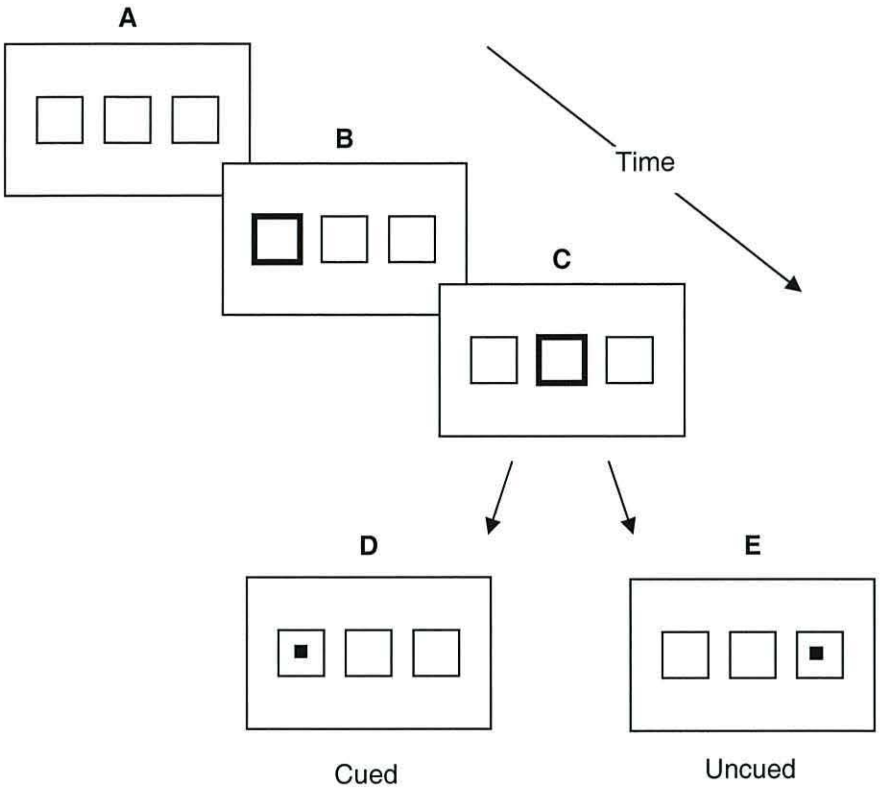

Figure 1.1 showing the basic experimental design used by Posner and Cohen (1984). Three boxes are presented to participants on a computer screen, one to the centre and one to either side (Panel A). A peripheral box flashes briefly for 100milliseconds (ms; Panel B) and participants are told that this is irrelevant and should be ignored. However, attention is automatically oriented to this location due to the sudden onset of the cue. The central box is then flickered, drawing attention back to the centre of the display (Panel C). A target then appears in either the cued (Panel D) or uncued box (Panel E). For short stimulus onset asynchronies (SOA) of approximately 100-150ms, detection of a target presented in the cued peripheral box is faster relative to the uncued box on the opposite side. However, when the SOA is longer (over 300ms), the effect is reversed and responses to targets appearing in the previously cued location are slower. This latter effect was termed 'Inhibition of Return' because attention is inhibited from returning to previously examined locations or objects.

The results clearly showed that detection of the target appearing in the recently cued location was much slower compared to a target appearing in the uncued location when the interval between the onset of the cue and the onset of the target (stimulus-onset asynchrony, SOA) was at least 300ms. Furthermore, in support of the notion of attention as an orienting mechanism, when the SOA was short (100-150ms), there was a facilitation of target detection in the recently cued location. The crossover point where facilitation changes to inhibition was between 200-300ms after cue onset (see Figure 1.2 below). Posner, Rafal, Choate, and Vaughn (1985) termed this effect *Inhibition of Return* (IOR)[1]. Importantly, attention has to be withdrawn (either by another cue or by the extended SOA) for this IOR effect to observed.

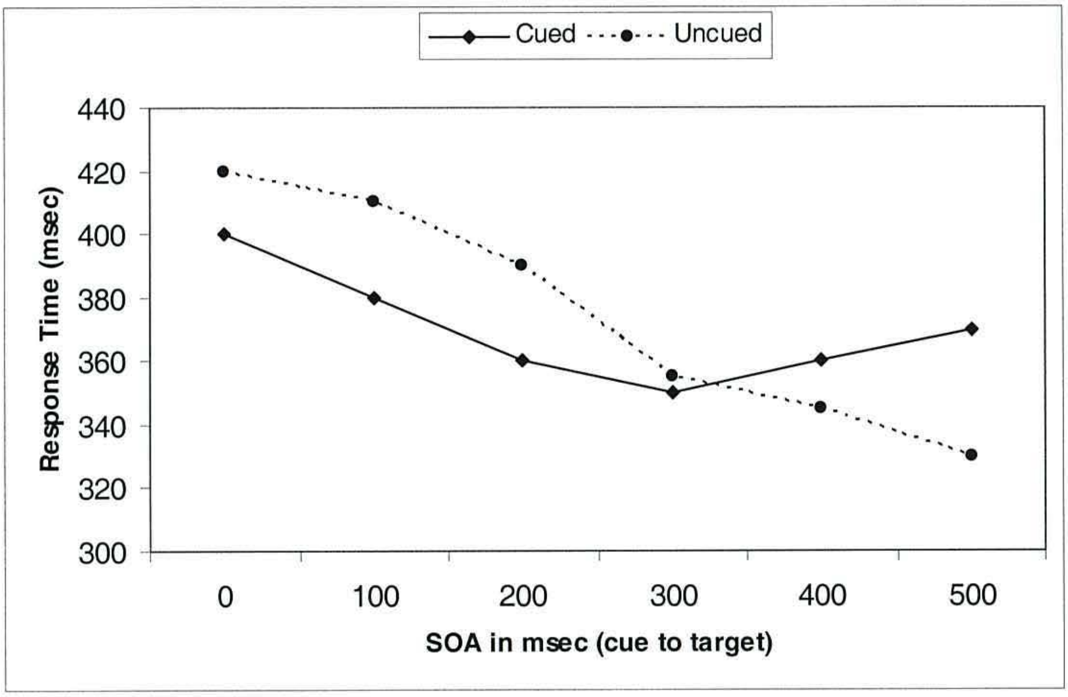

Figure 1.2 showing a prototypical set of data from Posner and Cohen's (1984) cueing paradigm. When the interval between cue onset and target onset (SOA, horizontal axis), is short (0-200ms), responses to the cued locations are faster than to the uncued locations resulting in a facilitatory effect. The crossover point, where facilitation becomes inhibition occurs around 300ms SOA. After which, responses to the cued location are impaired relative to responses to the uncued location resulting in an inhibitory effect.

Posner and Cohen reasoned that the facilitatory effect serves to orient our attention to the source of stimulation and in particular to new and novel stimuli and locations (an

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[1] The term 'Inhibition of Return' is somewhat misleading in that it defines a measurable effect (IOR) from which one can infer an underlying mechanism (inhibition) within its very name. As such, the term has often mistakenly been used to classify both the effect *and* the underlying mechanism (see Taylor and Klein, 1998 for an overview). For the purposes of this thesis, 'Inhibition of Return' is taken to mean the observable effect and 'inhibition' refers to the underlying assumed attentional mechanism.

orienting mechanism). However, the inhibitory effect, serves to facilitate efficient search because it 'tags' (Klein 1988) already searched locations and prevents inhibition from returning to them[2]. Such an inhibitory tagging mechanism might well serve as a memory for locations and objects during search and will be discussed in more detail later.

IOR has since been the focus of intensive study and has been observed in a wide range of tasks. To mention just a few examples, it can be observed when detecting target onset (Maylor, 1985; Posner & Cohen, 1984); it has been observed when eye movements are made to a target (e.g., Abrams & Dobkin, 1994); it is found when targets are to be discriminated in terms of identity (e.g. Chasteen & Pratt, 1999; Lupianez, Milliken, Solano, Weaver, & Tipper, 2001), colour discrimination (e.g., Lupianez, Milan, Tornay, Madrid & Tudela, 1997; Law, Pratt, & Abrams, 1995), orientation (Danziger, Kingstone, & Snyder, 1998; Pratt, Kingstone, & Khoe, 1997); identifying line arrangement (Cheal, Chastain, & Lyon, 1998); reaching tasks (Tanaka & Shimojo, 1996); and auditory frequency (Mondor, Breau, & Milliken,

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[2] As can be seen then, attentional mechanisms can constitute both facilitatory (excitatory) and inhibitory effects. While IOR is generally discussed in inhibitory terms in that it suppresses or inhibits responses to previously examined items, this facilitatory – inhibitory process might operate in one of two ways: as a single attentional process that presents itself biphasically by shifting from facilitation to inhibition or as being comprised of two independently coexisting processes, one facilitory, the other inhibitory. In the biphasic model (e.g., Rafal, Calabresi, Brennan, & Sciolto, 1989) attention starts off as a facilitatory orienting mechanism (the first phase) which, after disengagement of attention from the item of interest, is then followed (the second phase) by an inhibitory process (IOR) which suppress a return of attention to the previous item. In the two independent processes model (e.g., Tipper et al., 1997; Houghton & Tipper, 1994), facilitation and inhibition are independently and simultaneously applied to an item of interest. So in this account the early facilitation of responses is due to the facilitatory effect being greater than the inhibitory one and as facilitation decreases due to the removal of attention, inhibition begins to dominate. Since IOR is defined as the difference in the response to the cued item from that of the uncued item, it is still somewhat unclear if the inhibition measured is 'purely' inhibition or a mixture of facilitation and inhibition. Dissociating facilitation and inhibition is often difficult as the one may mask the other (see Klein, 2000 and Pashler, 1998 for a review of these and related issues).

1998). Furthermore, inhibition can transfer between modalities, such that orienting to an auditory cue will impair processing of a visual target at the same location (e.g., Spence & Driver, 1998). IOR would also appear to be an automatically evoked mechanism rather than one under conscious control in that it can be evoked when participants are unaware of the presence of cues (e.g., Lambert et al., 1999; for a review of IOR, see Klein, 2000).

While IOR is the main effect discussed throughout this thesis, there are many other facilitory and inhibitory effects that have been demonstrated in recent years and which may work in a reciprocally beneficial manner to facilitate selective attention. Examples include negative priming (e.g. Tipper, 1985; Tipper & Cranston, 1985), the attentional blink (e.g. Raymond, Shapiro, & Arnell, 1992; Shapiro, 1994), repetition blindness (e.g. Kanwisher, 1987), and visual marking (e.g. Watson & Humphreys, 1997). While each of these effects is generally demonstrated in different methodological procedures, there are many areas of neural, methodological, and theoretical overlap which suggests that similar underlying mechanisms may be at work.

In the typical negative priming task (NP) for example, attention is directed to a target item presented concurrently with a distractor item. When the previously ignored distractor becomes a target on a subsequent trial, responses are impaired relative to a baseline condition where the target and distractor are unrelated. While procedurally different in that IOR studies usually present stimuli consecutively (and exogenously) while NP studies present them concurrently (and endogenously), the two effects are very similar in that inhibition is applied to non-target items which interferes with detection of the item when it subsequently becomes a target. That these two processes might be sharing similar underlying mechanisms has been formally proposed and modelled by Houghton and Tipper (1994).

Studies of IOR and NP demonstrate how inhibition can be applied to items *before* the onset of a target whereas studies of the attentional blink (AB) show that inhibition can be applied *after* the onset of a first target. In the typical AB task, the identification of a target item in a stream of rapidly presented stimuli produces a post-target response deficit or 'attentional blink' so that a probe appearing approximately 100–450msec later in the stream is not reported. Like other processes described here, the AB is believed to facilitate processing of a target item amongst (in this case temporally proximal) distractors. Whether this blink is due to active suppression of the probe or by the probe not actually having a chance to be encoded is still a controversial issue (e.g., Shapiro, Driver, Ward, & Sorensen, 1997).

Similarly, while the AB is shown between a target and a subsequent (and unrelated) probe, studies of repetition blindness (RB) which use a similar procedure show an additional attentional deficit when the two items to be identified are identical (RB is shown even when the two words are non-consecutive and if they differ in case). The similarities in the time-course, function and, effect of AB and RB provide evidence to support the notion that the underlying attentional mechanisms mediating such processes might be similar (although there is evidence that the two processes can be dissociated, e.g., Chun, 1995, 1997; Ward, Duncan, & Shapiro, 1997). Furthermore, while the relation of these processes to IOR in particular is still being investigated, it can be reasoned that each of them share not only a similar time-course but also serve to facilitate attentional selection mechanisms.

Further evidence of this convergence comes from studies of Visual Marking (VM) which serves to inhibit old items so that they do not compete for subsequent attentional resources. In the typical VM task two conjunction task sets are used: in the first display-set distractor items are presented alone and in the second display-set, the original distractors are again presented in the same positions along with a new (second) set of distractors plus the target item. Detection performance of this target is virtually identical whether the first display-set of distractors is added or not. That is, the presence of the first set of distractors does not effect search for a target when presented along with a new set of distractors, suggesting that the first distractor-set is not searched again. It can be reasoned then that in the typical VM task, inhibition is applied to a whole search set in order to facilitate target detection. This potential overlap between IOR and VM has been a source of some conjecture. For example, Watson and Humphreys (1997) have argued that IOR is not present in VM tasks while Pratt and McAuliffe (2002) have argued that IOR does play a role but only under certain conditions (see also, Olivers et al., 2002). Quite fittingly perhaps, Pratt and McAuliffe suggest that IOR and VM might be thought of not as wholly separate processes but as a continuum which varies according to the type of search task required.

Clearly then, there are similarities and differences in both the method of investigation and the results between these many facilitory and inhibitory effects. As discussed throughout this thesis, even IOR itself can be interpreted as having two distinct components: one spatial, the other object-based. So while these facilitory and inhibitory effects have tended to be investigated disparately, there is no reason to assume that the underlying mechanisms are totally independent from one another as the behavioural effects which are demonstrated are often dependent upon task-demands and the method of investigation. The ability of our attentional systems to adapt to these varying behavioural goals and task-demands is quite startling.

While inhibition can be viewed as a mechanism that aids efficient visual search (and the IOR effect in particular), of central concern to the present thesis is which representations such a mechanism might be accessing. For example, the earlier example of searching for a mislaid pen in an office might suggest that a location-based representation is crucial to search because there are a finite number of locations in which the pen might be located. However, humans and other complex organisms have evolved to interact in a dynamic and ever-changing environment. It can be reasoned then that our attentional mechanisms have adapted to deal with such dynamic environments. For example, a predator hunting for prey would quickly starve if it were unable to efficiently track its elusive quarry. It can be reasoned then that attentional mechanisms have evolved to serve not only location-based representations, but object-based ones also. These representations or frames-of-reference will now be discussed further.

Frames of reference underlying visual attention: location– or object–based?

The term *frame of reference* refers to the internal mental representation of external events and stimuli. That is, how events and stimuli from the external world (outside the body) are mentally represented to our internal world (within the body). The dominant position has been that of a location-based representation where attention is oriented to spatial locations in the environment (e.g. Eriksen & Eriksen, 1974; Posner, 1980; Eriksen & St. James, 1986). Locations however, are rarely devoid of structure and objects and more recent investigations have therefore focused on the role that objects, irrespective of their location, might play (e.g. Kahneman & Henik, 1981; Duncan, 1984; Driver & Baylis, 1989; Tipper, Driver & Weaver, 1991; Baylis & Driver, 1992; Egly, Driver & Rafal, 1994; Vecera & Farah, 1994; Tipper, Weaver, Jerreat, & Burak, 1994; Tipper & Weaver, 1998; Weaver, Lupianez, & Watson, 1998; Tipper, Jordan, & Weaver, 1999; see also Jordan & Tipper, 1998). The need for both location- and object-based representations is, at first, seemingly intractable.

Evidence for location–based frames of reference

> "Attention can be likened to a spotlight that enhances the efficiency of detection of events within its beam." (Posner et al., 1980, p. 72)

Much of the evidence for location-based representations comes from the analogy of visual attention being likened to a moving *spotlight* (e.g. Eriksen & Eriksen, 1974; Posner, 1980; Posner, Snyder, & Davidson, 1980). As the attentional spotlight moves through intermediate spatial locations (Shulman, Remmington, & McLean, 1979), it can 'settle' on spatial areas of interest to initiate further processing (e.g. Eriksen & Eriksen, 1974). The nature of this spotlight beam, its size, speed, and such like, have also been the topic of much conjecture (see Cave & Bichott, 1999). A consequence of this theory is that it implies a location-based frame of reference where attention is associated with a physical location in environmental space[3].

Supporting the notion of a spotlight model of attention, early studies such as Posner (1980) used a spatial cueing paradigm similar to that of Posner and Cohen (1984) described above (see Figure 1.1). Participants made responses to a target appearing in a peripheral box to either side of fixation. Prior to the appearance of the target, participants received a cue that could be valid (i.e. it accurately predicted the target location 80% of the time) or invalid (i.e., the cue did not predict the location of the target 20% of the time). The cue could be an arrow pointing left or right or it could be the illumination of one of the peripheral boxes. The purpose of this cue was to

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[3] Rafal et al., 1989 demonstrated that it was physical, external locations in space with which inhibition was associated and not a location on the retina. This was demonstrated by showing that the size of the IOR effect did not change when an eye movement was made between the cue and subsequent target which ensured that they appeared at different retinal coordinates.

attract attention even while the gaze was directed at the central fixation box. Responses were faster to valid cues than invalid ones. That is, when the cue accurately predicted the target location (valid cue), responses were faster than when the cue did not accurately predict the target location (invalid cue). This finding was interpreted as facilitation for attention orienting to the *location* of the cue. As a result, responses to a target appearing in the same location were faster since attention had already been oriented to that location by the cue event.

Further support for the spotlight theory of visual attention comes from the work of Eriksen and Erkisen (1974) who demonstrated that although the width of the spotlight might be variable, there appears to be a minimum width to which it can be constricted. Eriksen and Eriksen had participants decide which of four target letters were present on a trial. Participants responded to one set of targets (the letters C and S) with one response key and another set of targets (the letters H and K) with another response key. Target letters could be flanked by identical distractors or the same or different response category (e.g., CSC or KCK respectively). Responses were slower when the flanking letters were less than 1° of visual angle from the target. This finding gave strong support to the notion that the spotlight processed all information within its beam as moving the flanking letters further from the target reduced the interference.

Studies of the spotlight theory of attention have also shown that the beam can be split (e.g. Shaw & Shaw, 1977; Egly & Homa, 1984); can move independently of eye-movements (e.g. Sperling & Reeves, 1980; Remington & Pierce, 1984); and moves through intermediary positions in space when shifting from one location to another (Shulman, Remmington, & McLean, 1979).

Evidence for object–based frames of reference

While the role of location-based representations subserving attentional mechanisms is well established, more recent interpretations have focussed on the role that objects themselves might play. For example, Duncan, (1984) demonstrated that visual attention can be allocated to objects, independent of their spatial location. In these seminal experiments, Duncan presented participants with an object at fixation – a rectangle which had a line bisecting it (see Figure 1.3 below). The objects were varied so that the rectangle might be long or short and maybe have a gap on its left- or right-hand side. The bisecting line might be dashed or dotted and be oriented to clockwise or anti-clockwise. Participants were asked to report two of the four dimensions of the object (e.g., large or small rectangle, gap on left or right) or to report two dimensions from different objects (e.g., gap on left, solid line).

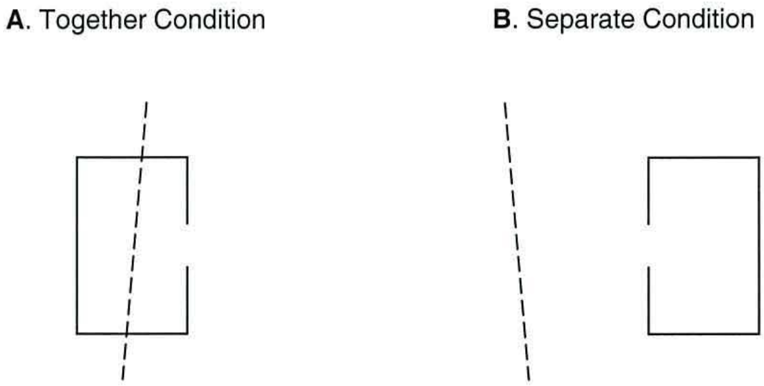


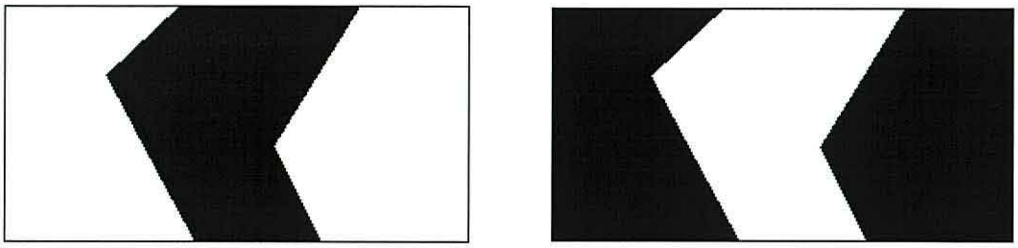
Figure 1.3 showing an example of the stimuli used by Duncan (1984). In Panel A, the two objects (a rectangle with a line bisecting it) are presented in the 'together' condition. Panel B shows the 'separate' condition. Participants were required to report two dimensions of the display (either two dimensions from the same object or one from each of the objects). Detection of dimensions within the same object was much better than if dimensions of two separate objects was reported.

When the two reported dimensions were reported from the same object, accuracy was as good as if they had reported only one dimension. However, when the two reported dimensions were from *different* objects, report of the second dimension was impaired – participants were less accurate when asked to make judgements about different objects. Duncan thus demonstrated that there is a cost associated with distributing or dividing attention between two separate objects even when they are very close to each other (and even when they overlap – in these experiments the entire stimulus subtended less than 1° of visual angle).

Vecera and Farah (1994) subsequently replicated Duncan's finding and further proposed that such object-based effects were only evident when the task actually required identification of an object's properties. When participants were instructed to ignore the objects and instead respond to the onset of the targets that appeared within the objects, the object-based effect vanished. Vecera and Farah concluded that when object identification is unimportant, attention simply determines the spatial location that the objects are occupying without processing the properties of the object.

Lavie and Driver (1996) provided further evidence for the flexibility of visual attention to select an object- or location-based representation according to task demands. They found that when participants were instructed to expect targets within a narrow spatial region of the display, object-based effects disappeared.

Baylis (1994) also found an advantage of one-object judgements compared to two-object judgements using ambiguous figures (a variation of Rubin's 1915 face-vase figures). By using colour to manipulate participant's perceptual set, they could reliably ensure that an identical figure could be perceived as one or two objects against a background. Participants were required to compare the height of the apices of the dividing contours and report the side with the lower apex (i.e., "right" in Figure 1.4 below). Despite the fact that the displays were identical, Baylis found longer response times when the display was seen to be comprised of two different objects. This finding again suggests that there is a cost associated with dividing attention between two objects and thus supports the notion that object-based representations are at work.



A. A single black figure is perceived

B. Two black figures are perceived

Figure 1.4 – showing an example of the stimuli used by Baylis (1994). The figure on the left (panel A) show a perceived single figure (black colour) while the figure on the right (panel B) shows two perceived figures (again, in black). A judgement was required as to whether the two central edges (the contour apices) were perceived to be lower than one another.

With reference to IOR in particular, Tipper, Driver, and Weaver (1991) have argued that IOR evolved to enable efficient search for objects, and hence inhibition of objects rather than just spatial location would enable more efficient search. Inhibition associated with objects is particularly important when searching for mobile targets, such as an animal hunting for moving prey or a human looking for a friend at the airport. If inhibition were only associated with a location, then time would be wasted re-attending to moving objects previously examined and rejected or to locations that previously contained objects which have since moved. Using an elegant moving-object experimental paradigm, Tipper et al. were able to disambiguate location- and object-based frames of reference (see Figure 1.5 below). Similar to traditional IOR cueing procedures (e.g. Posner & Cohen, 1984), a central fixation box was presented along with two peripheral boxes, one to each side of the fixation box. The peripheral boxes rotated around the central box so that the target appeared 90°, 180°, or 270° from the original position that the peripheral box had been cued in. Tipper et al. found that participant's responses were slower to the previously cued box than to the uncued box. This fascinating finding suggests that inhibition *moved with the object*, thus demonstrating object-based IOR in a scene with moving elements for the first time.

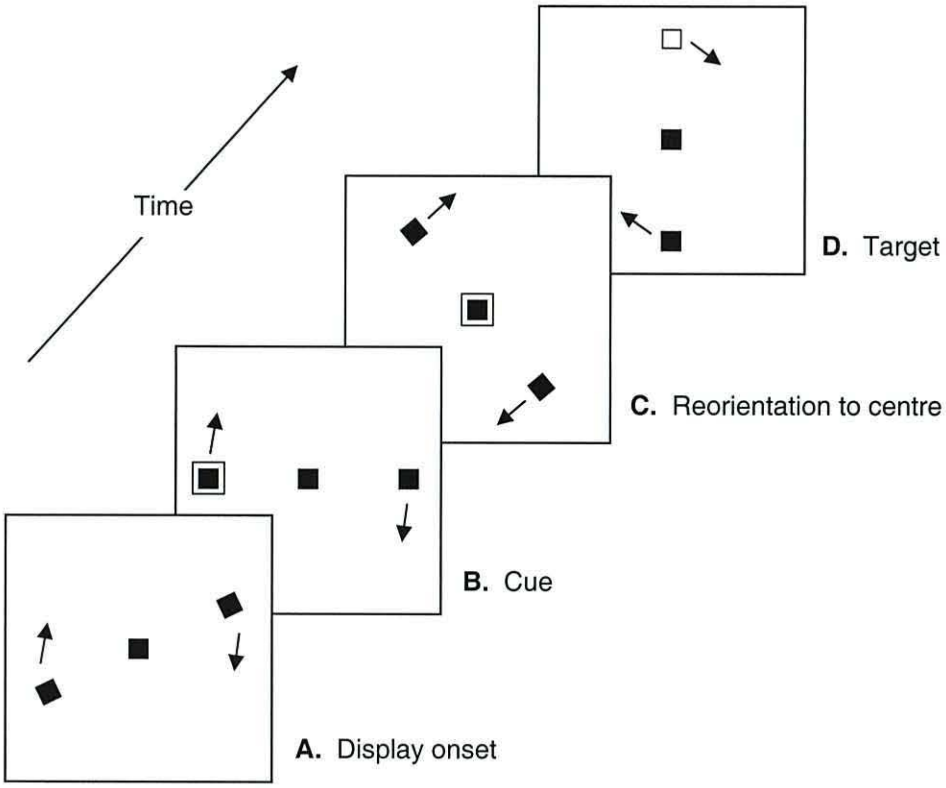


Figure 1.5 showing the basic experimental procedure used by Tipper, Driver, and Weaver (1991). Panel A shows the display onset with the peripheral boxes in motion. After the peripheral boxes rotate to the horizontal, a cue appears (B). Motion then continues and the central box is cued (C) to reorient attention back to fixation. Again, the peripheral boxes move and once the boxes are aligned in the vertical plane, a target appears (D). Responses to the previously cued box are impaired relative to responses for the uncued box indicating that the inhibition moved with the object. The arrows indicate the motion of the boxes and did not appear on the actual display.

Furthermore, Tipper, Weaver, Jerreat, and Burak (1994) showed both location- and object-based effects occurring simultaneously (and perhaps additively). They used a similar paradigm to Tipper et al. (1991) but this time with four boxes arranged around the screen at the 12, 3, 6 and 9 o'clock positions. As before, one of the boxes was cued and then all four boxes rotated 90° around fixation after which the target was presented in one of the boxes. They found that most of the inhibition was associated with the originally cued box in its new location suggesting that again, inhibition moved with the object (an object-based effect). Interestingly however, inhibition was also found (though not as strong) in the location that the originally cued box had previously occupied (a location-based effect).

It has been suggested that such moving object-based effects are more fragile, less robust and perhaps weaker than the static location-based effects found in 'traditional' IOR tasks (e.g., Mueller & von Muehlenen, 1996). However, strong object-based IOR has also been shown in static displays. For example, Jordan and Tipper (1998) used a visual illusion to suggest the apparent presence of objects and compared this to retinally-identical displays which were arranged so that no objects were apparent (see Figure 1.6 below). Targets were presented either within the apparent object or in a no apparent object area of space.

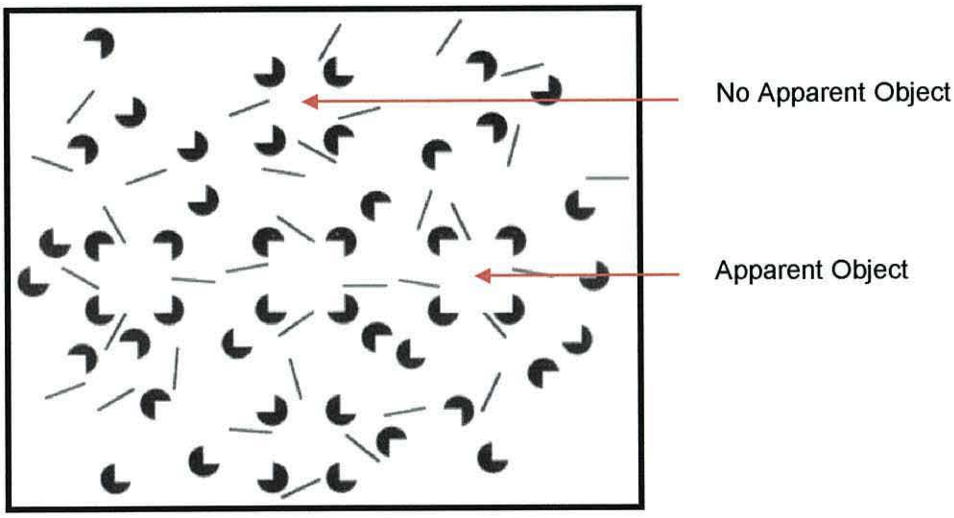


Figure 1.6 showing an example of the stimuli used by Jordan and Tipper (1998). Due to the arrangement of the Kanisza squares, apparent objects are visible in the horizontal plane.

Jordan and Tipper found that IOR in these static displays was significantly larger when an apparent object had been cued (42ms), as compared to cueing an empty location (18ms). Such a result confirms IOR operating in an object-based frame of reference in a static display.

It can be seen then that IOR can be represented in both a location- and object-based (moving or static) frame of reference. Converging evidence of such dual-frame mechanisms also comes from clinical populations.

Converging evidence from neurophysiological studies

Unilateral visuo-spatial neglect[4] is classically the result of damage, or lesion, to the right parietal lobe (Levine, Warach, Benowitz, & Calvanio, 1986). As a consequence of the condition, patients experience difficulty in detecting and attending to stimuli on the contralesional side of space, particularly when ipsilesional stimuli are also present. The condition, as the name implies, causes patients to 'neglect' or 'not see' the left-hand side of visual space. For this reason, neglect is often defined as a failure in the distribution of attention to the left side of space (e.g., Halligan & Marshall, 1993). It is not difficult then to see how neglect can be explained in terms of the spotlight theory of visual attention (or location-based representations in general). Locations to the left of visual space are impaired, and are thus simply not 'seen' by the spotlight.

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[4] The condition is sometimes referred to as hemineglect or hemispatial neglect (see Marshall, Halligan, & Robertson, 1993 for an overview of terminology).

Further evidence for both location and object-based frames of reference in clinical populations comes from the work of Behrmann and Tipper (1994) and also, Tipper and Behrmann (1996). Using a procedure similar to that of Tipper et al. (1991, 1994) right-parietal neglect patients were presented with a barbell stimulus comprised of two circles connected by a solid line. Patients were required to detect the presence of a target (a small white circle) appearing within the left or right circle component of the barbell stimulus. In the baseline condition, detection of targets appearing in the left-hand component of the barbell was significantly slower than targets appearing on the right hand side of the barbell (see panel A of Figure 1.7 below) even if the bar bell rotated 180° so that the left and right components were reversed. This result supports the notion that target detection in the left-hand side of space is impaired due to neglect accessing a location-based representation.

However, Behrmann and Tipper reasoned that if neglect were in fact associated with an actual object rather than just a location-based spatial map, then if the object were to move or rotate, then neglect would also move with the object. By rotating the barbell stimulus 180° about its central axis so that the left-hand side of the barbell rotated into the right-hand side of space, neglect moved with the object and impaired response to it even though it was now in the ‘un-neglected’ side of space (see panel B of Figure 1.7 below).

In reconciling these two seemingly opposed results, Tipper and Behrmann (1999) concluded that neglect can be subserved by both location-based and object-based frames of reference simultaneously as represented in panel C of Figure 1.7 below.

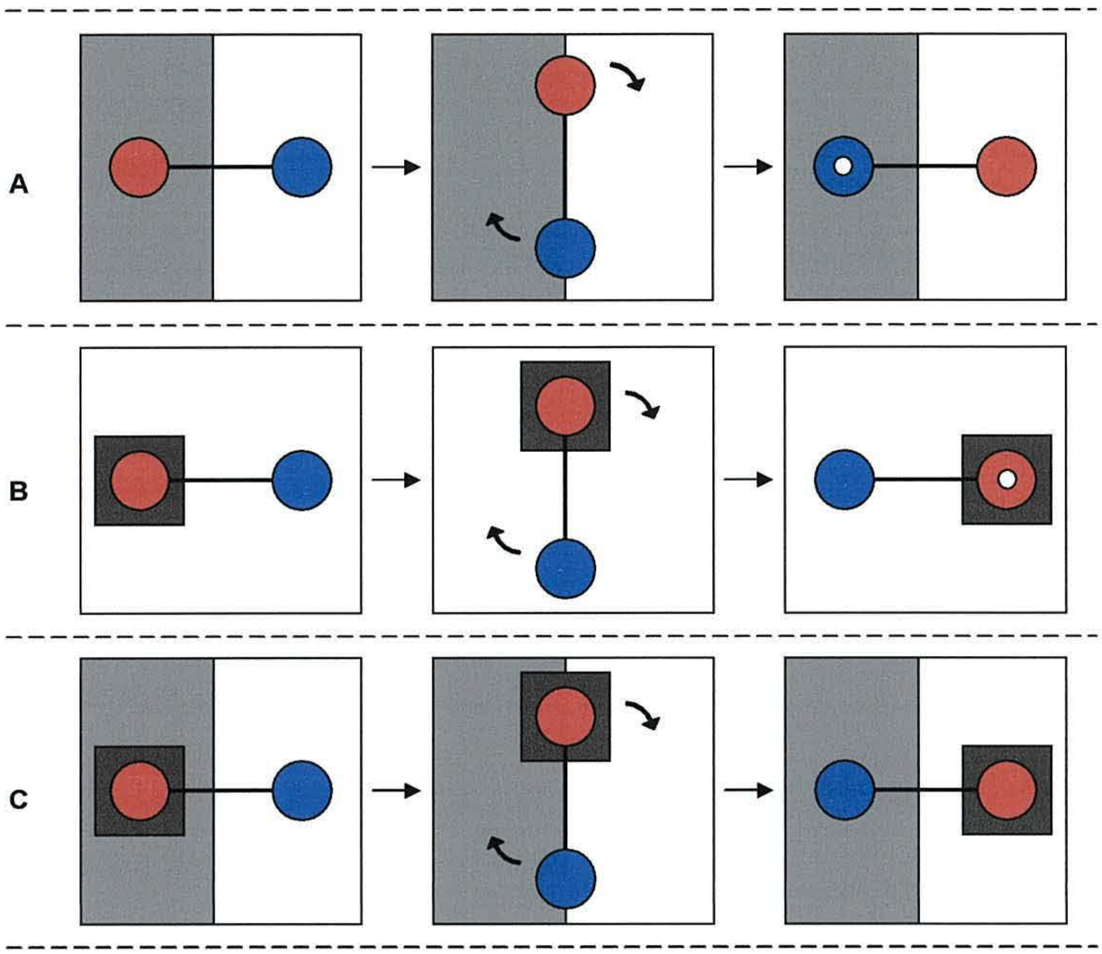

Figure 1.7 (adapted from Tipper & Behrmann, 1996), showing the effects of location–based (panel A) and object–based (panel B) neglect while panel C shows a proposed combination of the two. Light and dark grey shading indicates areas of neglect. A small white circle indicates the target event (panels A and B). In panel A (location-based neglect), the left side of visual space impairs responses to any objects within it. In panel B (object-based neglect) the left side of space is neglected (light grey shading) and neglect moves with the object (dark-grey shading) as it moves from the left to right side of space. Panel C shows a combination of the two frames where both location- and object-based representations can exist simultaneously. The left side of space is neglected (light-grey shading, a location-based effect) and furthermore, neglect can move with the object (dark-grey shading, an object-based effect).

It is evident then that IOR can be associated with both location *and* with objects that have subsequently moved to new locations and, furthermore, the two can be present simultaneously and perhaps additively. Such a dual-representation would (as Jordan & Tipper, 1998 discuss) suggest that traditional static IOR paradigms might not be measuring a purely location-based frame but that the presence of peripheral boxes throughout the cueing process might maintain inhibitory states (IOR) for longer due to the additive effect of objects acting as placeholders. For example, when empty locations are cued (e.g. Wright & Richard, 1996) only 15 ms of IOR was observed compared to the more typical 40-50 ms effects reported when peripheral boxes remain present (e.g., Posner & Cohen, 1984) and as Jordan and Tipper (1998) have demonstrated, 42 ms when apparent objects are cued and 18 ms when no objects are cued.

Clearly, the two frames of reference are not mutually exclusive, rather they can operate in tandem and perhaps additively (Driver & Halligan, 1991; Tipper et al., 1994). Furthermore, while the role of object-based representations is emphasised throughout this thesis, this is not to say that location based-frames are any less important. As is discussed below in the context of working (spatial) memory, there is strong evidence supporting the role of automatic spatial indexing mechanisms. For example, Tsal and Lavie (1993) presented participants with arrays of letters and were asked to report any letters that appeared after a specified cue letter which was defined by it's colour or shape. The results showed that these additionally reported target letters were those which had been adjacent to the cue item. Furthermore, the manipulation of the cue's colour or shape made no difference to the number of target letters that were reported – all letters reported were those adjacent to the location of the cue. The authors concluded that attending to any dimension of the cue (colour, shape etc) automatically entails encoding it's location. The particular frame of reference used would seem therefore, to be dependent upon 'task demand' (Pashler & Badgio, 1985; Vecera & Farah, 1994).

The role of location- and object-based frames of reference is of central concern to this thesis. Particular emphasis is placed on the role that object-based representations might play in maintaining inhibitory states over longer periods of time than is traditionally believed and also in maintaining and extending the number of items which might be influenced by such mechanisms. As such, an examination will now be made of how visual search (with particular reference to inhibition as a search facilitator) and memory are inter-related.

Memory for visual search

Further to Posner and Cohen's (1984) suggestion that IOR serves to facilitate visual search, Klein (1988) proposed that this 'inhibitory tagging' evolved as a 'foraging facilitator' which serves to enhance visual orientation to new objects and locations and also prevent attention from returning to those recently examined. Such a mechanism would be of vital importance in visual search strategies which required target detection (e.g., an animal foraging for food). Klein (1988) demonstrated this foraging facilitator concept by having participants search for a target in serial search displays containing a number of non-target distractors. When a target was presented at a location previously occupied by a distractor, response was impaired suggesting that attention had been inhibited from returning to previously searched locations. This experiment was important, because it was the first to demonstrate the role of inhibition in a serial search task.

Subsequent research challenged the notion that IOR facilitates visual search and can act on multiple loci. Firstly, Wolfe and Pokorny (1990) failed to replicate Klein

(1988), and indeed Klein and Taylor (1994) also subsequently reported failures to replicate. And secondly, Pratt and Abrams (1995), using the traditional peripheral cueing procedures, reported that inhibition was only associated with the last place cued. The latter finding suggests that the IOR effect is of limited utility, as search in real-world environments typically requires attention to be moved to numerous loci/objects before a target is found.

Furthermore, Horowitz and Wolfe (1998) have also recently challenged the role of memory in visual search. They had participants search for the letter *T* among *L* distractors in a traditional static visual search display containing 8, 12, and 16 objects. However, in order to explicitly impair memory-based mechanisms, a dynamic display was used where the target and distractors changed position every 111ms. Horowitz and Wolfe reasoned that if serial search depended on a memory-based tagging mechanism, then this display manipulation should severely disrupt the efficiency of visual search. However, the exact opposite was found – search rates in the dynamic condition were nearly identical to those of the static baseline condition in which the letters did not move. Such a result, according to Horowitz and Wolfe, implied that there was no tagging of distractors in visual search and thus no need for memory. They concluded that the visual system is 'functionally amnesic' in that it acts on fleeting neural representations and not on memory-based mechanisms.

However, Kristjánsson (2000) has recently challenged this finding and clearly demonstrated memory for visual search using a similar procedure to that of Horowitz and Wolfe. In the dynamic condition (experiment 1), Kristjánsson moved the targets to locations *previously occupied* by distractors (Horowitz and Wolfe had moved them to completely new random locations). Kristjánsson found that if the targets were relocated so as to appear in the locations previously occupied by distractors, then search time increased relative to a static baseline condition where there was no relocation. Therefore, there was memory for visual search. However, if the targets (and distractors) moved to completely new locations (experiment 2 and similar to Horowitz and Wolfe) then there was no memory, as attention had not already searched these locations. Kristjánsson concluded that a target must replace a distractor in order to interfere with memory-based search.

Adding further support, Gibson et al. (2000) demonstrated memory for visual search when participants were required to determine if one or two targets were present amongst varying number of similar distractors. Using a static and dynamic condition, Gibson et al. found that search was more efficient when two targets were present compared to only a single target being present because search could be terminated when both targets had been found on double-target trials; however search needed to continue for single-target trials to ensure there was no second target present. In the static condition this task was performed with a high degree of accuracy. In the dynamic condition, it was near-impossible.

Evidence for memory *across* trials in visual search has also been presented. For example, Maljkovic and Nakayama (1994, 1996) demonstrated a brief decaying memory trace on a pop-out target detection task that was cumulative over several trials. Further to this point, Kristjánsson, Mackeben, and Nakayama (2001) demonstrated how memory for visual search, or 'transient attention' as they refer to it, is not a simple reflexive mechanism but can demonstrate rapid learning of cue-target spatial relationships and that this learnt relationship can have a cumulative influence over consecutive trials. Chun and Jiang (1998) have also found evidence of implicit memory for context in visual scenes. Chun and Jiang had participants search for targets presented amongst repeated distractor configurations. When the distractor configuration was learned, there was a facilitation of target detection suggesting that this 'contextual cueing' demonstrated implicit learning and memory for visual scenes which guides visual attention.

Importantly, work by Tipper and colleagues focussed on reinstating inhibition as a mechanism to facilitate visual search. First, Tipper, Weaver, and Watson (1996) argued that the limits of inhibition to the last place cued reported by Pratt and Abrams (1995) were due to the particular experimental design. That is, only two locations were cued and could contain targets. More complex search environments would motivate the maintenance of longer-term inhibition. Therefore, Tipper et al. (1996) demonstrated that when targets could be presented in up to 4 loci, IOR was observed for up to at least 3 previously cued places. At that time Tipper et al. noted that the linear decline in IOR suggested that the effect would be observed for up to 4 or 5 previously cued/attended loci. Subsequent work with improved experimental designs (Danziger, Kingstone, & Snyder, 1998; Snyder & Kingstone, 2000) has confirmed that indeed IOR can be observed at multiple sequentially cued loci.

The second way that Tipper and colleagues attempted to reinstate the notion of inhibition as a search mechanism was via a suggestion based on a logical argument, rather than empirical data. As discussed above, Tipper et al. (1991, 1994) provided evidence that inhibition could be object-based. For example, after cueing attention to an object, if the object moved to a new location, the inhibition moved with it. They used this new notion of object-based IOR to reconsider the probe-following-search paradigm first used by Klein (1988) and made the following argument: "The original assumption (prior to Tipper et al., 1991) that IOR was environment-based may have resulted in the design of experimental procedures that are insensitive to object-based IOR effects. For example, in the Klein (1988) study and the subsequent study by Wolfe and Pokorny (1990), an attempt was made to observe the inhibition used to search through an array of stimuli to find a target. In such tasks, attention is directed toward objects, and our analysis here and elsewhere (Tipper et al., 1991) suggests that such search will be achieved by IOR to previously attended object-based representations. However, after search was completed in the aforementioned experiments, the objects were removed and a single spot of light was presented for speeded detection. If inhibition is associated with objects, as we claim, then the removal of the objects will remove the object-based inhibition." (pp 495-496, Tipper et al., 1994). Subsequent work has indeed confirmed that when previously searched objects remain visible, then Klein's (1988) original proposal that inhibition is a mechanism that facilitates serial search is in fact correct (e.g., Klein & MacInnes, 1999; Mueller & von Muehlenen, 2000; Takeda & Yagi, 2000; see Klein, 2000 for a review).

These findings give strong support to the notion that memory plays a crucial role in visual search and that inhibitory states can be maintained over multiple cue items and over a number of seconds. So, while the work of Horowitz and Wolfe (1998) and others would suggest that certain types of visual search can be performed in a relatively efficient manner without the aid of memory-based mechanisms, there is now irrefutable evidence that memory indeed plays a role in many visual search tasks (see Shore & Klein, 2000 for an overview). Furthermore, utilisation of these memory systems may depend on the relative cost and benefits associated with their operation. What memory systems might be at work in these visual search paradigms?

Memory for inhibition

Inhibition's role in visual search is now well established. Interestingly, IOR is generally discussed as a mechanism of selective attention and is rarely discussed in terms of a mechanism supporting memory. It is evident that orienting of attention triggers an inhibitory 'tag' that can effect or influence visuomotor performance over a brief period of time (e.g., Klein, 1988). That is, when attention has been withdrawn from a cued item or has had time to disengage (i.e. an SOA between cue and target of longer than approximately 300ms), then there is a slowing of response to the previously cued item. Given that these inhibitory states are being maintained during this cue-target interval, then these states must be associated with a memory process, or *memory for inhibition* as it shall be referred to throughout this thesis. Furthermore, such a memory-based mechanism would have limits in both the number of items that can be maintained and in the length of time that items could be 'held' in memory. What are these limits?

It is assumed that IOR is transitory in nature with short-term effects that have been shown to persist for intervals up to 3 seconds (Tassinari, Biscaldi, Marzi, & Berlucchi, 1989). Furthermore, initial studies of IOR assumed the effect acting only upon the last cued item (traditional procedures based on the Posner & Cohen, 1984 paradigm typically presented one cue before the target). However, this was more attributable to experimental constraints than the flexibility of the effect itself. More recent studies with more flexible designs using multiple sequential cueing have shown IOR acting on 4 or 5 previously cued items (Tipper, Weaver, & Watson, 1996; Wright & Richard, 1996; Synder & Kingstone, 2000) with the magnitude of the IOR effect being greatest at the most recently cued item and declining from there in a relatively linear fashion. These temporal (3-5 seconds) and capacity (3-5 items) constraints match well with those observed in the studies of short-term, working memory (e.g. Sperling, 1960; Vogel, Woodman, & Luck, 2001)[5]. It can be reasoned then that IOR and working memory are closely related and perhaps share the same resources. By learning more about how working memory operates will help us to understand the role of inhibition in memory tasks. What is working memory?

Working memory

The human memory system has often been dissociated into two related systems: short-term memory (often called *working memory*) and long-term memory. In fact this dissociation was made as far back as 1690 by the British philosopher John Locke (Locke, 1690). Working memory (WM), as is commonly understood, enables the temporary maintenance of a limited amount of information such as temporarily remembering a phone number from a telephone directory long enough to enter the numbers into a telephone. Such information is soon forgotten and is unlikely to be required for longer-term retrieval processes and thus encoded into long-term memory.

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[5] Miller (1956) originally proposed that short-term memory was limited to about 7 (plus or minus 2) 'chunks' of information. However, more recent studies have reduced this number to 3-5 items, with 4 being the average (see Cowan, 2001 for a review).

Long-term memory is associated with memories that are deeply encoded and long-lasting, such as ones name, date of birth, important events and such like. Given the transitory nature of IOR effects as discussed above and their relation to visual search, it is evident that short-term working memory plays a role in the maintenance of such transitory inhibitory states.

Perhaps the most influential accounts of short-term memory comes from Baddeley and Hitch (1974; see also Baddeley, 1986). In this account, a powerful central executive has flexible but limited processing power and is supplemented by subordinate or 'slave' systems which separate working memory for visuospatial information from that of verbal information into separate subsystems[6]. The *central executive* was seen to be responsible for decision making and coordinating the subordinate systems. One of the subordinate slave systems, called the *articulatory loop* (now more commonly referred to as the *phonological loop*) was seen to be responsible for the temporary retention of verbal material and plays a role in counting, mental arithmetic and in vocabulary acquisition in children. The other subordinate system was called the *visual-spatial sketch pad* (now more commonly referred to as the *visual-spatial scratch pad*) and was thought to be responsible for the retention of visual and / or spatial information.

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[6] Early support for this dissociation between verbal and visuospatial systems came from studies in which little or no interference was found when memory tasks were performed concurrently with visual memory tasks but there was substantial interference when the two tasks were in the same domain (e.g. Baddeley & Lieberman, 1980). This interference technique is used in Chapter 5 to test the form of internal representation mediating IOR.

Subsequent research has further suggested that visuospatial information is segmented into a further two separate components: *spatial* (which references locations of items in space and their geometric relationship) and *visual* (which references properties of items such as shape and colour; see Logie, 1995 for an overview)[7]. Such a division fits well with the discussion of location- and object-based frames of reference made above which likewise encodes information for location and object properties respectively. It is this latter visual or object-based sub component of visual WM which is of primary interest to this thesis. How might this information be stored and retrieved?

Automatic encoding to memory of attentional processes

One important distinction between typical IOR procedures and traditional studies of WM is that inhibition might be *implicitly* stored with object- or location-based representations in WM. That is, in traditional working memory tasks, participants are *explicitly* required (instructed) to actively 'hold' certain information in WM until a subsequent point in time and to then report them (often in the same order in which they appeared). In a typical IOR task however, participants are told to ignore cues and to only respond to the appearance of the target. In these typical IOR tasks then it would be reasonable to conclude that pre-target information would be implicitly

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[7] Such a division is reflective of the believed division of the visual system which processes spatial and object information via different processing streams: a dorsal, occipito-parietal, mango-cellular stream projecting to the posterior parietal cortex processing information relating to "where" objects are in the world; and a ventral, occipito-temproal, parvo-cellular stream which projects to the inferior temporal cortex processing information relating to "what" objects are (Ungerleider & Mishkin, 1982; Milner & Goodale, 1995). This issue is discussed in more detail in Chapter 5.

stored in WM. That is, inhibition might be *implicitly* stored with object- or location-based representations in WM during IOR tasks.

This implicit versus explicit difference might suggest that IOR and WM procedures are disparate in that WM tasks have tended to focus on explicit memory and IOR on implicit. However, other studies of WM (e.g., Phillips, 1974) have used serial presentation displays similar to those used in IOR studies (e.g. Snyder & Kingstone, 2000). Phillips presented an array of dots followed by a second array and participants were to determine if the displays were the same or different (i.e., did the dots change between displays?). In this study, while not being traditional implicit serial cueing used in many IOR studies, participants maintained memory of the first display to compare with the second. Studies such as these demonstrate an oftentimes common methodology in studying WM and IOR.

This contrast between implicit and explicit maintenance of spatial information is further made by Awh and Jonides (2001) who argue that spatial information is held in memory by attention remaining focussed on attended locations, keeping them active in WM. If some other stimulus is presented at the remembered location, it is more rapidly and accurately encoded. Traditional IOR procedures are completely opposite to this. Participants are instructed to ignore the cues, as they are irrelevant to their task. Yet in these IOR tasks, there is still evidence of memory for prior attentional processes which were triggered by the cues and which in turn, do not seem to be facilitatory but inhibitory instead.

Furthermore, earlier work has suggested that memory for location can be automatically processed (e.g., Hasher & Zacks, 1979). The automatic maintenance of spatial information is also discussed by Pylyshyn (1989) who developed an account of referencing or indexing multiple objects. In this model a number of indexes or *Fingers of INSTantiation* (FINSTs) are allocated to objects in the environment (approximately four objects could be indexed). The primary role of these FINSTs is to track objects as they move through space and this tracking is automatically maintained independently of attention. Furthermore, these FINSTs act only on the location of the object – they know nothing of the properties of the objects they are tracking. Even though gross location may be automatically encoded, Lansdale (1998) argues that finer location information has to be encoded intentionally. However, Maljkovic and Nakayama (1996) clearly demonstrated that relatively precise memory for spatial location could be automatically encoded and maintained over short intervals. In their experiments participants had to identify a target amongst distractors. The location of the stimuli was not a central feature of the task. However, they found that re-presenting a target stimulus in the exact same location facilitated performance, whereas presenting a target in the location previously occupied by a distractor impaired performance (produced an inhibitory effect). These automatic location-priming effects were observed over 5 to 8 previous trials which suggests the maintenance of attentional states. Such a finding gives support to the notion that attentional states can be maintained even without explicit instruction or conscious awareness.

Converging evidence for such automatic short-term memory processes has also been reported by Miller and Desimone (1994). Primates were trained to maintain an image in memory and match this image to a later sample. As expected, neural activity (recorded from cells in inferior-temporal cortex) was enhanced for the actively maintained images. However, other stimulus repetitions were presented in the series of non-target images. Neural suppression was observed for these latter repetitions, reflecting that the system was passively/automatically maintaining representations over the 3 intervening items tested in the study. Thus they concluded that there are two parallel short term memory mechanisms, one which actively maintains information in memory, and another which automatically records and maintains information. The present thesis is more closely concerned with the latter automatic system.

Objects and working memory

One other fundamental aspect of WM is how objects are encoded. As was seen above, recent work in IOR has demonstrated the importance of objects and object-based representations in attentional processes (e.g. Tipper et al., 1994). Interestingly, recent work has suggested that visual working memory stores integrated objects rather than merely individual features (Vogel et al., 2001; Luck & Vogel, 1997). For example, Luck and Vogel (1997) had participants make same-different judgements after seeing two temporally separate displays of multiple visual objects. In half the displays the objects were identical and in the other half they differed by a single feature. Luck and Vogel found that the number of objects in a display influenced accuracy – performance dropped as the number of objects increased above four. Furthermore, the number of features that defined an object did not influence performance since objects that were comprised of four features were recalled as accurately as objects that had one feature. Thus, the number of objects and not the number of features of an object seems to be what is recalled in these tasks.

Lee and Chun (2001) have even suggested that visual short-term memory is not influenced by the number of spatial locations per se, but rather what is important, is the number of objects occupying various locations. Thus the capacity of WM could be understood in terms of the number of objects and not simple features of objects or spatial locations. For example, it is possible not only to store up to 4 simple features (e.g., colour) but also 4 objects containing 4 features (such as size, colour, and orientation). This latter result shows that, if integrated into objects, 16 features can be accurately maintained. Such a result would support the notion that object-based (as opposed to purely location-based) representations could help maintain inhibitory states for longer periods of time, and perhaps for more items and this is the main focus of the present thesis.

Summary

To efficiently search complex environments one might assume that a number of previously attended locations would remain inhibited so as to prevent search from returning. Such a mechanism would efficiently guide visual search to new and un-searched loci. Inhibition is such a mechanism and is inferred from the Inhibition of Return paradigm where attention is inhibited from returning to previously examined irrelevant loci and objects.

The frames of reference which such attentional mechanisms might access has predominantly been believed to be location-based. That is, attention is allocated to and searches spatial locations in the environment. Converging evidence now suggests that object-based representations are also important as humans have evolved to interact with a variable and dynamic environment which is comprised of multiple objects. Furthermore, these two representations are not mutually exclusive, they can operate in tandem and perhaps additively with the frame of reference used depending on the prevailing behavioural demands.

There is now abundant evidence that memory plays a role in visual search. Given the nature of IOR as a search facilitating mechanism and that inhibition can last over several items and over several seconds, it can be assumed that inhibition might act as a form of memory during visual search. Given the transitory nature of inhibitory effects, short-term working memory seems most analogous to that accessed by such inhibitory systems. The capacity of short-term working memory and its temporal limits has been the subject of much investigation and converging evidence suggest that approximately 3-5 items can be actively maintained in working memory. It is speculated that object-based representations might maintain and extend this capacity even further.

Aims and objectives of the present thesis

This thesis examines the role that object-based representations play in the maintenance of inhibitory states. Specifically, it will be argued that inhibitory states can be maintained for longer periods of time and for a larger number of items when object-based representations are accessed as opposed to purely location-based representations.

Chapter 2 examines the capacity and maintenance of inhibitory mechanisms and specifically addresses for how long and over how many items can inhibitory states persist in a n-back sequential cueing IOR task similar to those reported in recent literature (e.g., Tipper et al., 1996; Snyder & Kingstone, 2000).

Chapter 3 builds on the experiments of Chapter 2 and further investigates the role of object-based representations by utilising more perceptually rich and salient stimuli in IOR n-back cueing tasks. Specifically, do more naturalistically realistic stimuli maintain inhibitory states for longer? An important investigation is also made of the role that objects might play in merely supporting memory for spatial locations.

Chapter 4 uses a traditional IOR experimental procedure but with photographs of human faces as the underlying stimuli over which cue and target masks can be overlaid. By using such complex and identity rich underlying stimuli, an examination is made of the role that higher-level object identity might play in maintaining inhibitory states and more specifically, do inhibitory mechanisms access such representations?

Chapter 5 introduces a new interference technique (similar to those used in working memory tasks) to disrupt and thus investigate the underlying spatial– or object – based representations mediating inhibitory mechanisms.

Chapter 6 discusses and summarises the experimental findings of the thesis and how they relate to our understanding of object-based representations and how they might influence inhibitory mechanisms.

Chapter Two

Object-based representations facilitate memory for inhibitory processes

Abstract

Previous work has shown that in a sequential cueing task inhibition of the return of attention (IOR) can be observed for up to 4 or 5 items. It was argued in Chapter 1 that the inhibitory processes mediating IOR are associated with object-based representations, and it is object-based representations that are maintained in memory. Experiments presented here show that when compared to standard conditions in which a number of identical grey squares are cued, cueing empty locations tends to reduce the memory for prior inhibitory processes; while cueing objects which are distinctive in colour and shape tends to increase memory for inhibition. Converging with other recent findings (e.g. Klein & MacInnes, 1999), it is concluded that memory for the inhibitory processes of attention facilitates visual search, and this memory is dependent on object-based representations.

Object-based representations facilitate memory for inhibitory processes

The three experiments presented in this chapter extends the investigation of the capacity of inhibition associated with object-based representations in memory. As discussed in Chapter 1, in serial cueing procedures it has now been shown that there is memory for previously attended items. This memory appears to be limited to 4 or 5 items (or perhaps 6, see Snyder & Kingstone, 2000), which matches reasonably well the limits reported in working memory (see Cowan, 2001 for review). However, it is unclear in what frame of reference this 'memory' is encoded.

In previous studies objects (usually empty squares boxes) have always been cued and are maintained in the scene throughout a trial. If indeed object-based representations are important for the memorial maintenance of inhibitory states, then the two following predictions are tested: First, compared to the standard procedure where grey squares are cued (adapted from the Methods of Snyder & Kingstone, 2000), when no objects are visible the inhibitory memory will be less stable. That is, IOR will not be observed beyond the first two or three items. The second approach undertaken here is an attempt to increase the memory for inhibition by making objects more salient and central to the task. That is, each object in a scene is unique in terms of colour and shape, as opposed to being all identical grey squares as in previous studies. Furthermore, each cue and target is unique to each specific object, rather than being identical across the scene. It is proposed that if memory for inhibition is object-based, then making objects more distinctive will improve the maintenance of inhibition, especially at more distant points in time.

In summary, the following IOR effects at more distant temporal moments (e.g., 3, 4, 5 & 6-back cues) are predicted: First, IOR will be largest when attention is oriented via an exogenous cue to objects that are distinguishable from one another in terms of colour and shape (Experiment 3). Second, IOR will be smallest when attention is oriented to empty locations via a peripheral cue (Experiment 2). And third, IOR will be of intermediate levels when attention is oriented to identical grey squares (Experiment 1).

The methodology of the three experiments of this chapter will first be presented before an analysis is made of the resulting data.

Experiment 1 (Grey Squares)

Experiment 1 served firstly as a replication of a 'traditional' sequential cueing paradigm (in this instance, a replication of Snyder & Kingstone's (2000) sequentially cued standard grey squares). And secondly, to establish sound experimental parameters for use in subsequent experiments.

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (24 females, 8 males, mean age 21.2 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

The experimental stimuli were essentially the same as those used by Snyder and Kingstone (2000). All stimuli were presented on a 17 inch computer monitor and were displayed on a black background with a grey central fixation cross measuring 0.5 degrees visual angle (va). Arranged around the central fixation cross in an imaginary circle (radius 6.5° va) were 8 grey-outlined squares each measuring 1.5° va (note: the squares were black with a grey outline, thus appearing to be empty grey squares against the black background). The squares were arranged so as to be equidistant from one another. Grey squares were cued by thickening their outline and changing the outline colour to white. The target appeared as a white asterisk (0.5° va) symbol in one of the grey squares. Response times were recorded by the computer and are measured in milliseconds. Figure 2.1 shows an example of the fixation, cue, and target displays.

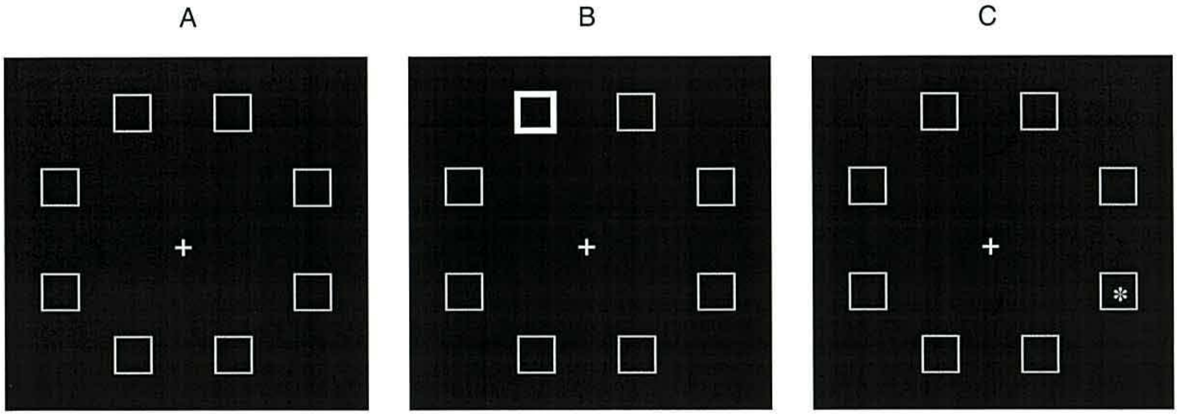

Figure 2.1 – showing an example of the fixation (panel A), cue (panel B) and target (panel C) screens for the Experiment 1 (grey squares).

Procedure

Participants were seated in a darkened room 57cm from the display screen and were instructed to maintain fixation throughout the experiment and to respond if and when a target appeared by pressing the space bar on the computer keyboard.

Each trial began with a 100ms trial onset tone. A fixation screen would then appear with the grey-squares in place. Following a 600ms stimulus onset asynchrony (SOA) the first cue would appear. Cues remained visible for 100ms, followed by an interval of 500ms where just the grey squares and fixation point was visible. Therefore the SOA between cues and between the last cue and target was 600ms. One, three, or six cues could appear before the target appeared or the trial ended (however, see design section for more details). Participants were instructed that the appearance of a cue did not predict the subsequent appearance of a target in that or any other location. The location of cues was random and no location / object could be cued twice in the same trial. Figure 2.2 shows an example of the typical six-cue trial with the target appearing in the four-back cued location.

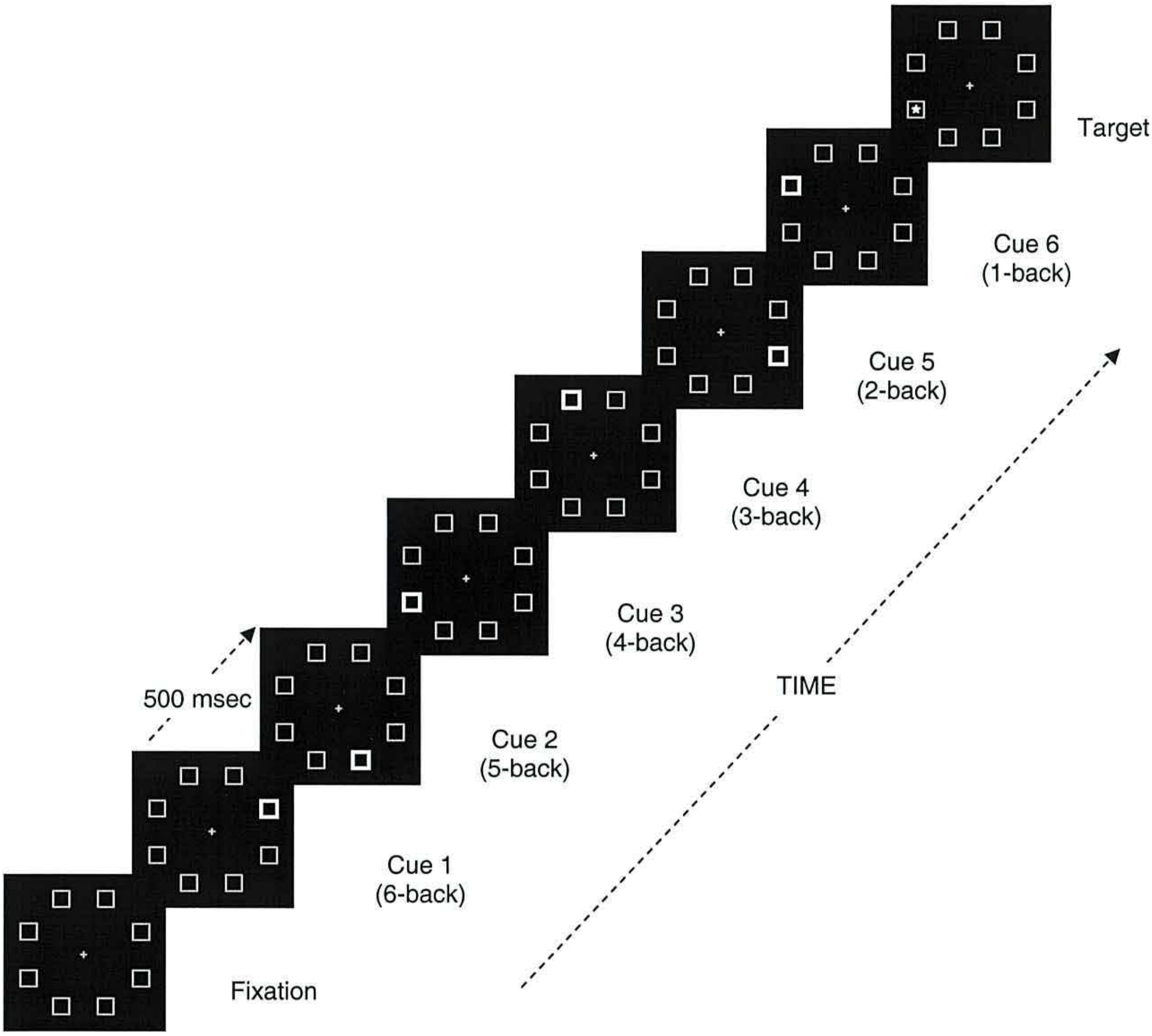

Figure 2.2 – showing an example of the typical 6-cue trial for Experiment 1 (grey squares). The target appears in the four-back condition, (the fourth-last cued location). Cues last 100ms with a 500ms Inter Stimulus Interval between cues (600ms Stimulus Onset Asynchrony).

Design

The design of this experiment was similar to that of Snyder and Kingstone (2000) except that fewer conditions were tested. This reduced design was adopted for efficiency, as testing was completed in approximately 50 minutes rather than nearly 2 hours. The experiment consisted of a total of 264 trials. Of these, 144 trials were distributed equally among the experimental trials (one-back, two-back, three-back, four-back, five-back, and six-back (24 trials in each condition). Note that 1-back, 2-back and so on, refers to the temporal relation of the cue counting *back* from the target, that is: *how many cues back from the target.* Therefore, the most temporally recent (later) cue would be 1-back, then 2-back and so on until 6-back which is described as the most temporally distant (earlier) cue (in the results section a distinction is made of 1-6-back and 2-6-back analysis). There were 48 invalid trials (where the target appeared in one of the two uncued locations). The experimental and invalid trials were all six-cue trials. The remaining 72 trials were distributed amongst three types of filler or catch trials – one-cue followed immediately by the target, three-cues followed by the target and six-cues with no target (no response trials). Cues did not predict target location and cue conditions were randomly presented. The target, when it did appear, remained visible for 100ms and the participant had 1000ms to respond to it. If no response was made when one should have been (a target miss) or a response was made before target onset (anticipation) or made when one should not have been (false alarms), the trial was recorded as an error and the participant received a 200ms error tone and the trial ended.

The experiment was divided into three equal blocks lasting approximately 15 minutes each, with a one-minute rest period between each block. Participants performed a 10 trial practice session at the start of the experiment.

Experiment 2 (No Objects)

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (27 females, 5 males, mean age 20.8 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Design, Apparatus, Stimuli and Procedure

This was identical to Experiment 1 (grey squares) except that the grey squares were not present throughout the whole trial; rather the cues and targets were presented on an empty screen. Figure 2.3 gives an example of the fixation, cue and target screens used for this experiments and Figure 2.4 shows the main components of the procedure.

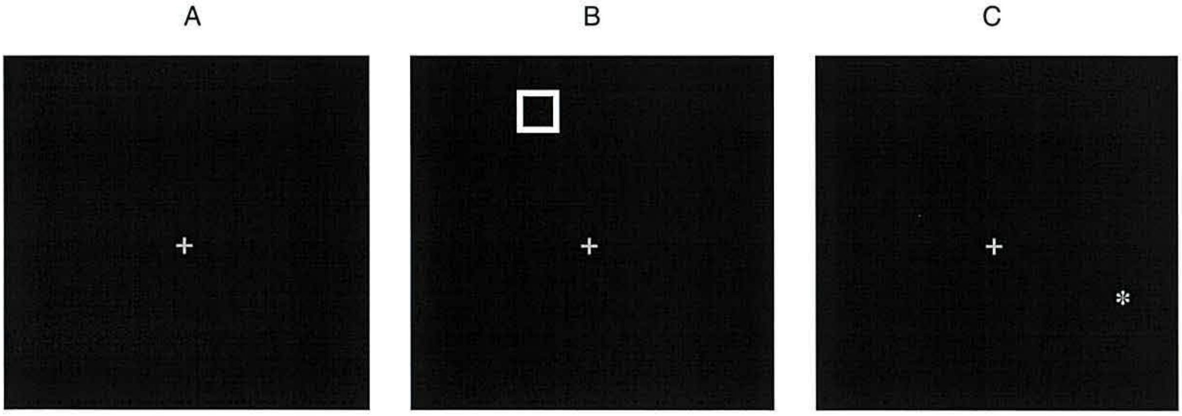

Figure 2.3 – showing an example of the fixation (panel A), cue (panel B) and target (panel C) screens for Experiment 2 (no objects).

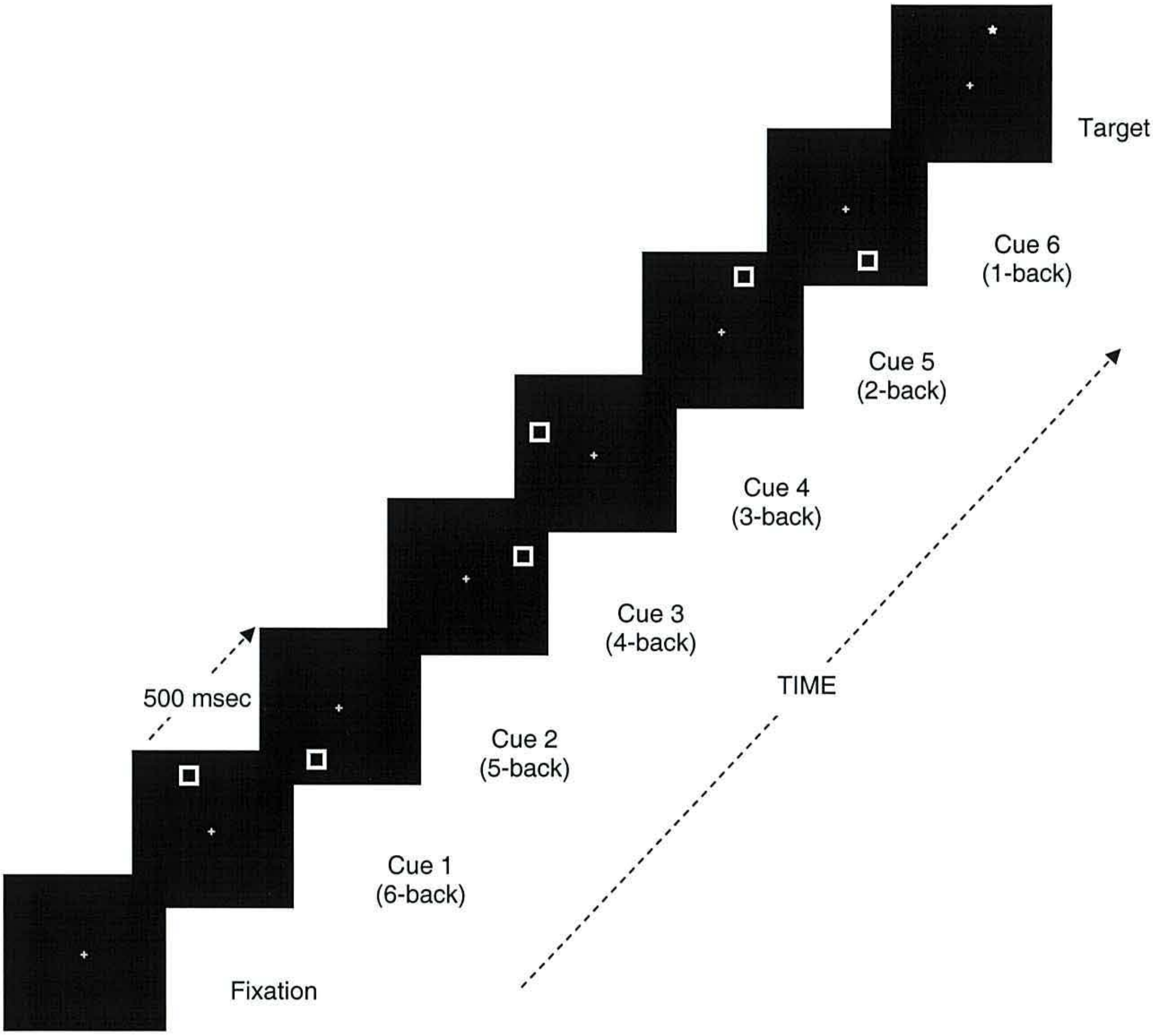

Figure 2.4 – showing the main procedure for Experiment 2 (no objects). In this instance, the target appears in the two-back condition (the second-last cued condition).

Experiment 3 (Coloured Objects)

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (23 females, 9 males, mean age 22 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

Stimuli comprised a number of small colour line drawings of every day items and objects. Each image measured approximately 1.5° va and was presented in the same locations as the grey squares had been. To vary the objects presented, three different sets of stimuli were used. Figure 2.5 shows the stimuli used in each of the 3 blocks. Each individual object in a display was presented in a different colour (Red, Blue, Orange, Yellow, Green, Purple, Grey, & Brown). The location of the colours was also varied across (but not within) blocks.

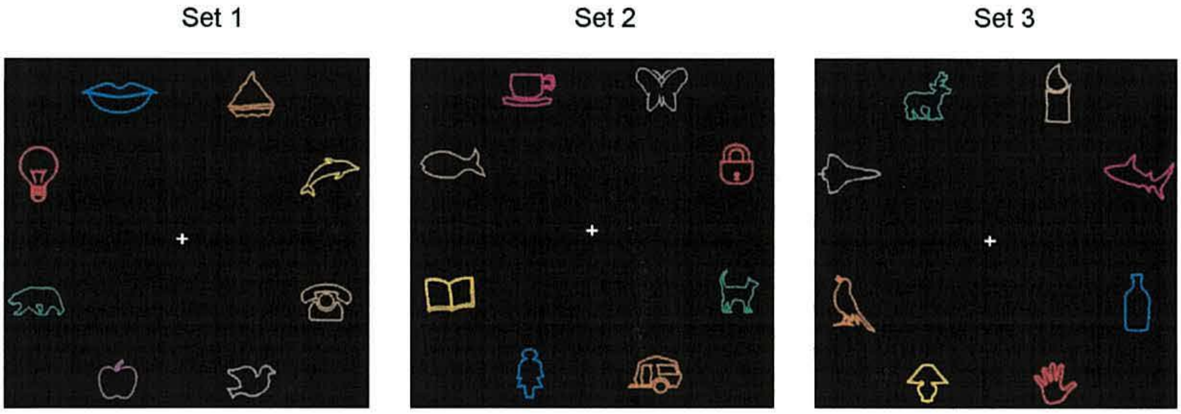

Figure 2.5 – showing the three different display sets used in Experiment 3 (coloured objects).

Procedure & Design

The procedure was identical to that of Experiment 1 and 2 with the following changes: three sets of stimuli were used, one for each block (see Figure 2.5 above). In order to familiarise participants with the stimuli, a static display of the stimuli to be used was briefly shown before blocks began. During the actual experiment, participants were presented with a static fixation screen with the coloured objects in place. Objects were cued by changing briefly from their original coloured outline to a thick white outline. Objects were targeted by filling with their original colour (participants were to detect the filling in of the object by pressing the space bar). Figure 2.6 shows an example of the fixation, cue, and target from this experiment and Figure 2.7 shows an example of the procedure.

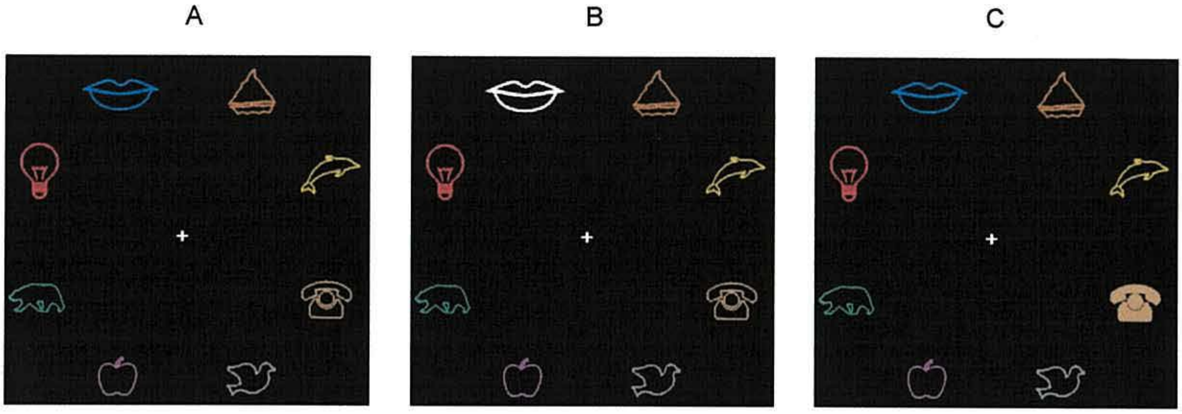

Figure 2.6 – showing an example of the fixation (panel A), white cue (panel B) and coloured target (panel C) screens for Experiment 3 (coloured objects).

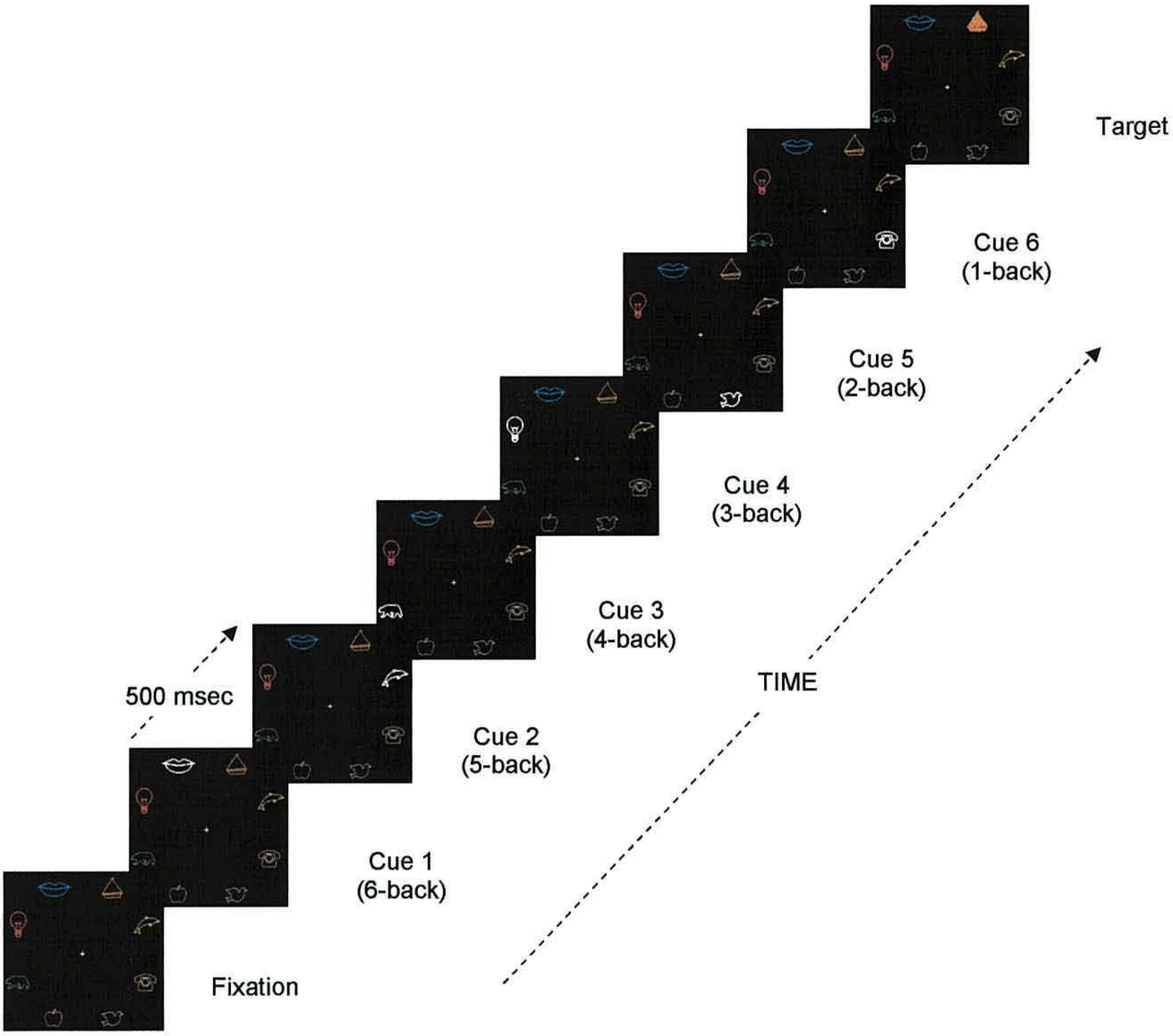

Figure 2.7 – showing the main procedure for Experiment 3 (coloured objects). In this example, the target appears in the uncued location.

Results

Mean reaction times (RT), standard deviation, errors and actual IOR effects are represented in Table 2.1. All data presented are for six-cue trials, the catch trials were too few to warrant further analysis and are not discussed further. The standard IOR effect is observed when response to the cued n-back target is slower than to uncued targets.

Experimental trials (1-6 back and uncued) on which errors occurred were excluded from analysis (1.36% overall in the Grey Square condition, 1.19% in the No Objects condition, and 7.66% in the Coloured Objects condition). There was a significant main effect of cueing in the Coloured Objects condition [$F = 6,186 = 2.5$, $p < .05$]. Planned means contrasts showed that this was due to the strong 1-back facilitation (see below) as comparisons of 1-back to 2-, 3-, and 4-back were all significant in this condition. All other errors were non-significant.

1-6 back analysis

Initial analysis of the complete (1-6 back vs. uncued) data set was undertaken with a two-way mixed 7 x 3 ANOVA [cueing (uncued, 1-back, 2-back, 3-back, 4-back, 5-back, 6-back) x experiment (no objects, grey squares, coloured objects)]. The between-experiments factor of object condition was highly significant [$F(2, 93) = 40.8$, $p < .0001$]. Detection of the coloured targets in the Coloured Objects condition (Experiment 3) [531ms] was significantly slower than in the Grey Square condition (Experiment 1) [401ms, $p < .0001$] and the No Objects condition (Experiment 2) [418ms, $p < .0001$]. There was no significant difference in RT to detect targets between the Grey Square and No Objects conditions. The within-participants cueing effect was significant [$F(6, 558) = 9.1$, $p < .0001$], as was the predicted interaction between object condition and cueing [$F(12, 558) = 9.0$, $p < .0001$].

Table 2.1 – Showing mean reaction time (RT) scores (in milliseconds), standard deviation, percentage errors and actual IOR effects for each cue condition for Experiments 1, 2, and 3. Errors are collapsed across the condition in which they (would have) occurred. Errors were: no response when there should have been one (a miss), a response when there should not have been one (false alarm) and, responding before the target onset (or no target for the invalid trials; anticipation). Statistical significance is included for the IOR effect at each cue condition (*p* < .01; **p* < .05). Note 1bk and 2-6bk conditions were subjected to separate statistical analysis.**

		1bk	**2bk**	**3bk**	**4bk**	**5bk**	**6bk**	**Uncued**
Exp. 1 Grey Squares	Mean RT	415	405	408	398	396	396	391
	Std. Dev	49	51	58	51	54	52	52
	% errors	1.69%	1.30%	2.21%	0.78%	1.30%	1.04%	1.17%
	IOR effect	24**	14**	17**	7*	5	5	--
Exp. 2 No Objects	Mean RT	434	422	420	414	413	410	413
	Std. Dev	74	69	73	74	71	75	75
	% errors	2.21%	1.17%	0.91%	0.91%	1.30%	0.78%	1.04%
	IOR effect	21**	9**	7*	1	0	-3	--
Exp. 3 Coloured Objects	Mean RT	512	540	538	540	530	532	523
	Std. Dev	65	64	62	68	65	68	65
	% errors	5.21%	8.59%	9.24%	8.85%	7.03%	7.55%	7.16%
	IOR effect	-11	17**	15**	17**	7	9*	--

2-6 back analysis

Due to the specific predictions concerning the role of objects in memory for inhibition, further analysis concentrated on the more distant temporal cueing moments of 2-back, 3-back, 4-back, 5-back, and 6-back cues (therefore 1-back was excluded from this analysis). Analysis of the standard Grey Squares condition (Experiment 1) revealed overall significant IOR effects at these more distant cueing times [$F(5, 155) = 6.5, p < .0001$], with significant effects at 2-back [$F = 16.4, p < .0001$), 3-back [$F = 23.5, p < .0001$] and 4-back [$F = 4.4, p < .04$] conditions. In the No Objects condition (Experiment 2) there was an overall significant IOR effect [*F*(5,

155) = 3.7, *p* < .01], with significant effects at 2-back [*F* = 7.8, *p* < .01] and 3-back [*F* = 4.1, *p* < .05]. Finally, there were significant overall IOR effects in the Coloured Objects condition (Experiment 3) [*F*(5, 155) = 4.2, *p* < .002], and this was significant at 2-back [*F* = 13.5, *p* < .001], 3-back [*F* = 10.8, *p* < .002], 4-back [*F* = 12.9, *p* < .001], and 6-back [*F* = 4.0, *p* < .05] cueing conditions (see Figure 2.8).

Recall that a specific order of IOR effects at more distant temporal cueing moments in time (2- to 6-back) was predicted: Coloured Objects > Grey Squares > No Objects. Further analysis of the overall IOR effects (cueing conditions (2-6) minus uncued) confirmed this. There was an overall effect of experiment [*F*(2, 93) = 3.9, *p* < .03]. Planned contrasts showed that the overall 13ms IOR for Coloured Objects was significantly larger than the 3ms IOR for No Objects [*F* = 7.6, *p* < .01], while the contrast between Grey Squares (9ms IOR) and No Objects (3ms) was also in the predicted direction, and marginally significant [*F* = 2.9, *p* < .1).

Finally, it was initially suggested that there might be no significant contrasts between object-based conditions in the most recently cued conditions (1-back cueing) following the work of McAulliffe et al. (2001). Indeed, in conditions similar to theirs, in which the No Object and Grey Squares conditions were contrasted in separate blocks of trials, similar results were observed. That is, significant IOR in both Grey Squares [24ms IOR: *F*(1, 31) = 44.6, *p* < .0001] and No Objects [21ms IOR: *F*(1, 31) = 47.2, *p* < .0001]. However, unexpectedly, there was a non-significant trend for positive priming [-11 ms, *F*(1, 31) = 2.4, ns] in the Coloured Objects condition.

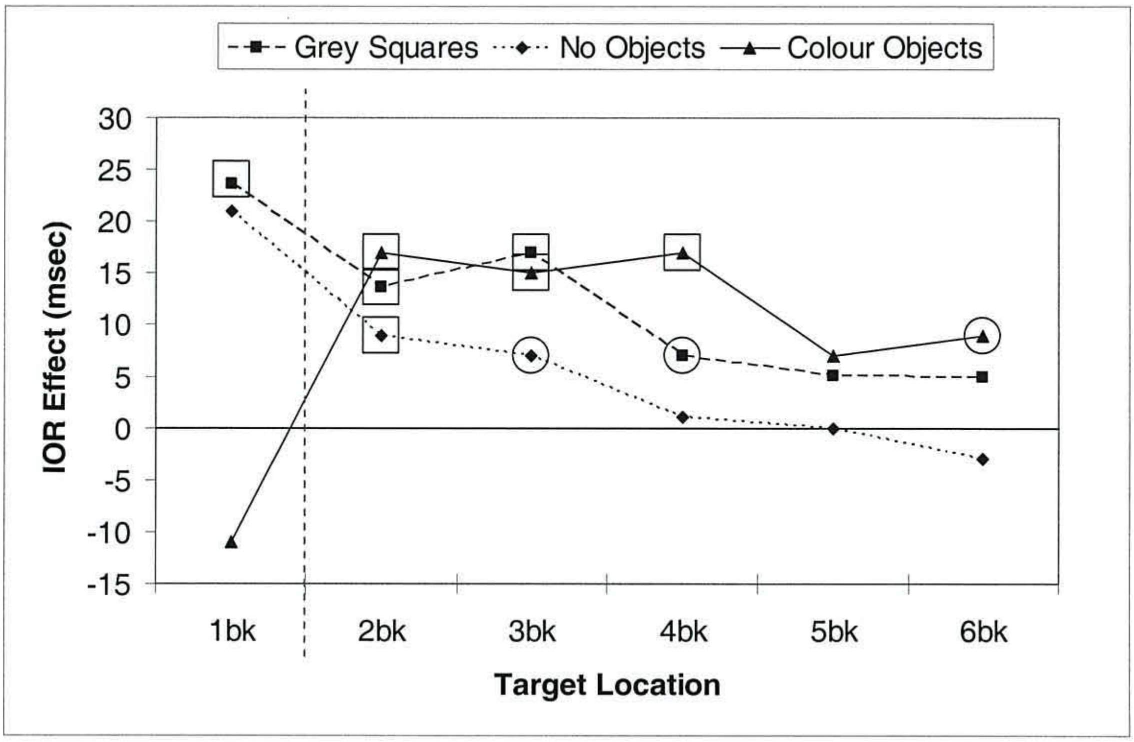

Figure 2.8 – showing the size of the IOR effects for Experiment 1 (grey squares), Experiment 2 (no objects), and Experiment 3 (colour objects). Circled and Squared data indicate statistical significance (squares, $p < .01$; circles, $p < .05$). Note 1bk and 2-6bk conditions were subjected to separate statistical analysis.

General Discussion

There are a number of features within the data patterns that must be discussed, firstly starting with the one-back cueing conditions, as these are similar to the standard IOR effects reported in the literature. A discussion is then made of the earlier cueing conditions (2-back to 6-back) which are the most pertinent to the current discussion of the role of objects in memory for inhibition.

Recent research by McAuliffe et al. (2001) questioned the earlier findings by Jordan and Tipper (1998) that larger IOR was observed when objects (squares) were cued than when empty locations were cued. McAuliffe et al. (2001) initially replicated the

Jordan and Tipper findings when objects and empty loci were cued in the same display. However, when these conditions were presented in separate blocks of trials, no contrasts were observed. The design in the present study is similar to that of McAuliffe et al. in that the grey squares (Experiment 1) and no objects (Experiment 2) conditions are tested in separate groups of participants. The 1-back cueing data replicates the McAuliffe et al. results, where similar IOR is observed when objects (grey-square outlines, Experiment 1) and empty space (no objects, Experiment 3) are cued (24ms and 21ms, respectively). However, other procedures have confirmed the original observations of Jordan and Tipper (1998) that IOR is larger when objects as compared to empty loci are cued (Leek, Reppa & Tipper, in press). Therefore the role of objects in 1-back cueing situations remains an unresolved issue.

The more striking results in these 1-back cueing conditions can be seen in Experiment 3 (coloured objects) where a trend towards a facilitation effect is observed. It could be that this latter unexpected result is due to the difficulty of target discrimination in this coloured object condition. That is, detecting the filling-in of the object colour was much more demanding than detecting the onset of the asterisk target (reaction times were longer and errors were higher). Others have observed a similar effect. For example, Lupianez et al., (1997, 2001) have shown that when target colour or shape identification tasks are examined, IOR emerges later than when simple target detection is required (see also Danziger et al., 1998). Similarly, Klein and MacInnes (1999), using highly complex scenes (Where's Waldo?), also noted that IOR was much more robust in their two-back as compared to their one-back conditions. The explanation for the delayed onset of IOR is that attention takes longer to disengage from an object when analysis of the searched for target is complex or when searching within complex scenes (see Klein, 2000). The findings presented here add to this literature in that they show this effect of task difficulty within target detection tasks, rather than as a contrast between shape discrimination tasks (Lupianez et al., 2001).

The central focus of this chapter concerned the role of objects in the maintenance of inhibition in working memory. It was predicted that inhibition associated with objects would produce a more stable trace in memory. More specifically, that inhibition associated with coloured objects would be more stable at earlier points in time than that associated with grey squares, which in turn would be more stable than inhibition associated with empty locations. When considering IOR effects from 2-back to 6-back cueing trials in Figure 2.8 (above) it is clear that this predicted pattern was observed in virtually all conditions. The influence of objects on the memory for inhibition should be most salient at earlier points in time where it is most fragile. Note that at 6-back cues the IOR effect for the coloured objects (Experiment 3) is 9ms, for the grey squares (Experiment 1) it is 5ms, and for no objects (Experiment 2) it is –3ms, just as predicted.

An important unresolved issue concerns the memory capacity for inhibition. In Experiment 2 (no objects) the IOR effect is not significant at earlier points in time, certainly from 4-back cues there is no hint of any inhibition. In contrast, when objects are cued there are IOR effects at these earlier epochs. In particular, significant effects for the coloured objects (Experiment 3) are found even at 6-back cues. Therefore the conclusions of Snyder and Kingstone (2000) that IOR can probably be observed after orienting attention to at least 6 objects can be agreed with[8]. Furthermore, with increased power and new experimental techniques the memory capacity for IOR may be even larger. Indeed, this is an issue that could be pursued further. A more fruitful approach might be to cue meaningful objects presented in their usual environmental context. For example, cueing objects in a kitchen or living room scene. It is possible that search through semantically rich and structured environments may activate inhibition that can be longer lasting. Chapter 3 addresses some of these issues by cueing photos of real-life objects as opposed to the colour line drawings of objects used in Experiment 3.

The results of this chapter generally support the view that inhibition of objects is an important mechanism that facilitates search for a target. This observation is in agreement with other studies examining the role of objects in visual short-term memory (e.g., Lee & Chun, 2001; Luck and Vogel, 1997) where the evidence supports the idea that visual short-term memory is mediated by object-based representations. In the three experiments presented here, this object-based inhibition is maintained in memory over a number of locations and for approximately 2.5 seconds. What is most striking is that the evidence converging on this basic notion of object-based inhibition comes from strikingly different experimental procedures. That is, the visual search tasks (e.g., Klein & MacInnes, 1999) examine endogenous/conscious forms of search where the participant strategically orients attention around the environment to find a target – the participant has endogenous control over where and when attention will be oriented. In contrast, the cueing

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[8] Snyder and Kingstone (2000) observed significant IOR up to 5 cued objects. As discussed, there are a number of differences between their study and the experiments presented here. In general however, a replication of their findings has been successful, and the slight differences in data do not affect the main aims of this chapter, which are to contrast various object conditions within the same procedure.

procedures that measure IOR orient attention in an automatic manner with exogenous cues. That is, in the latter case participants do not have any control over where and when attention will be oriented, as this is controlled by the sudden onset cue.

That there are numerous contrasts between such endogenous and exogenous orienting mechanisms (e.g., Shore & Klein, 2000; Mueller & Rabbitt, 1989) makes the similarities in inhibitory search mechanisms all the more striking, and suggests that some fundamental invariant properties of attention are being observed. Indeed, even those who have made the radical proposal that no memory guides visual search (e.g., Horowitz & Wolfe, 1998), acknowledge that their data is compatible with a search mechanism where a limited number of previously attended objects (perhaps 3) are inhibited to facilitate search (Horowitz & Wolfe, 2001)[9].

Summary

The results from the three experiments presented in Chapter 2 have shown that the type of object cued can affect memory for prior inhibitory processes. Specifically, cueing empty locations on a screen tends to reduce IOR (Experiment 2), while making the objects more distinctive in colour and shape increases IOR. Using traditional grey squares as objects (Experiment 1) tends to fall between these two boundaries. That memory for inhibition can be maintained for a longer period of time and/or over a larger number of events would seem to be dependent upon object-based representations. The more distinctive the object, the more it facilitates visual search.

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[9] It should be noted however that are many methodological differences between the work presented here and the 'no-memory' work of Horowitz and Wolfe (1998, 2001).

Chapter Three

Do naturalistic stimuli influence the maintenance of object-based representations and do objects act as spatial landmarks?

Abstract

As was seen in Chapter 2, when compared to standard conditions in which a number of identical grey squares are cued, cueing empty locations tends to reduce the memory for prior inhibitory processes while cueing objects which are distinctive in colour and shape tends to increase memory for inhibition. Chapter 3 continues on this theme. Experiments 4a and 4b extend the experimental procedure used in the previous chapter by making objects that are both more realistic (in this instance, actual photographs) and more unique (each trial contained unique images that were never repeated). Experiment 4a used objects that were permanent (i.e. present throughout the whole trial) and is comparable to Experiments 1 (grey squares) and 3 (colour objects). Experiment 4b had a similar procedure to that of Experiment 2 (no objects) in that objects appeared with the cues. It was found however that both the more realistic and the more unique stimuli showed no significant change in the maintenance of IOR. Although there was a failure to replicate and indeed extend the memory for IOR, it is argued that perhaps this is indicative of an invariant limit to the number of items that can be associated with inhibition / held in working memory. It may also be the case that a slight change in the experimental procedure (adding a 3.5 second fixation screen at the start of the trial) may have induced a recency effect. Furthermore, flashing objects briefly or having them statically remain in place had no effect on the level of inhibition observed.

Experiment 5 addressed a different issue, namely that memory for inhibition might be extended by the presence of objects which are in fact acting as placeholders or landmarks with which inhibition can be associated. Removing the objects (as in

Experiment 2) reduced the memory when compared to having the objects permanently in place (as in Experiment 1). Experiment 5 used the same procedure as Experiment 2 but had the addition of permanent 'landmarks' near to where the objects could appear. IOR was found to be very robust even at the extended cueing periods. It is argued that objects may act as landmarks with which inhibition can be associated even if they themselves are not cued.

Do naturalistic stimuli influence the maintenance of object-based representations?

The present chapter is concerned with investigating a number of issues raised by the three experiments reported in Chapter 2. To review, Experiments 1, 2 and 3 demonstrated that IOR can be observed over a number of previously cued loci. However, the maintenance of this inhibition was influenced by whether objects were cued, as predicted by other accounts describing the role of inhibition in visual search (e.g., Klein, 1988; Mueller & von Muehlenen, 2000; Tipper et al., 1994). That is, IOR was most robust at earlier cueing times (e.g., 3- to 6-back) when distinctive objects were cued whereas no effects were observed when empty locations were cued.

The following issues are addressed in the next three experiments. First, the contrast between no-object (Experiment 2) and coloured-shapes (Experiment 3) make it difficult to compare the data. That is, the target detection task was much harder in the coloured shapes experiments, having significantly longer RTs and greater errors than observed in the no-objects experiment. This difference in task difficulty was revealed in the qualitatively different effects observed in the 1-back cueing condition: inhibition was observed in the easier asterisk detection in the no-objects condition, but facilitation was observed in the colour detection task in the coloured objects experiment. Therefore it is necessary to examine IOR associated with distinctive objects in tasks where target detection is easy and hence IOR is observed in the traditional 1-back cueing condition.

Second, in the coloured objects task (Experiment 3) the same displays were viewed repeatedly. Therefore it is possible that the distinctiveness of the cued objects declined due to habituation. Furthermore, each object would be cued many times, and hence the effects could decline if inhibition is associated with an object's identity (see Chapter 4). To avoid these problems, it is necessary to undertake an experiment where every display (each trial) is unique. That is, each cued object is only seen *once* throughout the experiment. In such a study over 2000 different objects would be encountered. It is hoped that much more stable memories for inhibitory processes will be produced in these situations. Hence IOR at the more distant points in time (3- to 6-back) will be even more robust than observed previously in Experiment 3.

Third, a further issue concerns the maintenance of inhibition across time and multiple cued loci. The assumption has been that objects have to remain visible for the inhibition associated with them to be maintained. This assumption is based on comments reported in the Tipper et al. (1994) discussion of the original Klein (1988) report of inhibition in visual search and the subsequent failures to replicate (e.g., Wolfe & Pokorny, 1990; Klein & Taylor, 1994). Tipper et al. argued that this failure to replicate was because the objects in the search display were removed after search and a probe for rapid detection was presented in an empty field. Thus the inhibition associated with the distractor objects was no longer present, hence no IOR effects were observed. Therefore, if unique objects are briefly presented at the time of cueing, but are not maintained in view until the presentation of the target, inhibition will not be maintained so efficiently. To test this idea, a second experiment again presents unique objects, but these are only presented at the time of cueing. It is predicted that the decline in inhibition will be similar to that observed in Experiment 2 where no objects were presented during cueing.

Alternatively, if presentation of a unique object on each trial can leave a longer lasting trace of inhibition, even when the object itself does not remain visible, then cueing effects may be more stable, similar to those observed in Experiment 3. That is, a unique object is presented as a cue, and the same object is re-presented in the same spatial location, as the target. Inhibition associated with the object's identity may be re-activated on processing of the same object presented as a target (Tipper, 2001). In the work of Klein (1988), Klein and Taylor (1994), and Wolfe and Pokorny (1990), the ignored object during search and the subsequent probe were completely different objects, hence inhibition associated with an object-based representation could not be revealed. Indeed, in support of these ideas, previous studies of the inhibitory processes associated with an object, observed via negative priming effects, have suggested that inhibition can be maintained even when an object is not continuously visible. Thus, when a moving ignored object disappeared behind an occluding surface, and then re-appeared at a different place in the display, responses were still slower to this inhibited stimulus (Tipper et al., 1990). Experiment 4a (constant unique objects) and Experiment 4b (brief unique objects) in this chapter test the above ideas.

Finally Experiment 5 engages another issue. One assumption has been that inhibition is maintained for a longer period over multiple cued loci because objects are associated with inhibition. As noted, previous research has shown that inhibition can be associated with moving objects (Tipper et al., 1991, 1994, 1999) and that inhibition is larger when objects, as opposed to locations, are cued (e.g., Jordan & Tipper, 1998). This work led to the suggestion that object-based representations are associated with inhibition.

However, there is a further contrast between IOR when objects have been cued as compared to situations where no objects have been cued. That is, objects provide structural landmarks within the experimental environment that are not present when cues are flashed in empty loci. Therefore, in the former object-present conditions, cue and target location is predicted by the presence of objects in the environment. Perhaps it is the case that inhibition is not larger and more stable because objects have been cued, but rather because the visible objects provide environmental features to help maintain memory for location-based inhibition. Certainly our visual perceptual systems have evolved in environments that always contain structure, such as the texture gradients described by Gibson (1979) in natural environments, linear perspective in man-made environments, and the ubiquitous presence of objects (see Hershenson, 1999 for a review).

Indeed, studies of memory for location have confirmed that imprecise information about location can be encoded in memory, and that structural landmarks can improve accuracy. For example, Huttenlocher, Hedges, and Duncan (1991) required participants to report the location of a dot in a circle. Error in report of location increased as the stimulus was presented further from a physical reference point, which in this study was the circumference of the circle. Similarly, Landsdale (1998) demonstrated more accurate report of the location of a stimulus placed on a shelf, when the stimulus was at the end of the shelf. Again, environmental background features appear to be supporting the encoding of a stimulus' location.

Experiment 5 tests this idea. In this study objects are never cued. In this sense this experiment is similar to the procedure of the no-objects study of Experiment 2. Therefore if cueing objects is critical for the maintenance of inhibition, fragile effects at the more distant points in time (3- to 6-back cueing) should be observed. However, in this study small lines are presented adjacent to the location of the cue and target. So although no object was cued, spatial landmarks are available at the cued site. If it is the case that memory for inhibition is more stable because of the landmarks provided by objects, and not by cueing of objects, then IOR should be more stable in this situation, even though no objects were ever cued.

As Experiments 4a and 4b use a very similar experimental design, the methods are presented first, followed by separate analysis and discussions.

Experiment 4a (constant unique objects)

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (21 females, 11 males, mean age 21.2 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

Stimuli comprised a total of 2192 individual images (244 experimental trials x 8 on-screen locations = 2112 unique images + 10 practice trials x 8 on-screen locations = 80 unique images = a total of 2192 images). All stimuli were presented on a 17 inch display monitor positioned 57cm away from the participant. Individual images measured 2.8cm x 2.8cm (80 x 80 pixels) and subtended 2.8° va. As in experiments 1-3, stimuli were arranged so as to be equidistant from one another in an imaginary circle centred on the fixation cross (6.5cm radius, 6.5° va). Individual stimuli were randomly chosen and then randomly allocated to one of the eight possible on-screen locations in each trial. Therefore, each trial was perceptually unique in that the same stimuli were never seen again within the experiment – the displays changed across, but not within, trials. Figure 3.1 below, gives three examples of stimuli used for three different trials while Figure 3.2 shows an example of the fixation, cue, and target in this experiment. Stimuli were cued by a red outline appearing around the image for 100ms (see panel B of Figure 3.2 below) and stimuli were targeted by a green outline appearing around the image for 100ms (see panel C of Figure 3.2 below). The outline was 5 pixels in thickness.

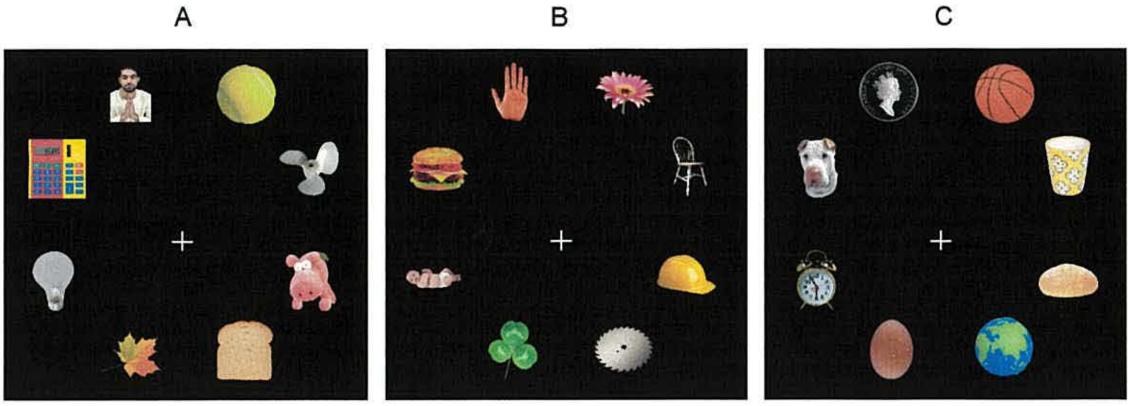

Figure 3.1 – showing three random examples (trials) of the stimuli used in Experiment 4a. Stimuli were selected randomly from a possible 2192 images and were unique in that they were shown only once (one set of stimuli per trial sequence), thus stimuli were seen only within a trial and never repeated).

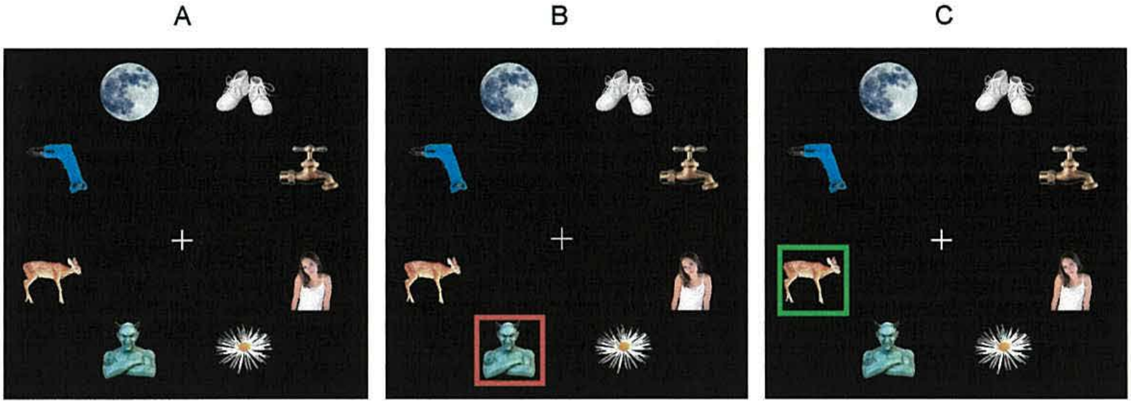

Figure 3.2 – showing an example of the fixation (panel A), red outline cue (panel B) and green outline target (panel C) for Experiment 4a.

Procedure & Design

The procedure and design was identical to that of Experiments 1 and 3 with the following changes (Figure 3.3 below shows an example of the procedure): after the initial black screen with a fixation cross in place lasting 1500ms, the 100ms tone sounded exactly as in Experiments 1, 2 and 3. The objects then appeared and remained static for 3500ms (see panel A of Figure 3.2 above). This was to ensure that the participants had a brief opportunity to see the stimuli in place (pilot data had suggested there was a strong urge by the participants to ‘scan’ the images before the cueing started). Participants were instructed to take a brief look at the stimuli and then return their eyes to the fixation cross. The only other change to the experiment was that the objects were cued and targeted differently as specified in the apparatus and stimuli section above. Participants performed a 10 trial practice block before starting the experimental trials which were again broken into three blocks, each lasting about twenty minutes with a one minute rest-break between blocks. Participants were instructed to respond as quickly as possible (by pressing the space bar on the computer keyboard) if and when a green outline appeared around one of the objects.

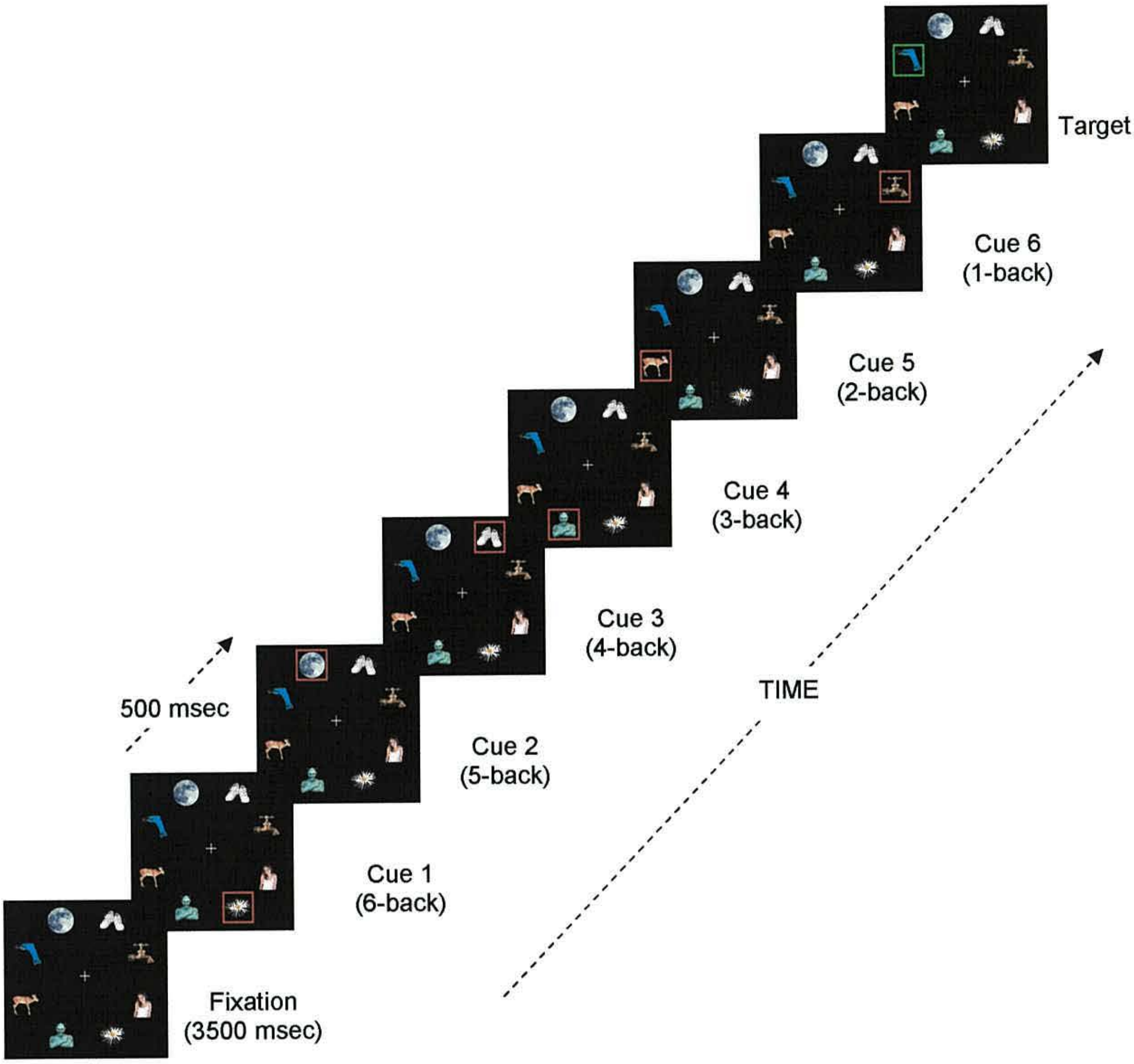

Figure 3.3 – showing the main part of the procedure for Experiment 4a. This example shows a typical six-cue trial with the target appearing in the uncued location.

Experiment 4b (brief unique objects)

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (19 females, 13 males, mean age 22.3 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

Stimuli used were exactly the same as those for Experiment 4a except that the stimuli did not remain visible throughout the whole trial and instead appeared with the cue or target outline as appropriate.

Procedure & Design

The procedure and design was identical to Experiment 2 but using the stimuli and cueing procedure from Experiment 4a. Figure 3.4 shows an example of the fixation, cue, and target in this experiment and Figure 3.5 shows the procedure. Individual objects appeared briefly (100ms) on-screen with the cue or target border already in place. Since the objects were not present throughout the whole trial and were briefly presented with cue or target in place, the initial fixation screen of the objects in place (as used in Experiment 4a) was replaced with a black screen for the current experiment.

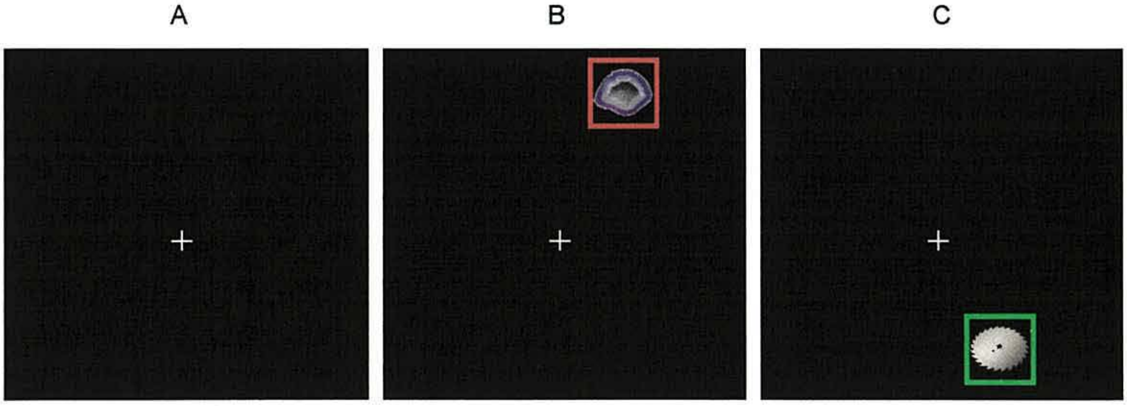

Figure 3.4 – showing an example of the blank fixation (panel A), red outline cue (panel B) and green outline target (panel C) for Experiment 4b. Images appeared one at-a-time with the cue or target outline in place.

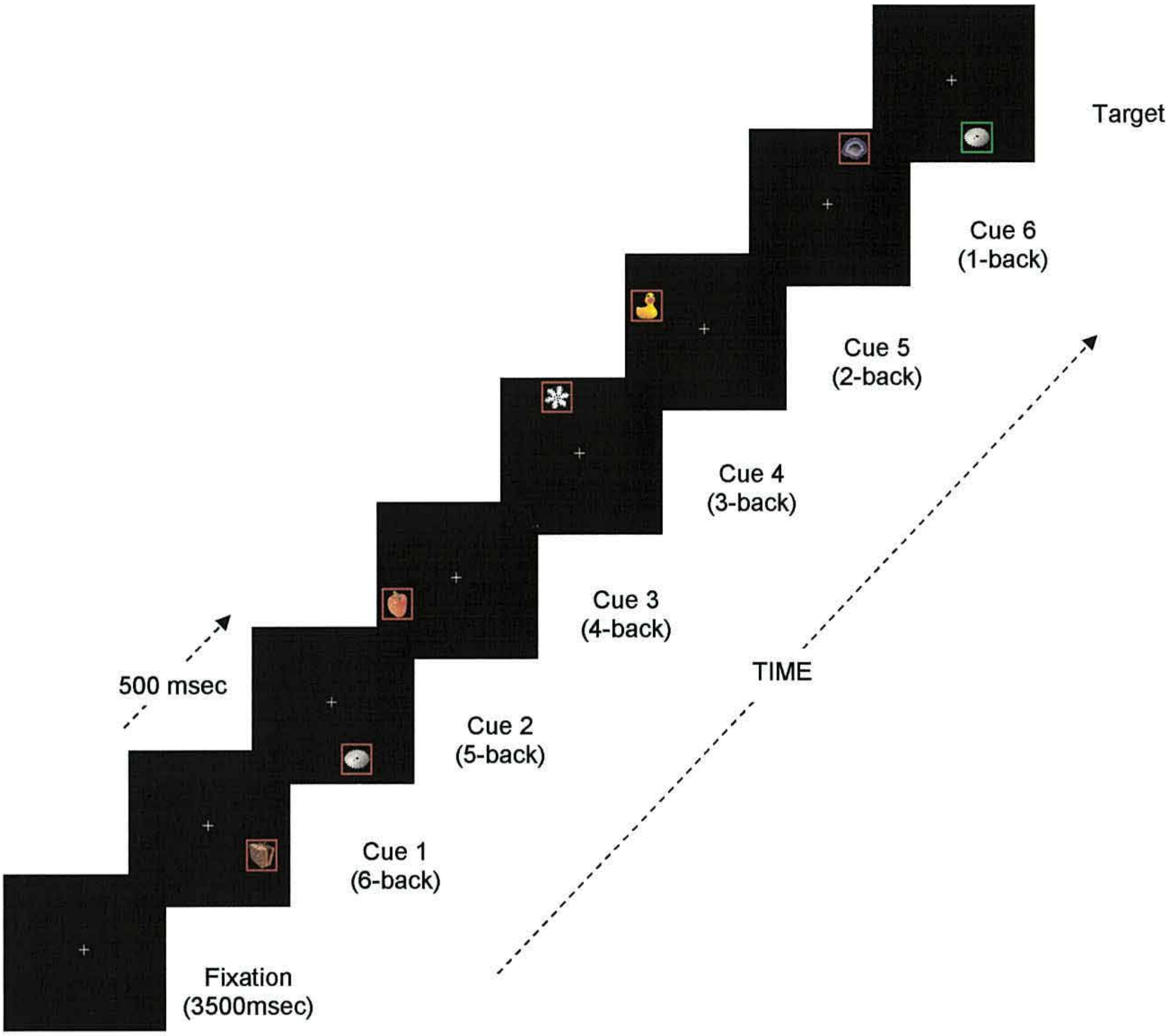

Figure 3.5 – showing the main part of the procedure for Experiment 4b. This example shows a typical six-cue trial with the target appearing in the five-back condition (the fifth-last cued location).

Results

Mean Reaction Times (RT), standard deviation, percentage errors, and actual IOR effects for Experiments 4a and 4b are shown in Table 3.1 while Figure 3.6 shows a graph of the actual IOR effect for each location for both experiments. All data presented are for six-cue trials, the filler and catch trials were too few to warrant further analysis and are not discussed further. Trials on which errors occurred were excluded from analysis.

Table 3.1 – showing mean reaction time (RT) scores (in milliseconds), standard deviation, percentage errors and actual IOR effects for each cue condition for Experiment 4a and 4b. Errors are collapsed across the condition in which they (would have) occurred. Errors were: no response when there should have been one (a miss), a response when there should not have been one (false alarm) and, responding before the target onset (or no target for the invalid trials; anticipation). Statistical significance is included for the IOR effect ($p < .01$; *$p < .05$).**

		1bk	2bk	3bk	4bk	5bk	6bk	Uncued
Exp. 4a Constant Unique Objects	Mean RT	422	410	404	401	405	398	398
	Std. Dev	47	48	48	50	56	45	48
	% errors	1.43%	2.08%	1.56%	2.08%	2.34%	1.82%	2.54%
	IOR effect	24**	12**	6	4	7*	0	--
Exp. 4b Brief Unique Objects	Mean RT	401	389	382	384	390	383	380
	Std. Dev	53	57	51	55	53	57	52
	% errors	1.82%	1.82%	1.43%	1.56%	1.30%	0.91%	1.82%
	IOR effect	21**	8**	2	4	10**	3	--

Errors

There were no significant main effects of errors in either of the experiments and no interactions.

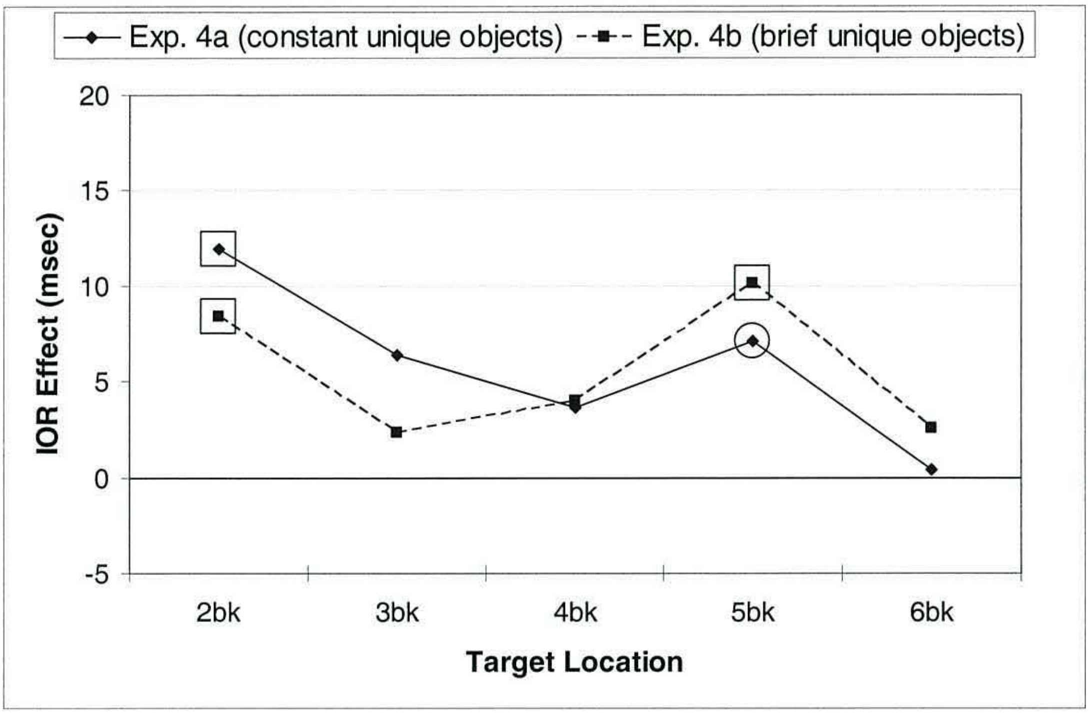

Figure 3.6 – showing the size of the IOR effect for Experiments 4a (constant unique objects) and 4b (brief unique objects). Squared and circled data indicate statistical significance (measured in an analysis of 2-6 back data; squares *p* < .01; circles *p* < .05).

Experiment 4a

1-6bk: Analysis in a one way within-subjects ANOVA of the complete data set (1-6 back) found a significant effect of cueing [$F(6, 31) = 10.4$, $p < .0001$]. Planned contrasts detected significant cueing effects at 1-back ($F = 43.5$, $p < .0001$), 2-back (F = 10.5, $p < .01$), and marginally significant at 5-back ($F = 3.7$, $p = .0554$).

Furthermore, analysis of the more distal temporal moments of 2-6 back were made (this analysis matches that performed on the data from Experiments 1, 2, and 3):

2-6bk: Analysis in a one way within-subjects ANOVA of the 2-6 back conditions found a significant effect of cueing [$F(5, 31) = 3.2$, $p < .01$]. Planned contrasts detected significant cueing effects at 2-back ($F = 11.2$, $p < .01$), and 5-back ($F = 4.0$, $p < .05$).

Experiment 4b

1-6bk: Analysis in a one way within-subjects ANOVA of the complete data set (1-6 back) found a significant effect of cueing [$F(6, 31) = 10.2$, $p < .0001$]. Planned contrasts detected significant cueing effects at 1-back ($F = 43.8$, $p < .0001$), 2-back ($F = 7.1$, $p < .01$), and 5-back ($F = 10.3$, $p < .01$).

Again, an analysis was made of the more distal temporal moments of 2-6 back:

2-6bk: Analysis in a one way within-subjects ANOVA of the 2-6 back conditions found a significant effect of cueing [$F(5, 31) = 3.2$, $p < .01$]. Planned contrasts detected significant cueing effects at 2-back ($F = 7.5$, $p < .01$), and 5-back ($F = 10.9$, $p < .01$).

Combined analysis of Experiments 4a and 4b

1-6bk: Initial analysis of the complete (1-6 back vs. uncued) data set was undertaken with a two-way mixed 7 x 2 ANOVA [cueing (uncued, 1-back, 2-back, 3-back, 4-back, 5-back, 6-back) x experiment (constant unique objects (4a), brief unique objects (4b))]. There was a significant main effect of cueing [$F(6, 6) = 19.9$, $p < .0001$].

2-6bk: Further analysis of the more distant temporal cueing moments of 2-back, 3-back, 4-back, 5-back, and 6-back showed a main effect of cueing [$F(5, 5) = 6.7$, $p < .0001$.

Discussion

The combined analysis of Experiments 4a and 4b showed that there was significant IOR effects at work. However, there was no interaction of cueing by experiment type. In this instance then it can be concluded that presenting objects that were static throughout the whole trial (constant unique objects, Exp 4a) as compared to presenting objects along with the cue (brief unique objects, Exp 4b) made no difference to the maintenance of IOR as was the case with the albeit simpler line-drawing stimuli of Chapter 2. How might direct comparisons of the experiments presented here with those of Chapter 2 fare?

Experiment 4a

Previously it had been shown in Experiment 3 that when distinctive objects are cued IOR appears to be relatively stable. Effects were observed out to the 6-back cueing condition. However, these effects were somewhat small and variable (e.g., 5-back was not significant). It was suggested that the effects were relatively weak because the same displays were shown over many trials. So although each item was distinctive from other items in the display, the same object was cued in the same location over many trials. Therefore it is possible that there is interference between trials that builds up throughout the experiment. Thus the inhibition activated by a cue on a particular trial would be overlaid on the inhibition activated in many previous trials.

The aim of Experiment 4a was an attempt to increase the stability of memory for inhibition. In this study each object was unique in that it was only encountered once in the experiment. For example, when an object such as the image of a chair was cued, the inhibition associated with the object creates a distinct episode. Thus when the target was presented to measure the level of inhibition associated with the object there were no other instances where cues and targets had been associated with that particular object on numerous other trials.

However, as can be seen in Figure 3.7 below, comparing IOR in Experiment 4a with that of Experiment 3, distinctive objects did not increase the stability of IOR at more distant cueing points of 3- to 6-back. Indeed planned contrasts only detected a marginally significant effect at 5-back. Combing the 2-6 back data of Experiment 4a with that of Experiment 3 in a mixed two way ANOVA showed that there was significant IOR overall (a main effect of cueing) [$F(5, 5) = 6.0, p < .0001$] and a main effect of experiment type [$F(1, 62) = 88.5, p < .0001$] with the responses to the constant unique objects (Exp 4a) being faster (402ms) than to the colour objects (Exp 3, 533ms). This latter main effect of experiment type highlights the relative difference in the cue and target detection of the two experiments: Experiment 4a was simply the detection of a green outline from red outlined cues whereas Experiment 3 had targets of many possible different colours. There was however, no interaction of experiment type by cueing [$F(5, 310) = 1.7$, ns]. Therefore making every cued object unique has *not* increased the capacity or stability of IOR in this task. There are two possible reasons for the failure to increase memory for inhibition. First, there are invariant limits to the capacity of IOR: like other limits in working memory, this may be about 4 or 5 items, with occasionally small effects glimpsed beyond this limit if objects are cued. Second, perhaps the quality of the images was not good enough. That is, although complex real-world objects were shown, the images were quite small (2.8° visual angle). Therefore, further work with improved techniques might be worthwhile.

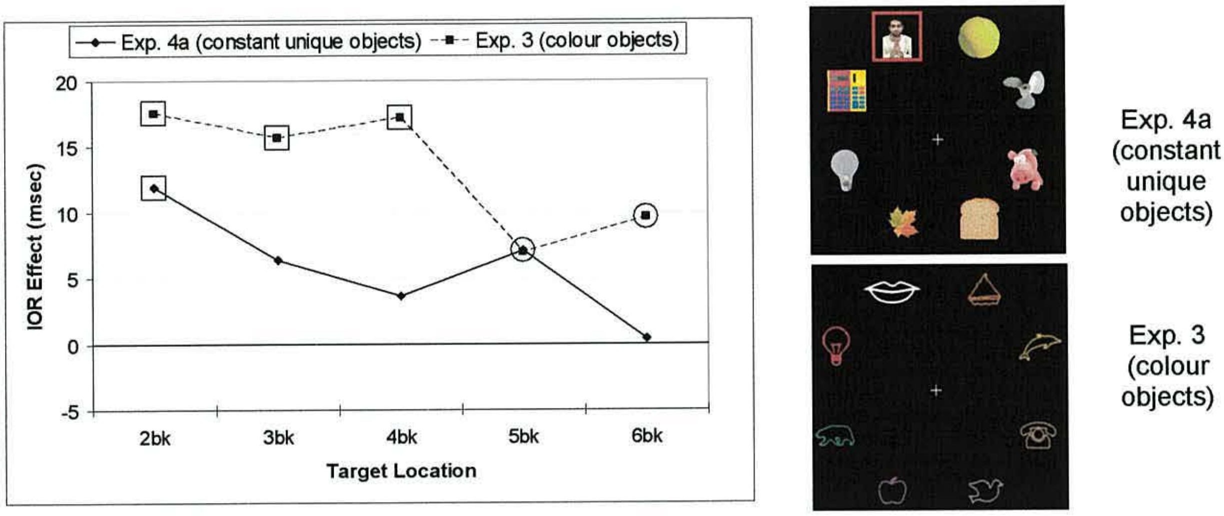

Figure 3.7 – showing a comparison of Experiments 4a (constant unique objects) and Experiment 3 (colour objects). Squared and circled data indicate statistical significance when the 2-6 back data of the experiments were analysed individually (squares, $p < .01$; circles, $p < .05$). Note, the significant effect of $p < .05$ at 5-back is for Experiment 4a.

Indeed, if anything, the effects in Experiment 3 are more robust at the more distant points in time. This seems to be the case even though the same objects were viewed over many trials. The following idea, although very speculative, may be worth considering in future research. In Experiment 3, detection of the target colour filling-in was quite difficult. This was the reason for the small, unexpected, facilitation effect at 1-back cueing. That is, attention was slower to disengage from the cued object. Therefore the onset of inhibition was delayed in this experiment and hence this has shifted the IOR effect back in time. In this context the 6-back condition would really be considered 5-back from the most recent visible sign of inhibition (2-

back). Again, this would support the notion of an invariant limit to the number of objects that can be associated with inhibition. That is, once inhibition is activated, it can only be associated with up to 4 or 5 objects.

Experiment 4b

A central assumption has been that objects must remain visible to maintain inhibition over time and subsequent re-orienting of attention. However, the results obtained do not unequivocally support this assumption. Overall IOR is as robust when objects are briefly flashed (Experiment 4b) as when they remain constantly visible (Experiment 4a). Indeed, as can be seen in a comparison of Experiment 4a and 4b (Figure 3.6 above), IOR seems to be a little larger at the more distant cueing points of 4- to 6-back when objects are briefly flashed (5-back was highly significant for Experiment 4b while only marginal for Experiment 4a).

Furthermore, comparing Experiment 4b to Experiment 2 which used a similar procedure shows the more salient objects of Experiment 4b producing *less* IOR than simply cueing grey boxes at the early cueing times (2- and 3-back; Figure 3.8 below). However, at the more distal cueing points (4- to 6-back) the unique objects of Experiment 4b do indeed produce stronger IOR effects than Experiment 2. The highly significant effect at 5-back for Experiment 4b highlights this and provides evidence that the naturalistic object based stimuli are having an effect. This is borne out by a comparison of the 2-6 back data of Experiment 4b with that of Experiment 2. A mixed two way ANOVA showed a significant main effect of cueing (IOR) [$F(5, 5) = 4.4, p < .001$] and a significant interaction of experiment type by cueing [$F(5, 310)$

= 2.5, $p < .05$]. There was no main effect of experiment type [$F(1, 62) = 3.7$, ns]. This significant main effect and the interaction of cueing by experiment suggests that the brief unique objects of Experiment 4b significantly differed from the no object stimuli of Experiment 2 and an examination of Figure 3.8 below suggests that this change was at the more distant cue points of 4-6 back. This interesting finding supports the notion that the brief appearance of the unique photo objects of Experiment 4b (with the cue or target in place) influenced the amount of inhibition shown compared to the brief appearance of a cue or target alone (Experiment 2).

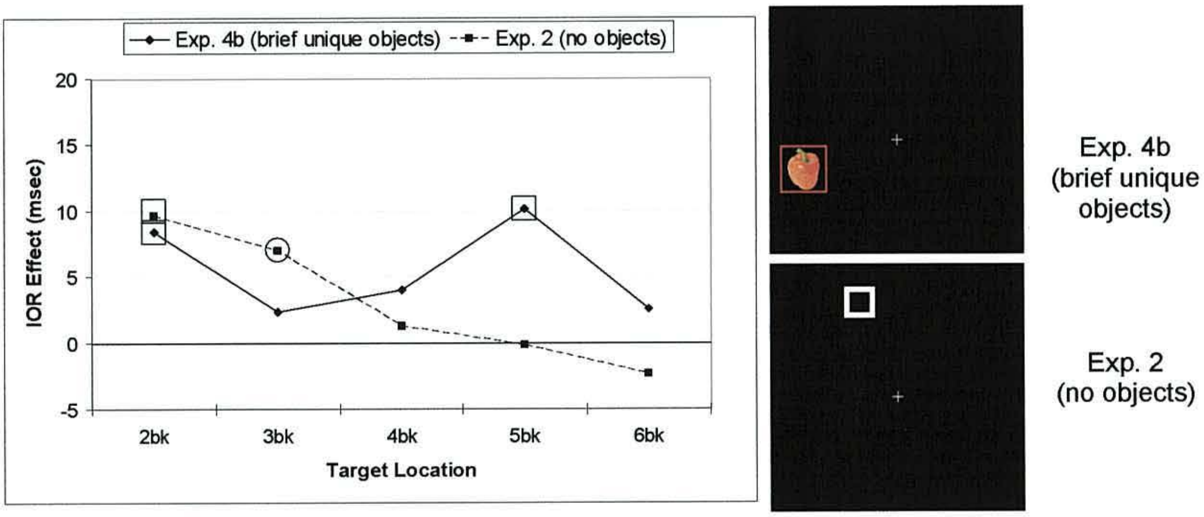

Figure 3.8 – showing a comparison of Experiment 4b (brief unique objects) with Experiment 2 (no objects). Squared and circled data indicate statistical significance when the 2-6 back data of the experiments were analysed individually (squares, *p* < .01; circles, *p* < .05).

Therefore, in contrast to some traditional views of IOR, it is possible that objects do not necessarily have to remain visible throughout the whole of a trial for inhibition to be observed. Other research does in fact support the findings here. As discussed above, Tipper and colleagues (1990) demonstrated that after ignoring a distractor, negative priming remained associated with the object even though it disappeared behind an occluding surface.

In the current context the following can be proposed: As noted by Tipper et al. (1994) the previous failures to replicate Klein (1988) by Wolfe and Pokorny (1990) and Klein and Taylor (1994) were due to the removal of the searched objects. That is, after search, the display was cleared and a target probe stimulus different to any of the objects was presented for detection. In Experiment 4b objects are also removed after attention is oriented to their sudden onset. However, a critical difference to the previous work is that the target for detection is the same object and is in the same location as the object previously cued (previous work changed the identity of the target and thus would fail to recall the prior encoding of the cue as the target is unrelated to it). Therefore if inhibition is associated with an object, it can be retrieved (re-accessed) when the same object is encountered shortly afterwards (see Tipper, 2001).

Finally, a consistent observation that may be worthy of comment concerns the 5-back cueing condition. As can be seen, in both experiments 4a and 4b, IOR seems to be larger at 5- than 6-back cueing, but then declines again at 4-back. Why this larger effect at 5-back? The following speculation may be worthwhile. In this study there is a relatively long interval of 3.5 seconds between starting the trial and the onset of the first cue (in Experiment 4a this is while the objects are in place, in 4b there is a black fixation screen). It could be that participants cannot predict when the first cue will appear, and hence encoding of the cue with the object may be impaired for the first cue (the 6-back condition). However, the first cue acts as an alerting signal that ensures that the processing of the next cue (5-back) 600ms later is more efficient. Hence the inhibition activated by the cue is more robustly associated with the object toward which attention was oriented. This is, in a sense, a primacy effect as compared to the robust recency effects observed at 1- and 2-back cueing. Primacy and recency effects are well established in the literature on memory and refer to the ability of the first (primacy) or last (recency) few presented items to be very well recalled (e.g., Postman & Phillips, 1965; Hitch, 1975).

In contrast, inhibition associated with the 3- and 4-back cue is less robust. Although these cues are more recent than 5-back, they are also in the middle of the sequence of cues. Thus, as is well established in studies of primacy and recency effects, items in the middle of a list are less easily recalled as they suffer from competition from items previously encoded, and from items more recently encoded which are still active.

One further point to note here is the distinction between the number of items that inhibition can be applied and the amount of inhibition that is applied. In the comparison of Experiment 4a to Experiment 3 (both object based experiments) there is not only stronger inhibition for the colour objects of Experiment 3 (perhaps due to the relative task difficulty shown in the main effect of experiment), but also that the inhibition appears to last longer as demonstrated by the significant effects at up to 6-back. A comparison of Experiments 4a and 2 showed that again, the presence of objects extended the number of items to which inhibition was applied rather than the amount of inhibition that was applied. This was also the case with the object based effects seen in Experiment 3 (colour objects). The main distinction here is that in general the object based effects are increasing the number of items that are being inhibited relative to experiments with no-objects.

Experiment 5 – do objects act as spatial landmarks?

Thus far the importance of objects for maintaining IOR has been emphasised. In general, cueing objects have tended to produce more stable inhibition at the more distant points in time of 4- to 6-back cueing. Although there are clear limits to how many objects can be inhibited. The core idea throughout this thesis is that objects are associated with inhibition, and it is object-based representations that support the maintenance of inhibition.

However, there is a further critical property that distinguishes object displays such as those of Experiments 1, 3, and 4a from that of no object displays such as Experiment 2. In Experiment 2 there are no physical landmarks in the display. That is, cues and targets are briefly flashed on a blank screen, and any memory for the location of a stimulus such as a cue will be somewhat imprecise. In contrast, in each study where objects remain visible throughout the cueing sequence, the location at which the cue was, and the subsequent target will be presented, is very well specified by the physical presence of the object cued. Physical landmarks clearly divide space and support memory for the location of events in the environment.

However, it should be noted that Experiment 4b was similar to Experiment 2 in that objects were *not* continuously visible. Cues were briefly flashed for 100ms on an empty screen. In Experiment 4b recall that there was some evidence for the maintenance of inhibition at more distant points in time. Certainly, IOR was clearly significant at 5-back cueing. Experiment 4b therefore suggests that even when objects do *not* provide continuous physical landmarks, memory for inhibition can be improved. However, these latter IOR effects remain small, and hence they do not rule out the role of object landmarks in IOR effects.

Experiment 5 therefore tests the landmark hypothesis. In this study, cues and subsequent targets are *never* associated with objects. That is, the cues and target are briefly (100ms) flashed on an empty blank computer screen. This is essentially exactly the same procedure as that of Experiment 2. However, in sharp contrast to Experiment 2, landmarks are introduced in Experiment 5. Consider Figure 3.9, in this display small white lines are adjacent to the location of cue and target presentation. These lines indicate where cues and targets *could* appear. In such a situation attention is never drawn to an object by the cue. Therefore there will be no role for object-based IOR. On the other hand, the location of cues and target is well defined by the spatial structure provided by the landmarks. If such structural landmarks facilitate maintenance of inhibition, then the IOR effects at more distant cueing points (4- to 6-back) will be more robust. In contrast, if the effects observed so far are entirely due to cueing of objects, then Experiment 5 should produce data identical to that of Experiment 2, as no objects are ever cued in these studies.

Participants

Thirty-two undergraduates from the University of Wales, Bangor participated for course credit (25 females, 7 males, mean age 22.3 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

Stimuli used were identical to those of Experiment 2 (no objects) with the addition of landmarks (small tick marks) arranged on screen to act as localisers for the appearing cues and targets. Figure 3.9 shows an example of the fixation, cue, and target used in the present experiment.

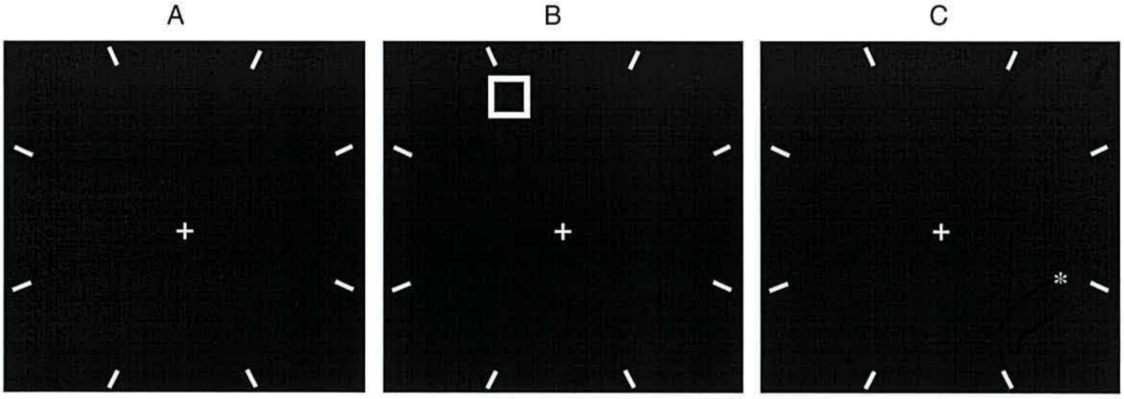

Figure 3.9 – showing an example of the fixation (panel A), cue (panel B) and target (panel C) screens for Experiment 5. The landmarks (tick marks) around the screen remained in place throughout a trial and the cue or targets appeared briefly.

Procedure & Design

The procedure (shown in Figure 3.10) and design were identical to that of Experiment 2 but with addition of the landmarks.

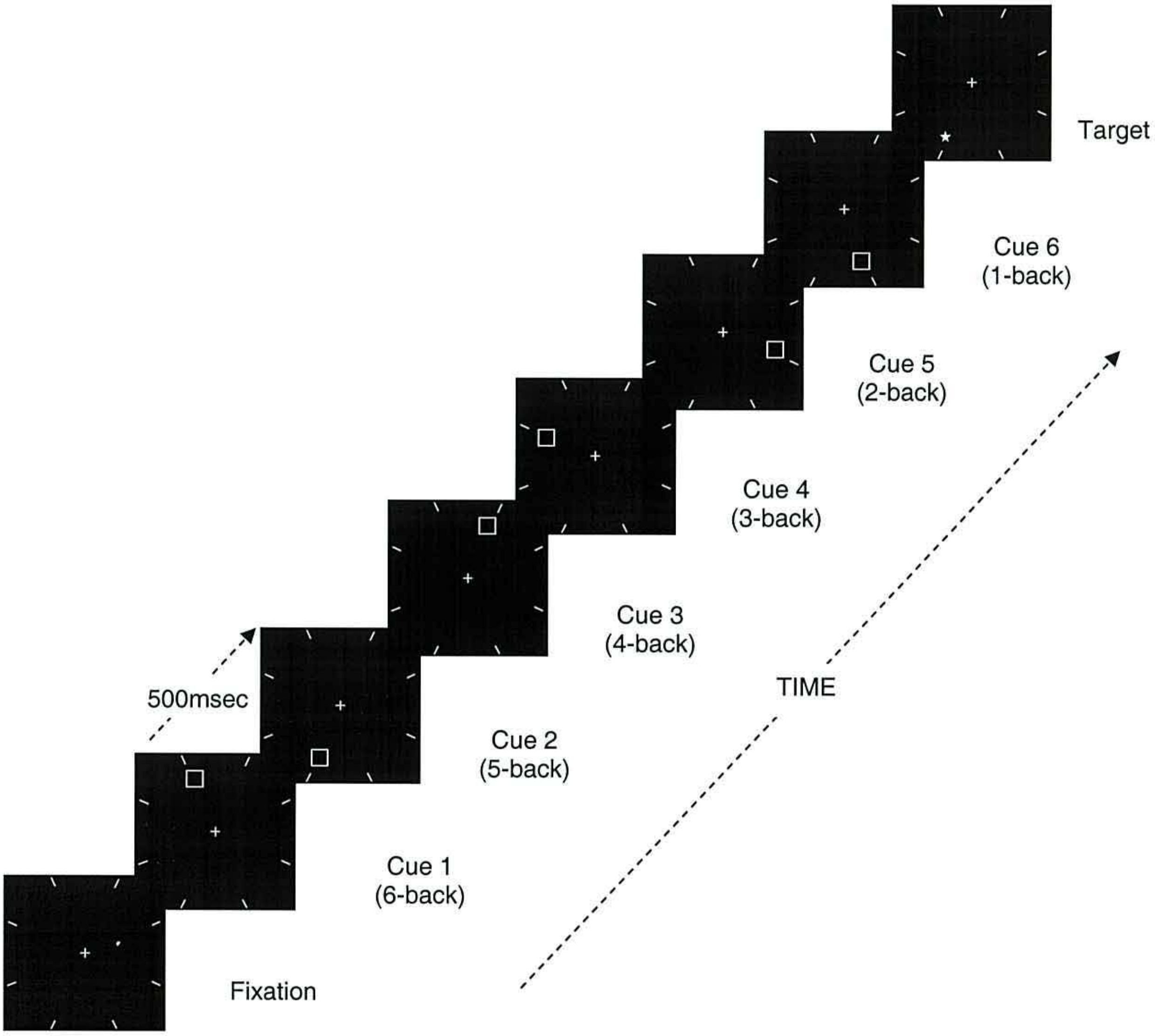

Figure 3.10 – showing an example of the typical 6-cue trial for Experiment 5. In this example, the target appears in the five-back condition, (the fifth-last cued location).

Results

Table 3.2 shows the results for this landmarks experiment and Figure 3.11 shows the actual IOR for each location. All data presented are for six-cue trials, the filler and catch trials were too few to warrant further analysis and are not discussed further. Trials on which errors occurred were excluded from analysis.

Table 3.2 – showing mean reaction time (RT) scores (in milliseconds), standard deviation, percentage errors and actual IOR effects for each cue condition for Experiment 5. Errors are collapsed across the condition in which they (would have) occurred. Errors were: no response when there should have been one, a response when there should not have been one and, responding before the target onset (or no target for the uncued trials). Statistical significance is included for the IOR effect at significant cueing conditions (*p* < .01; **p* < .05).**

		1bk	**2bk**	**3bk**	**4bk**	**5bk**	**6bk**	**Uncued**
Exp. 5 Visual Markers	Mean RT	423	407	410	404	403	401	396
	Std. Dev	51	52	48	51	51	51	47
	% errors	2.73%	2.73%	2.08%	2.73%	1.30%	2.34%	2.28%
	IOR effect	28**	11**	14**	8*	7	6	--

Errors

There were no significant main effects of errors and no interactions.

1-6bk: Analysis of the complete data set (1-6bk) in a one way within-subjects ANOVA found a significant effect of cueing [$F(6, 31) = 11.0, p < .0001$]. Planned contrasts detected significant cueing effects at 1-back ($F = 54.9, p < .0001$), 2-back ($F = 9.2, p < .01$), 3-back ($F = 15.1, p < .0001$), 4-back ($F = 4.7, p < .05$) and marginally significant at 5-back ($F = 3.8, p = .0524$).

Again, an analysis was made of the more distal temporal moments of 2-6 back:

2-6bk: Analysis in a one way within-subjects ANOVA of the 2-6 back conditions found a significant effect of cueing [$F(5, 31) = 3.8, p < .01$]. Planned contrasts detected significant cueing effects at 2-back ($F = 10.0, p < .01$), 3-back ($F =16.3, p < .0001$), 4-back ($F = 5.1, p < .05$), and 5-back ($F = 4.1, p < .05$).

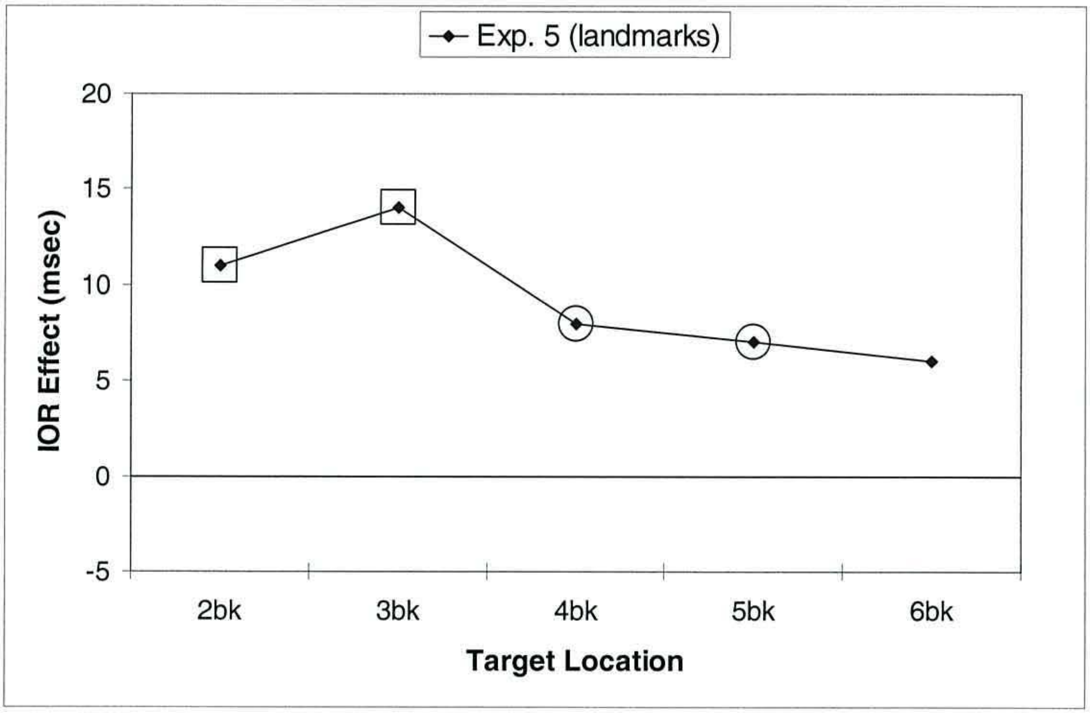

Figure 3.11 – showing the results of the Experiment 5 (landmarks). Squared and circled data indicate statistical significance (squares, $p < .01$, circles, $p < .05$).

Discussion

The data from Experiment 5 (landmarks) are compared to the effects observed when no objects are cued (Experiment 2) in Figure 3.12, Panel A (below). Analysis of the IOR effects showed that these were significantly larger at the more distant points in time (2- to 6-back) in the landmark conditions of Experiment 5 ($p < .02$). In contrast, as can be seen in Panel B of Figure 3.12 which contrasts Experiment 5 (landmarks) with Experiment 1 (grey squares), there was no difference in IOR effects. Therefore it is clear that IOR remains relatively stable when landmarks are provided. There is no difference between the cueing effects in this landmark situation and those where objects (grey squares) were cued.

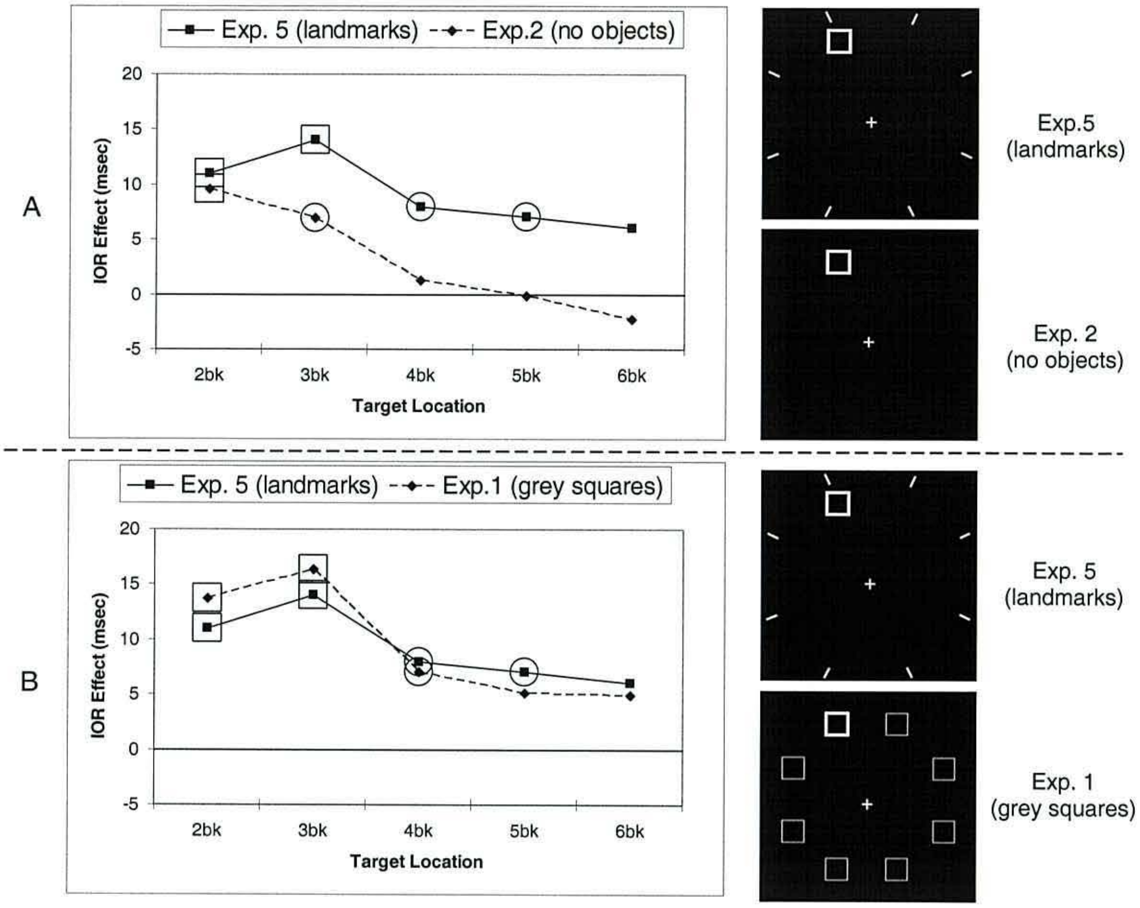

Figure 3.12 – Panel A (top) shows a comparison of Experiment 5 (landmarks) and Experiment 2 (no objects). Panel B (bottom) shows a comparison of Experiment 5 (landmarks) and Experiment 1 (grey squares). Squared and circled data indicate statistical significance (squares, *p* < .01, circles, *p* < .05).

Therefore it would seem that one component of the role of objects in IOR is to act as environmental landmarks that update location-based frames of reference. That is, the spatial location of the cue is preserved over time if landmarks are present. This observation is of fundamental importance in that it challenges a number of assumptions concerning the frame-of-reference within which IOR functions. The argument has been that IOR is associated with both location- and object-based frames of reference. For example, Tipper et al. (1994) demonstrated that after cueing, target detection was impaired at a location cued and within the object cued, even when it has moved to a new location. Similarly, Jordan and Tipper (1998) demonstrated that

IOR was larger when objects, as opposed to empty locations, were cued. They concluded that IOR was larger in the former object condition because location and object effects were additive.

However, Experiment 5 demonstrates that stronger IOR (compared to Experiment 2) can be obtained (at least at more distant points in time) when no objects have been cued but spatial landmarks are present. Therefore it might be possible to re-interpret the previous findings in terms of objects providing landmarks that support spatial IOR, rather than objects themselves being associated with inhibition. Thus, when objects move (e.g., Tipper, 1991, 1994, 1999) the motion simply up-dates the spatial locus of inhibition. Similarly, IOR is larger when objects are cued, as compared to empty space (Jordan & Tipper, 1998), because the object provides a better landmark to constrain the locus of inhibition and to maintain it through time.

The results of Experiment 5 therefore provide a fundamental challenge to notions of object-based IOR. IOR can be increased even when objects are not cued. However, although demonstrating the importance of objects providing landmarks, there still remains some evidence that inhibition is associated with objects during visual search. For example, Experiment 4b provides data demonstrating that even when objects do not remain visible throughout a trial, reinstating a unique object during processing of the target can provide some evidence for the maintenance of inhibition. That is, IOR was highly significant in the five-back cueing condition.

Therefore at this point the more cautious conclusion must be that IOR is more stable when objects have been cued for two reasons: First, the objects provide environmental landmarks that support the memory for the location previous cued/attended. Second, inhibition is directly associated with the internal representations of objects (see next chapter). Thus when the object requires further processing, retrieval of the inhibition associated with it slows down this subsequent processing. The next series of experiments further attempt to confirm that inhibition can be associated with object-based representations. This work develops new approaches to tackle this issue.

Summary

The present chapter examined what role objects play in the maintenance of IOR. Firstly, Experiment 4a used objects that were present throughout the whole trial and was compared to Experiment 3 (coloured objects). Contrary to predictions, the more photo-realistic objects of Experiment 4a failed to maintain IOR effects at the more distal points in time. In fact the less realistic stimuli of Experiment 3 seemed to produce a more consistently robust effect at more distant cueing points perhaps due to slower attentional disengagement. However, Experiment 4b also used photo-realistic objects but this time they appeared briefly with the cues in place and were not present throughout the whole trial. When compared to Experiment 2 (no objects), this experiment showed a trend for stronger maintenance of IOR at the more distal cueing points with a particularly strong effect found at 5-back. This result would suggest that perhaps object identity is indeed important even when no landmarks are present. However, both experiments 4a and 4b had a slight procedural change to that of earlier experiments where a 3.5 second fixation screen was seen before cueing began. It could be the case that the resulting data may have been influenced by a primacy-recency effect being initiated when cueing began. Such an influence may well delay the onset of inhibition. A more directly comparable design and procedure to that of Experiments 1-3 might be fruitful in future work (perhaps without the extended 3.5 second pre-cueing that was used in experiments 4a and 4b).

Secondly, Experiment 5 questioned whether objects are only acting as landmarks with which inhibition can become associated. If this were the case, then IOR could be maintained or increased even when objects are *not* cued. This notion was supported by the results of Experiment 5. Such a result would suggest that object identity is not intrinsically important for the maintenance of IOR, objects simply act as spatial landmarks with which inhibition can become associated. However, when balanced against the results of Experiment 4b, it may be the case that IOR can be maintained longer when a unique object is reinstated during the target sequence. A tentative conclusion at this point is that IOR is maintained for a longer period of time when objects *are* present. This issue is discussed further in the following chapter.

Chapter Four

Identity Specific Inhibition of Return?

Abstract

Chapter 4 builds on the tentative conclusions from the previous chapter which showed how unique colour objects might influence the maintenance of inhibitory states. Building on this issue of unique object identity, three experiments are presented which examine if object identity is indeed important and if so, to what level can this identity be encoded? Furthermore, the notion that encoding and retrieval processes may be important for reinstating prior attentional states is examined.

Experiment 6a used an IOR design based on the classic Posner and Cohen (1984) study. In the present experiment however, the underlying objects were photos of faces instead of simple square outlines. Cues and targets were semi-transparent ellipses presented over the face objects which allowed the objects to remain visible. Faces in the cue were presented in an upright orientation and rotated by 45 degrees in the target so as to remain upright and identifiable. A robust IOR effect was found.

Experiment 6b, using the same design, had the cue faces appear inverted and the target faces appear upright. In this instance, IOR was reduced by approximately 50% of baseline (Experiment 6a). This result suggests that IOR can be disrupted by an *encoding* failure. That is, inhibition has difficultly being associated with the inverted cue faces as they are difficult to identify (and thus encode). The subsequent target therefore, cannot recall the prior inhibitory state as the target is perceived to be a unique object.

Experiment 6c, using the same design, had the cue faces appear upright but the target faces rotated 45 degrees so as to become inverted and less recognisable. As a result of the loss of object identity between the cue and the target, IOR was reduced by nearly 50% to that of baseline (Experiment 6a). This result suggests that IOR can be disrupted by a *retrieval* failure. That is, the inhibition associated with the upright cue faces is not reinstated during target recall as the target faces are inverted (and difficult to identify) and therefore un-associated with the prior cue episode, and thus the prior inhibitory state.

These findings, while speculative and preliminary (and taken in the context of semantic identity-based inhibition demonstrated in studies of negative priming), support the notion that inhibition can be associated with the identity of an object and that retrieval of prior inhibitory states is crucial for IOR.

Identity Specific Inhibition of Return

Chapters 2 and 3 have suggested that objects play an important role in the maintenance of inhibitory states. In review, cueing objects (Experiments 1, 3, and 4a) compared to cueing empty space (Experiment 2) has shown longer-lasting inhibitory effects for more items in a serial search paradigm. However, Experiment 5 suggested that objects themselves might not be solely associated with inhibition; instead they might merely be acting as landmarks supporting location-based inhibition. Further supporting the role of object-based representations however, data from Experiments 4b again suggested that objects with unique identities can also influence the maintenance of inhibition. As can be seen, the results are not conclusive.

For example, because inhibition appears to move with an object (e.g. Tipper et al., 1991), this does not necessarily mean that the object is associated with inhibition. The movement could simply update a spatial representation. Similarly, because IOR is larger when objects are cued (Jordan & Tipper, 1998), and lasts longer (as seen in Chapters 2 and 3), does not necessarily imply that object-based information is inhibited and is additive with spatial information. Rather, it is possible that objects provide stable landmarks that help to maintain the location of spatial inhibition over time and intervening events.

Even if one were to accept that object-based IOR exists, it is still unclear what object-based representations can be associated with inhibition. The 3 experiments of this chapter sought to determine if higher level representations such as the identity of an object could become associated with inhibitory processing. That is, when a unique object is presented in a prime cue and is then recalled (attentionally reinstated) in a subsequent probe target, can IOR be influenced by whether or not the object is still recognisable? If IOR was shown to be associated with an object's identity, this would clearly disprove the above proposal that all the IOR effects are purely spatial. Furthermore, it would show for the first time that inhibition can accesses higher level internal representations of objects.

That object identity can be associated with inhibition has been well established in studies of Negative Priming (Tipper, 1985) which concerns the fate of irrelevant or ignored stimuli. The typical negative priming (NP) procedure (e.g., Tipper, 1985; Tipper & Cranston, 1985) has two letters or simple line-drawn objects superimposed over one another. Trials are presented in successive pairs of displays where the first display is the prime component and the second display is the probe component (response is measured on the probe). In both prime and probe, the red target item is to be selected and the green distractor item is to be ignored. NP is demonstrated when the previously ignored distracter from the prime becomes the target in the probe, and the subsequent response times is impaired (relative to a control condition where new objects are shown), suggesting that previously ignored stimuli are processed even when they are irrelevant to the current goal or task. Tipper and Cranston have argued that in order to select the red target, one must actively inhibit the green distractor during the prime encoding sequence. If the distractor is thus inhibited, it should take longer for that particular representation to become active on a subsequent display and as a result, this new target (the previously ignored distractor) should be retrieved or recalled more slowly. Such findings have been shown to be robust across a variety of stimuli types including letters (Allport, Tipper & Chmiel, 1985), pictures (Tipper, 1985), words (Strayer & Grison, 1999), and faces (Khurana, 2000; for reviews see Tipper, 2001; Neil, Valdes, & Terry, 1995; and Fox, 1995).

With respect to object identity, studies of NP have shown that stimuli which are irrelevant to the current task are processed to a semantic (identity) level. For example, NP has can be observed transferring between objects in the same semantic category such that ignoring a picture of cat in a prime trial, would show reduced response to the word "dog" in probe (Tipper & Driver, 1988). No such deep level effects have thus far been found in studies of IOR. However, it should be noted that NP and IOR may be accessing similar underlying inhibitory mechanisms, as suggested by Houghton and Tipper (1994), and hence predict similar properties.

However, it is still unclear what particular object-based representation can be associated with inhibition. The general view is that candidate objects, or object-files (Kahneman, Treisman & Gibbs, 1992), are encoded in parallel across the visual scene, via the Gestalt grouping mechanisms (e.g., common fate, feature similarity etc). These initial object representations are candidates for subsequent processes of object identification. For example, a moving object can be represented, but further processes are required for identification: is it a bird, ball, or aeroplane? It is these low-level representations that are inhibited during visual search (e.g. Driver et al., 2001). There is little evidence that inhibition can be associated with higher-level representations such as the identity of an object. The possibility that inhibition can be associated with object identity was tested in the following experiments.

Cueing procedures similar to Posner and Cohen (1984) were used to investigate object identity specific IOR. In the present experiments however, rather than cueing simple outline squares to the left and right of fixation, faces were presented with semi-transparent cues and targets superimposed over them[10]. Furthermore, faces could change orientations between presentation in the cue and subsequent target (upright-upright, upright-inverted, or inverted-upright; experiment 6a, 6b, and 6c respectively) thus allowing the identity of the target to be varied depending on the preceding cue.

Experiment 6a tests the general prediction that IOR can be found in a new cueing design with unique face stimuli serving as the underlying objects. Specifically, if a semi-transparent cue were presented over an upright face and then the same upright face were subsequently presented with a semi-transparent overlaid target, then recognition of the underlying object (the face) in both instances should be relatively easy and a robust IOR effect should be found[11]. In this instance, the later stimuli (the face presented with the target) matches the former encoding episode (the face presented with the cue) and subsequently retrieves the inhibitory states associated with the prior encoded cue episode. Similar ideas concerning retrieval of prior attentional states have been developed by Neill (1997) to explain negative priming effects (see also Tipper, 2001). The core idea is that if inhibition can be associated with an object's identity during attentional orienting, this inhibition can only be observed if a subsequent stimulus also accesses the same representations.

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[10] In the present studies, faces were used because humans are very efficient at processing faces (e.g. Bruce & Humphreys, 1994), and furthermore, faces have the unique property that identification is seriously impaired when a face is inverted (Yin, 1969).

[11] Recall that Posner & Cohen also superimposed their cues and targets over grey outline boxes.

Therefore, if a face were inverted in the cue but upright in the subsequent target (Experiment 6b), then object recognition between cue and target would be impaired and there would be no retrieval of the prior inhibitory state. That is, the inhibition that was encoded and associated with the difficult-to-identify cue would not be retrieved by the subsequent target as the target is seen as a new and unique object and therefore unrelated to the prior encoding episode. This situation examines the association of inhibition with object identity during initial *encoding*.

Likewise, if the cue face were upright and the subsequent target face inverted (Experiment 6c), object recognition would again be impaired since the target face would be hard to identify. That is, inhibition would be encoded with the identifiable upright cue face but would not be retrieved and reinstated during target recall as the target is unrecognisable and thus, unrelated to the inhibitory state associated with the earlier cue. This situation examines the association of inhibition with object identity during subsequent *retrieval*.

If IOR is only associated with low-level representations of candidate objects, where object identity has not yet been computed, then IOR should be of equivalent size in the upright and both the inverted conditions. That is, inhibition will be associated with both the location and the object cued, which previous work has suggested can be additive (Jordan & Tipper, 1998). This is because low-level candidate objects are represented in both situations. However, if inhibition is associated with specific object identities, then it will differ in these conditions. Thus, inhibition associated with a specific face identity will be more easily retrieved when the face can be recognised in the cue and target display in the upright-upright condition. In contrast, when the face is inverted in the cue or target display, recognition of the individual will be impaired, and hence IOR associated with the object identity will be impaired. In sum, the IOR when the object faces are unrecognisable will only be associated with the location and low-level object-file representations; whereas in the upright-upright condition when the object faces are recognisable, IOR will be associated with these representations, as well as object identity. Hence inhibition will be significantly larger in the upright-upright condition.

Since the methodologies of the three experiments of this chapter are virtually identical and between-experiments analyses will be made, the methods sections for the three experiments will be presented before an analysis and discussion is made of the resulting data.

General Methods

Experiment 6a (upright-upright)

Participants

Fourteen undergraduates from the University of Wales, Bangor participated for course credit (11 females, 3 males, mean age 18.9 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

Stimuli were male and female faces presented against a black background. Individual faces were enclosed in ellipses 8 degrees visual angle (va) wide by 10.5° va tall and were presented to the left and right of fixation with a lateral separation of 20° va. Faces were randomly paired male-male, male-female, female-female, and female-male. A total of 108 face-pairs were used (12 in the practice session and 96 in the main experiment). As a result of this paring, each participant would see the same pairs of faces but in random order and importantly the condition under which the faces were seen was randomised. That is, one participant could see one pair of faces in an invalid-left condition whereas another might see the exact same pair of faces but this time in a valid-right condition. In this way, the stimuli themselves could not cause any peculiar stimuli effects (such as one pair of faces being more salient or attentionally demanding than another perhaps). In the cue sequence, stimuli were presented in an upright orientation with the left face oriented 45 degrees counter-clockwise from vertical and the right face rotated 45 clockwise from vertical (see Figure 4.1). In the target sequence, the same two left and right faces were presented as in the cue except that they rotated 90 degrees clockwise and counter-clockwise respectively. Faces were cued by the brief appearance of a small red ellipse (5.5° va x 5° va) appearing over the still visible face. Likewise, targets were green semi-transparent ellipses again appearing over the still visible face.

A typical *cue* display in Experiment 6a with the faces in the upright orientation

A typical *target* display in Experiment 6a with the faces in the upright orientation

Figure 4.1 – showing an example of the stimuli used in Experiment 6a where the cue and target faces both appear in the upright orientation.

Procedure

Participants were seated in a darkened room 57cm from the display screen and were instructed to maintain fixation throughout the experiment and to respond if and when a green target appeared by pressing either a left or right target key on the keyboard for the corresponding target appearing on the screen (the response keys were marked with green stickers). If no target appeared, no response was to be made.

The main sequence of events in a typical trial is shown in Figure 4.2. Trials began with a blank (black) screen for 1000ms followed by a 100ms tone to indicate the start of a new trial. After a fixation screen of 1500ms a pre-cue pair of faces (with neither cue nor targets present) was presented for 1000ms. A semi-transparent red cue would then appear over one of the two faces for 100ms followed by the original (uncued) faces for 300ms. A 3000ms fixation screen was then presented before the target sequence began for which the same faces were re-presented re-oriented by 90 degrees (direction according to condition) for 500ms. A semi-transparent green target could then appear over one of the faces for 100ms before being replaced by the neutral faces for 300ms (see design section for catch trials). A 1000ms fixation screen replaced the neutral faces and participants had 1000ms from target offset to respond. If no response was made when one should have been (a target miss) or a response was made before target onset (anticipation) or made when one should not have been (false alarms), the trial was recorded as an error and the participant received a 200ms error tone and the trial ended. Participants were instructed that the appearance of a cue did not predict the subsequent appearance of a target in that or the other location. As noted, the inter-stimulus-interval between the offset of the cue face and the onset of the target faces was 3.8 seconds, longer than traditional IOR techniques which tend to be less than 3 seconds. In Chapter 2 it was shown that the number of items for which inhibition can be maintained matches those generally attributable to working memory tasks. The extended SOA in the three experiments presented here was introduced to build on this idea that inhibitory mechanisms can not only hold more items than is commonly believed, but also that inhibitory states can be held for longer periods of time also. This issue of maintaining inhibitory states for longer periods of time is examined in more detail in Chapter 5. Indeed, the fact that IOR can last over durations and items considered to generally be in the realm of working memory processes is one of the central themes of this thesis.

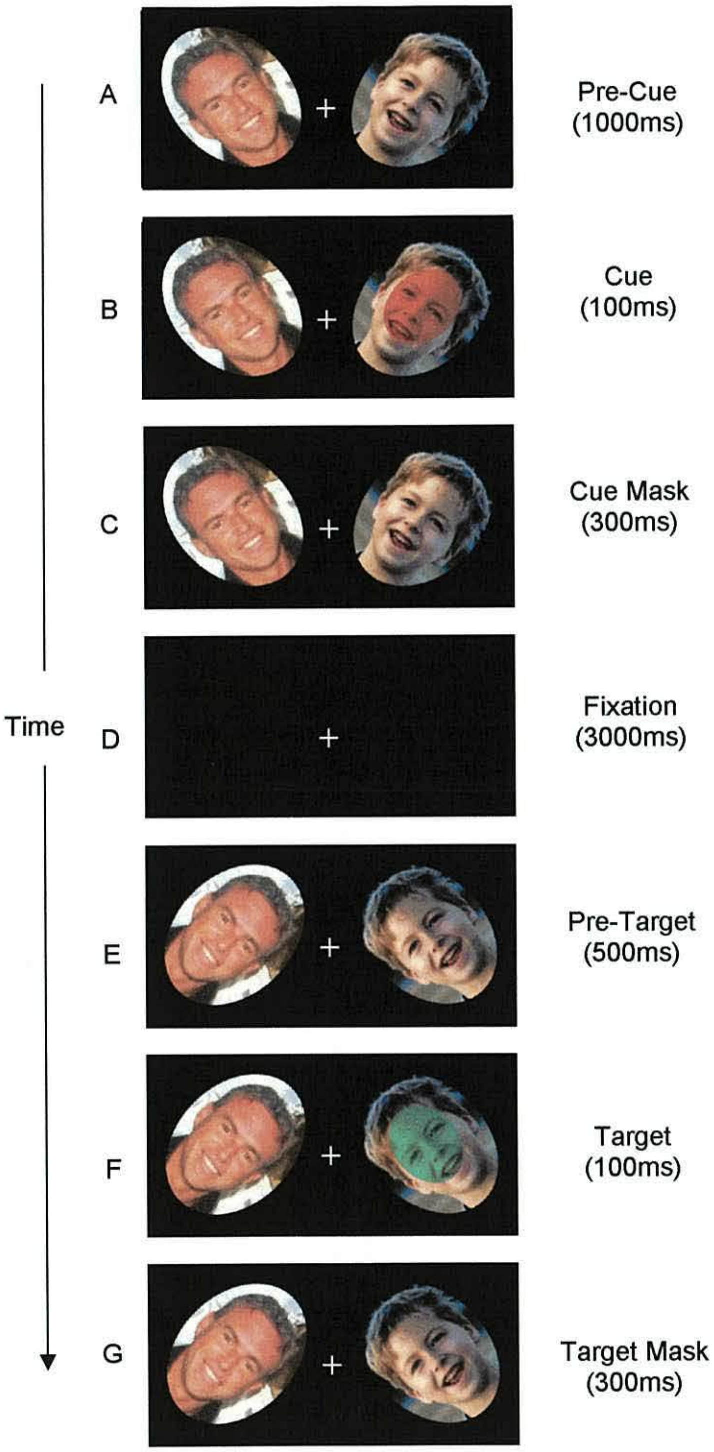


Figure 4.2 – showing the main sequence of events in a typical trial. The faces are presented for 1000ms (A). A red semi-transparent cue, which maintained the visibility of the face, was superimposed over the face for 100ms (B), and then the face was presented normally for 300ms (C). The screen then remained blank aside from the fixation cross for 3 sec (D). The same faces were then re-presented re-oriented by 90 degrees for 500ms (E). The green target, which was a semi-transparent green filter maintaining face identity, was presented for 100ms (F). Then the faces reverted to the normal display for 300ms (G). This example represents an Upright-Upright cued trial where the red cue and subsequent green target were presented over the same face. Participants were required to report the location of the green targets (left or right) by pressing an appropriate key on the keyboard as quickly as possible.

Design

There were 20 trials per condition (valid-left, invalid-left, valid-right, and invalid-right). Valid trials were ones where the cue and target appeared in the same location, invalid were ones where the target appeared on the opposite side to the cue. The standard IOR effect is observed when response to cued targets is slower than to uncued targets (valid to invalid). If an error was made on any trial it was recorded as an error and excluded from analysis.

To ensure processing of stimuli in both the cue and target sequences, two types of catch trial were introduced: an *early response* condition in which the green target appeared in the cue sequence and a *no-go* condition in which no target appeared and a red semi-transparent ellipse identical to that used in the cue was presented in the target sequence. There were 8 of each of the two types of catch trial counterbalanced for left and right faces. The total 96 trials were presented randomly. Participants performed a 12 trial practice session to familiarise themselves with the task after which the experimental trials began and lasted approximately 20 minutes.

Experiment 6b (inverted-upright)

Participants

Fourteen undergraduates from the University of Wales, Bangor participated for course credit (9 females, 5 males, mean age 19.9 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

The stimuli used were identical to those of Experiment 6a except that the cue faces were rotated 135 degrees from vertical so as to appear inverted (see Figure 4.3).

A typical *cue* display in Experiment 6b with the faces in the inverted orientation

A typical *target* display in Experiment 6b with the faces in the upright orientation

Figure 4.3 – showing an example of the stimuli used in Experiment 6b where the cue faces are inverted and the target faces are upright.

Procedure and Design

The procedure and design were identical to that of Experiment 6a.

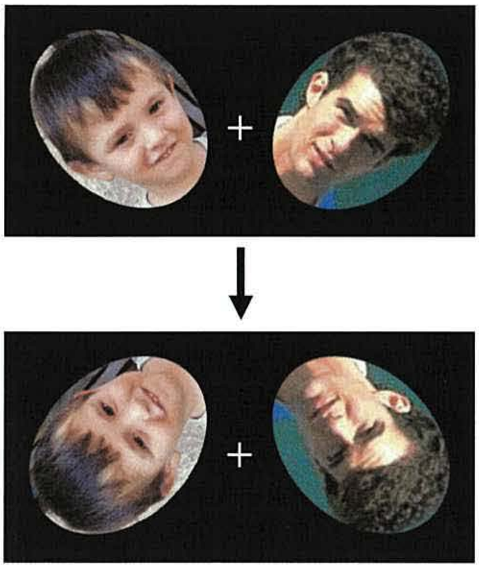
Experiment 6c (upright-inverted)

Participants

Fourteen undergraduates from the University of Wales, Bangor participated for course credit (11 females, 3 males, mean age 19.1 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness.

Apparatus and Stimuli

The stimuli used were identical to those of Experiment 6a except that the target faces were rotated 135 degrees from vertical so as to appear inverted (see Figure 4.4).



A typical *cue* display in Experiment 6c with the faces in the upright orientation

A typical *target* display in Experiment 6c with the faces in the inverted orientation

Figure 4.4 – showing an example of the stimuli used in Experiment 6c where the cue faces appear upright and the subsequent target faces appear inverted.

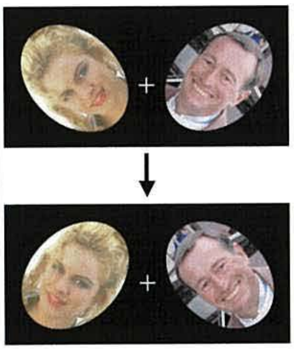
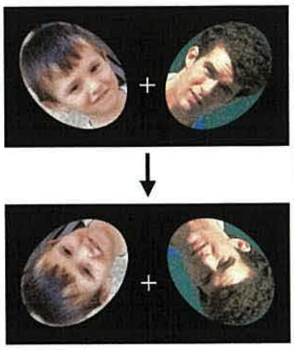
Procedure and Design

The procedure and design were identical to that of Experiment 6a.

General Results and Discussion

Table 4.1 below shows the mean reaction times (RT), standard deviation, errors, and actual IOR scores for Experiments 6a, 6b, and 6c. All data presented are for valid and invalid trials, catch trials were too few to warrant further analysis and are not discussed further. Trials on which errors occurred were excluded from analysis.

Table 4.1 – showing mean reaction times (RT, in milliseconds), standard deviation, percentage errors and actual IOR effect for cued and uncued trials for experiments 6a, 6b, and 6c. Errors are collapsed across the condition in which they (would have) occurred. Errors were: no response when there should have been one (a miss), a response when there should not have been one (false alarm) and, responding before the target onset (or no target for the invalid trials; anticipation).

	6a – Upright–Upright		**6b – Inverted–Upright**		**6c – Upright–Inverted**	
Cue **Target**						
	Uncued	**Cued**	**Uncued**	**Cued**	**Uncued**	**Cued**
Mean RT	369	410	395	418	411	433
Standard Deviation	44.41	51.13	72.26	67.72	46.93	56.04
% errors	2.86%	2.86%	0%	0.71%	0.71%	2.86%
IOR effect	**41**		**23**		**22**	

Side (left and right) was also included in the analyses but there were no significant main effects or interactions. Further, no predictions were made as to the effect of side and this variable is not discussed further.

Experiment 6a (upright-upright)

Analysis in a one way within-subjects ANOVA found a significant effect of cueing [$F(1, 13) = 75.5, p < .0001$].

Experiment 6b (inverted-upright)

Analysis in a one way within-subjects ANOVA found a significant effect of cueing [$F(1, 13) = 21.4$, $p < .001$].

Experiment 6c (upright-inverted)

Analysis in a one way within-subjects ANOVA found a significant effect of cueing [$F(1, 13) = 11.8$, $p < .01$].

Combined Analysis

When combining the three experiments, analysis in a mixed two-way 2 x 3 ANOVA [cueing (cued, uncued) x experiment (6a, 6b, 6c)] revealed a highly significant IOR effect [$F(1, 39) = 83.5$, $p < .0001$]. Of most importance, a significant interaction between target face orientation (Upright vs. Inverted) and IOR was also obtained [$F(2, 39) = 3.9$, $p < .05$]. In support of the specific object identity processing hypothesis, IOR was significantly larger when faces were upright, and hence could be easily recognised (41ms, upright-upright (Experiment 6a)); as compared to being inverted in the cue (22ms, inverted-upright (Experiment 6b)) or target (23ms, upright-inverted (Experiment 6c)).

Comparisons

Furthermore, supporting the notion that there was a difference between recognisable faces and unrecognisable faces, an analysis of experiment by cueing condition showed significant differences of Experiment 6a (upright-upright) to Experiment 6c (upright-inverted) [$F(1, 26) = 5.4$, $p < .05$] and Experiment 6a (upright-upright) to Experiment 6b (inverted-upright) [$F(1, 26) = 7.3$, $p < .05$]. However, and in line with the hypothesis, there was no difference between the two inverted conditions Experiment 6b (inverted-upright) and Experiment 6c (upright-inverted) [$F(1, 26) = .001$, ns].

Errors

Experiment 6c (upright-inverted) showed a significant main effect of cueing errors [$F(1, 13) = 8.5, p < .05$] supporting the hypothesis that not only was the task significantly different from the upright-upright task, but it was also more difficult. There were no other significant error effects or interactions.

Discussion

The results from these experiments are very interesting. Firstly, a significant effect of cueing (IOR) was found for all three face orientation conditions. This finding is interesting in itself in that for the first time, IOR has been obtained using a new experimental procedure using a unique set of face stimuli. Such a finding opens up a whole new area of investigation suggesting that perhaps IOR can now be examined with perhaps more ecologically valid stimuli, situations, and procedures, thus generalising the effect away from the laboratory setting. Furthermore, an extended SOA of nearly four seconds was utilised in an attempt to determine if inhibitory states can be maintained for lengths of time generally attributable to working memory. This hypothesis was supported.

The main focus of these experiments however has been the notion that IOR can be associated with the identity of an object. To restate the original hypothesis: If IOR were only associated with low-level representations of objects where object identity has not yet been computed, then IOR should be of equivalent size in the upright and both the inverted conditions. If, however, inhibition were associated with the specific identity of the object, then IOR will differ in these conditions because if recognition of the object were impaired, IOR associated with the object identity would also be impaired. The results presented here tentatively support this latter prediction.

Experiment 6a acted as a baseline with both the cue and target faces appearing in the upright orientation and thus recognisable. Experiment 6b showed that by inverting the cue faces but presenting the target faces in the upright orientation, the IOR effect diminished to nearly half that of baseline (23ms compared to 41ms). In this instance, the cue faces are inverted and difficult to recognise and as a result, difficult to encode to memory. The subsequent target attempts to recall the prior inhibitory state and has difficulty due to this *encoding* failure. Alternately, Experiment 6c showed that by keeping the cue faces upright and inverting the subsequent target faces, there was again a reduction in the amount of IOR shown when compared to baseline (22ms compared to 41ms). In this instance, the cue faces are upright and therefore more easily recognisable and more easily encoded. However, the subsequent target faces are inverted and difficult to compare to the cue faces and are therefore unassociated with the prior encoding of the cue suggesting a failure of *retrieval* (and thus reinstatement) of the prior inhibitory state.

An important point to note here is that the physical change on the retina between cue and target faces is equivalent across all three experiments where faces are re-oriented 90 degrees. That is, although faces may change orientation, the physical location of the cues and targets are always exactly the same (hence the same perceptual input to the retina). If it were simply the case that a purely location-based or spatial representation were being accessed where just the green target is identified (and thus not encoding the identity of the underlying object), then there should be no difference between face orientation conditions. This is clearly not the case – there is a strong effect of face orientation.

It should be noted however that inverting the face in the cue or target introduces an element of change from the upright-upright baseline experiment. Such an inversion is known as the Face Inversion Effect (FIE) and is believed to show a detriment in the encoding of inverted faces (Rossion & Gauthier, 2002; Yin, 1969) but others have argued against this conclusion (see Valentine, 1988). Again though, if a spatial based frame of references were utilised where the detection of a simple green oval (the target) were employed, why would the underlying face orientation need to be processed? Clearly these issues are of interest and worthy of further research.

Inhibition acting on an object links to the issue of encoding and retrieval that was touched upon in Chapter 3 (Experiment 4b). That is, not only might the most recent attentional processes associated with an object be active upon its retrieval upon a probe event (the target), but also that the *entire* processing episode might be retrieved. Such an episode would contain the attentional state of the entire attentional network. For instance, in the upright-inverted condition (Experiment 6c), even though inhibition might be associated with a recognizable face, when the target is presented the face cannot be easily recognized due to its inverted orientation (certainly not in the 500ms before target presentation). Therefore although inhibition might be associated with face identity, there is a failure of retrieval of this processing episode. The implications for identity-based inhibition upon the possibility of retrieval of inhibitory states are significant. For example, as observed in studies of negative priming, it is possible for long-term retrieval effects to be produced (DeSchepper & Treisman, 1996) whereby the prior inhibitory state can be reinstated after a substantial amount of time has passed. Clearly, such long-term retrieval is beyond the realm of working memory. The findings presented in this chapter certainly suggest that such a line of investigation of long-term retrieval would be very worthwhile in the IOR paradigm.

The present findings may also have implications for neurophysiology studies. A number of different research approaches have confirmed that IOR is mediated by the superior colliculus (SC; Rafal et al., 1989). For example, IOR is abolished by damage to the SC (Posner et al.,1985; Sapir et al., 1999). However, the current observations demonstrate that IOR cannot be solely mediated by this mid-brain structure. The encoding of faces requires sophisticated analysis in cortical structures such as the fusiform gyrus (Kanwisher, 1998), and the data presented here indicate that the observation of inhibition is dependent on such processes.

The present results, when combined with the tentative conclusions of Chapter 3 and results of similar studies of negative priming showing inhibition being associated with objects, provide converging evidence that objects do not merely act as spatial reference points, rather, the identity of an object itself might be associated with inhibition. This lends support to the notion that such inhibitory mechanisms are accessing higher-order processes (such as identity) and not merely acting on low-order processes such as common fate, perceptual salience etc as is generally believed.

Future studies: episodic retrieval issues

One criticism of the interpretation of the data presented here is that the effects could be attributable to an episodic retrieval account (or a conflict in response retrieval). For example, when the left face is presented with the red mask (the cue) attention is drawn to that spatial location and the instruction "do not press the left button" is part of the encoded episodic trace. If the target were subsequently presented in the same location, there would be a conflict between the required left response and the episodically retrieved "do not press the left button" trace. As a result there would be a slowing of responses in this way. However, the green cues and red target colours are yoked to an attentional state, not a response per se, just as Posner and Cohen's (1984) original design with bright outlines and asterisks' as targets are associated with an attentional state, not with a response. One possible approach to control for this in a future experiment would be to change the response dimension by simply having a single key press response to all targets rather than differentiating left and right.

Future studies: perceptual mismatch issues

The same logic would hold true for response mismatch accounts based on the colour change between cue and target. That is, one could argue that there is a perceptual mismatch between cue and target in that the cue face is overlaid with a red cue mask and in the subsequent target the same face is re-presented with a green target mask (see Park & Kanwisher, 1994; Tipper, Weaver, & Milliken, 1995). In this instance, when the face is recalled between cue and target, it could be argued that there is a perceptual mismatch because the same face was earlier associated with a different colour mask (and therefore different response dimension). However, this issue could also be addressed in a future study where there is no perceptual mismatch between cue and target. That is, participants could be presented with a colour signal before the onset of each cue/target sequence (i.e. which colour to respond to in this instance only). Therefore, in this new design, the cue could be associated with a red "do not respond" tag and then in the subsequent target with a red "respond" tag.

Future studies: generalising the identity effect

If it is true that object identity is important in the encoding and retrieval of prior inhibitory states, then it should be possible to show the effect using a slightly modified design where the faces remain upright but switch position. That is, if both the left and right faces in the cue display were presented upright and then in the subsequent probe display, they remained upright but switched positions, there should also be a reduction of IOR compared to a control condition where the faces remained the same.

Future studies: temporal dimensions of IOR

As was outlined in the methods section, an extended SOA was used to determine if inhibitory states could be maintained for longer than is generally assumed. While this was shown to be supported, it may be the case that the resulting IOR effects are weaker than would be the case in a more traditional IOR paradigm with a shorter SOA. As was seen in Chapter 2 (see also, Snyder & Kingstone, 2000), there was a generally linear decline in the number of items with which inhibition could be associated. That is, the further back from the target onset, the weaker the IOR effect. Of course, correlated to the number of items presented is also of course the SOA between cue and target. So in the experiments of Chapter 2 for example, the SOA between cue and target in the 1-back condition was 600ms whereas it was 3700ms for the 6-back condition. It would follow then that not only would there be a linear decline in the number of items being held in memory, but also a limit on the amount of time an item can be held in memory if a more traditional IOR paradigm with the usual 1-back design were used. Therefore, in the studies presented here in Chapter 4, it could be argued that perhaps the effects are actually weaker than would be the case if a more traditional SOA were used. This issue could be easily explored in an extension of the data presented here. It may be the case however that encoding of higher levels of representations requires a longer time. That is, if it is indeed the case that using more realistic stimuli accesses higher level representation (and previous studies might therefore be accessing low-level representations), then this in turn might necessitate a longer time for such higher level encoding to take place. Again, this is an issue that could be the work of future research.

Summary

The present chapter examined the idea that IOR can be associated with the identity of an object. Firstly, IOR was established in a new experimental design using face stimuli rather than the traditional grey boxes (Experiment 6a). Secondly, two further experiments showed how making the identity of the object (the face) unrecognisable between cue and target (Experiment 6b) or target and cue (Experiment 6c), reduces IOR by nearly 50% compared to a baseline where the identity of the object is clear in both cue and target. The result of these two latter experiments suggests that inhibition of object identity requires that the later target stimulus *match* the earlier cue stimulus. As a result of this match, the target reactivates the prior inhibitory states associated with the earlier cue. These preliminary findings, presented here for the first time, support the notion that inhibition can be associated with the identity of an object and as such, it is reasonable to assume that IOR might is be accessing higher-level representations.

Chapter Five

Modulation of inhibitory mechanisms via interference techniques

Abstract

Chapter 5 presents two experiments that seek to further investigate the frame of reference mediating IOR. Using the basic paradigm of Chapter 4 (where faces were used as objects with which inhibition could become associated), an intervening lexical or spatial decision task was introduced between the cue and target face sequences. By observing the resulting effects that the intervening task would have on the maintenance of IOR, the representation mediating such mechanisms could be discovered. It was proposed that the introduction of a spatial intervening task (Experiment 7a) would disrupt spatial based IOR whereas identity based IOR would be disrupted by the lexical decision intervening task (Experiment 7b). Results from the two experiments support the notion that IOR is mediated by spatial representations in this particular task. Furthermore, these experiments also showed IOR lasting for over 11 seconds, much longer than is traditionally supposed.

Modulation of inhibitory mechanisms via interference techniques

In this chapter a new technique to investigate the frames of reference mediating inhibitory mechanism is described. Previous studies as well as the work presented in this thesis have already argued that IOR is mediated by both spatial- and object-based representations. Thus inhibition of both an attended location *and* object has been confirmed here and elsewhere (e.g., Tipper et al, 1994). As was briefly mentioned in the introduction to this thesis, there is strong anatomical data for the dissociation of these two forms of internal representation. As proposed by Ungerleider and Mishkin (1982), it is believed that visual information is projected via a common pathway to the occipital lobe in a region of the striate cortex know as V1. From V1 onwards, there are two independent routes. One, a dorsal magnocellular pathway, projecting to the parietal cortex via V5 in the occipital lobe is believed to process spatial location ("where" an object is). The other, a ventral parvocellualr pathway projects to the temporal cortex via V4 is believed to process object identity ("what" an object is).

In studies of working memory (WM), interference procedures have been extensively employed to investigate these different forms of internal representation. The basic premise is that if a stimulus interferes with maintenance of information in WM then this is because they have overlapping neural representations. In contrast, if a stimulus does not interfere, then its representations are different to those mediating working memory. For example, a study by Brooks (1968) demonstrates the logic of this approach. In this experiment participants were presented with a block letter F and were required to move around a mental image of this letter and report "yes" if the corners were at the bottom or top of the letter, or a "no" responses otherwise. The critical feature of this experiment was the method of reporting "yes" or "no". In one condition participants pointed to the response "yes" or "no" randomly scattered on a page, and in another condition they verbally reported "yes" or "no". Only in the former pointing condition was performance impaired. This suggested that the image of the letter F was maintained in a visual-spatial form, as the spatial response of pointing interfered with its maintenance.

A number of other studies have employed such interference techniques, and recent work has distinguished between visual and spatial memory. The former is concerned with encoding and maintaining perceptual properties of a stimulus related to identity, while the latter is concerned with the spatial location of a stimulus. For example, Tresch, Sinnamon, & Seamon (1993) demonstrated that object memory was selectively impaired by a colour discrimination object interference task, whereas spatial memory was selectively impaired by a movement discrimination spatial task (see also Baddeley & Liebberman, 1980; Logie & Marchetti, 1991).

Other converging approaches have also confirmed visual (object/identity) and spatial forms of visual memory. For example, neural activation while undertaking visual or spatial working memory tasks, as measured via positron emission topography (PET), has revealed different neural systems mediating these forms of memory. Thus during spatial memory right-hemisphere activity in occipital, parietal, and prefrontal areas was observed whereas left inferior frontal and parietal activation was observed in object tasks (Smith et al., 1995). Further neuroanatomical evidence comes from studies using event related potential studies (ERP) with WM interference techniques which have shown that object identity and object location are separately rehearsed and retrieved from WM (Mecklinger & Meinshausen, 1998).

Studies of patients with brain injury have also demonstrated that these two forms of working memory can be dissociated. For example, Farah, Hammond, Levine, and Calvanio (1988) described a neuropsychological patient who was unable to report visual properties of named objects but showed normal performance in tasks requiring report of spatial location. The patient had damage to the right temporal lobe and the right inferior frontal lobe (and damage to the temporo-occipital regions of both hemispheres – areas believed to be associated with object identity processing. Hanley, Pearson, and Young (1990) reported the opposite dissociation, namely a patient with deficits in spatial processing (due to a right hemisphere aneurysm) while visual object recognition was unimpaired. Double dissociations such as these give strong support to the functional autonomous nature of these two systems.

These two streams of processing of "what" (identity) and "where" (location) are the central focus of this chapter, in terms of identity- and location-based IOR. The experiments in this chapter adapt this approach to investigate IOR by presenting a task intervening between the cue and target displays. Tasks that interfere with the maintenance of inhibitory states may be assumed to have similar internal representations, and be employing the same neural systems or resources mediating IOR. Tasks that do not interfere can be assumed to be accessing different neural networks.

The new methods described in the previous chapter will be used in these experiments. The inverted/upright face experiments (experiments 6a, 6b & 6c) have provided evidence that inhibition might be associated with the identity of a stimulus, therefore such stimuli are useful for investigating the effect of intervening tasks on IOR effects. Because of the design of these new studies necessitating the insertion of an intervening task, the interval between cue and target display is extended to over 11 seconds. This is much longer than the 3.8 seconds of Experiments 6a, 6b, and 6c. Furthermore, this interval is far longer than previous published studies of IOR, which have tended to test intervals of only a few seconds. Therefore it is not known whether any IOR effects will be observed over this long interval, or what form IOR will survive in. That is, whether spatial- or identity-based inhibition will be observed.

The intervening tasks in these studies are either object identification (Experiment 7a) or object spatial localisation (Experiment 7b). Exactly the same stimuli (words or non-words) are presented as the intervening task, but one group of participants make a lexical decision (identity task), while a second group report whether the word was above or below the centre of the screen (spatial task). How the identity and spatial intervening tasks affect IOR enables one to infer the frame-of-reference within which the inhibition is mediated over this extended interval of 11 seconds. Thus lexical decision and face recognition, although clearly not identical computations, both take place in the ventral (temporal) stream and would interfere with inhibitory mechanisms if they were accessing an identity-based representation. In contrast, report of spatial location will be computed through the dorsal (parietal) stream and would interfere with location-based inhibitory mechanisms. The following are the various patterns of data that are possible, depending on the internal representations mediating inhibition in this task.

Panel A of Figure 5.1 (below) shows the predicted pattern of IOR if it were *only* mediated by identity based inhibition. When the intervening task is a lexical decision, this object processing task should interfere with the maintenance of identity-based IOR. As there is no location-based IOR, no effects should be observed in either the upright-upright or upright-inverted conditions. In contrast, when the intervening task is spatial, then the upright condition, where face identity is encoded, should produce identity-based IOR; whereas the inverted condition, where identity cannot be easily accessed, should show little IOR as was seen in Chapter 4.

Panel B represents the situation where IOR is mediated solely by a spatial or location frame-of-reference. In this situation IOR will be obtained in the lexical decision intervening task as this should not interfere with spatial representations, and this should be equivalent for upright and inverted faces as there is no identity-based IOR. In sharp contrast, location-based IOR will be disrupted by the spatial decision task, and so no effects should be observed.

Panel C represents the predicted pattern of IOR effects if both location- and identity-based IOR exists over this relative long cue-to-target interval. In this situation IOR will be observed in the lexical decision tasks due to spatial-based effects. There will be no differences between upright and inverted faces, because the lexical decision task will have disrupted these identity-based effects. In contrast, when undertaking the spatial intervening tasks, IOR will still be observed in the upright condition, mediated by the identity of the objects. But no effects will be observed in the inverted condition, because the spatial task will disrupt spatial IOR and there is no identity information to support identity-based effects.

These experiments are the first to use intervening tasks as a means of identifying the internal representations mediating IOR in various situations. Definitive results are not expected, rather, these new experiments must be considered exploratory in the development of new approaches to studying such inhibitory processes in attention.

The general methods used for the experiments of this chapter will be discussed first before moving onto the individual experiments in more detail.

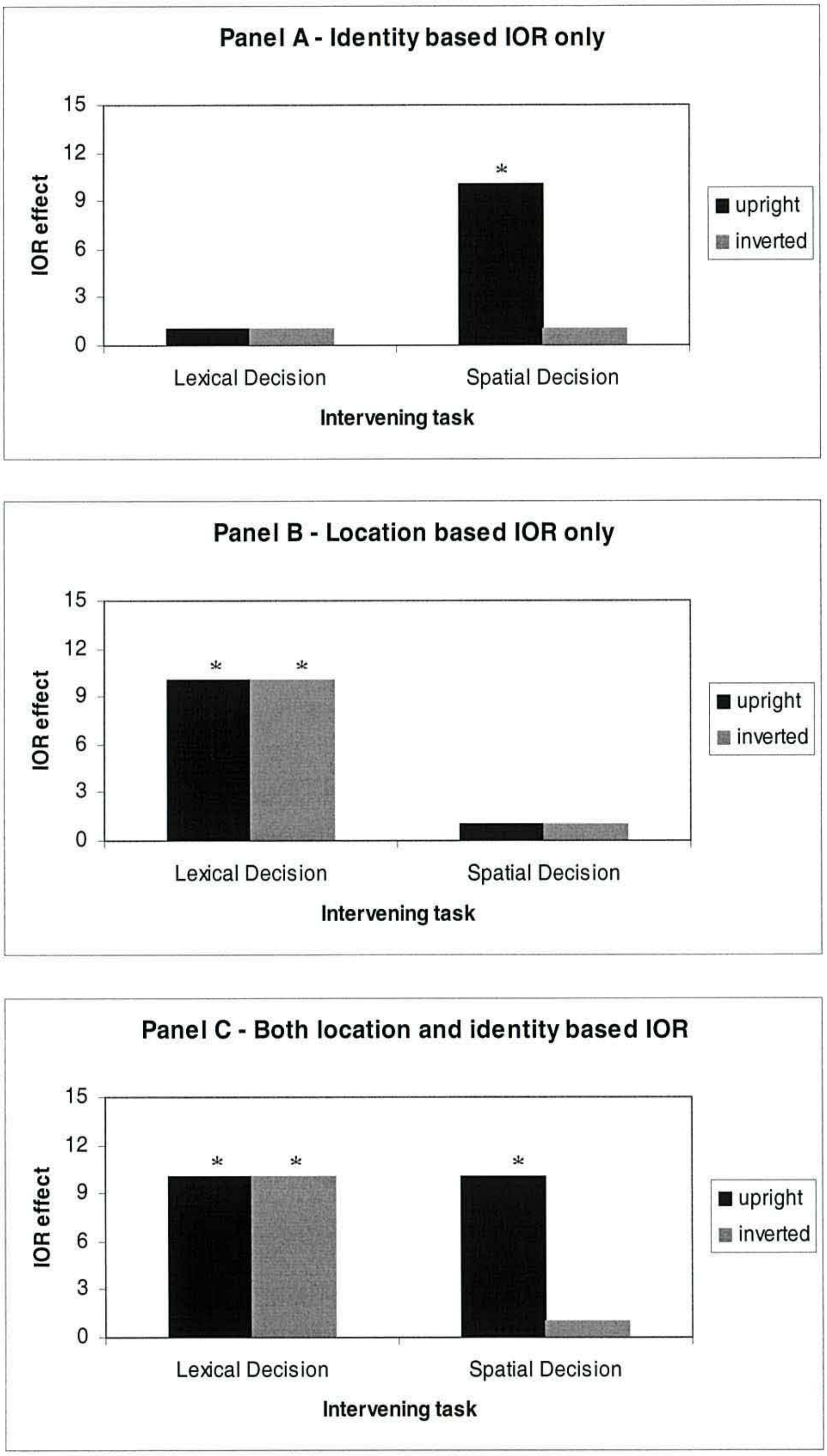


Figure 5.1 – showing the predictions for the present experiments. Panel A shows the predicted results for identity-based IOR only, Panel B, the predicted results for spatial-based IOR only, and Panel C, the predictions for combined identity- and location-based IOR. Bars marked with an asterisk show predicted significant main effects.

General Methods

Apparatus and Stimuli

The stimuli were the same male and female faces as used for Experiments 6a and 6c. In addition to the pre-established face task, an intervening word task was implemented. A total of 48 lexically legal words were selected randomly from a database of words of 5-8 characters in length (taken from the MRC psycholinguistic database, 1987). Words were matched and controlled for familiarity and frequency of use in the English language. A non-word / pseudo-word generator was then used to convert the 48 legal words into non-words (Pseudo, 2000). The resulting 96 individual words (48 legal and 48 non-legal) were randomly assigned to one of the 96 trials of the individual experiments.

Words and non-words were presented individually around the fixation point on the screen (which was absent during the actual word task part of the trial). That is, the words could appear slightly above or below where the fixation point would have been were it present as well as slightly to the left or right (a total of 18 counterbalanced locations were possible).

Procedure

Figure 5.3 (below) shows the full procedure for the two experiments presented in this chapter. The general procedure was identical to that of experiments 6a and 6c but with the addition of the intervening word task which was placed between the cue and target face sequences. After the cue faces sequence had been completed, a reminder screen that the next part of the trial was the word task was presented for 2000ms (see Panel B of Figure 5.2 below). A black screen was then presented for 1500ms after which a single word or non-word appeared toward the centre of the screen for 1000ms (participants were instructed to respond ‘word’ or ‘non-word’ (Experiment 7a) or “above centre of the screen” or “below centre of the screen” (Experiment 7b) by pressing appropriate keys which were labelled on the keyboard. The (non)word then disappeared and was replaced by a black screen for 1500ms. A reminder screen that the face sequence (in this case the target face sequence) was about to begin was then presented for 2000ms (see Panel C of Figure 5.2 below). A 1500ms black screen was then presented followed by a fixation screen with the small white fixation cross in place for 1500ms. The target sequence then continued exactly as in Experiments 6a and 6c with the pre-target faces appearing for 500ms followed by the target for 100ms and then the post-target faces for 300ms. Finally, a 1000ms fixation screen then appeared and the trial ended.

Participants initiated the start of each trial by pressing a key on the keyboard and were presented with a reminder screen to do so (see Panel A of Figure 5.2 below).

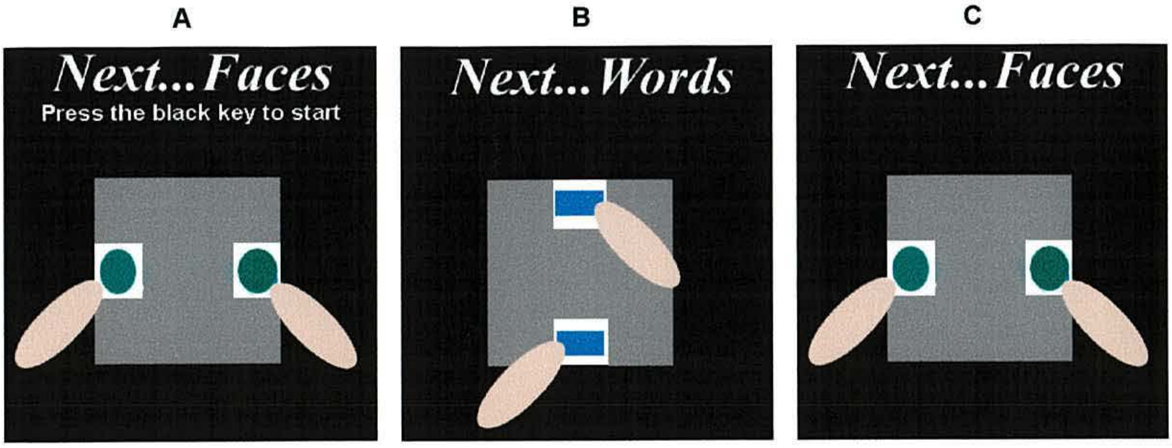


Figure 5.2 – showing the reminder screens that were shown to the participants in the current experiments. The trial start screen is shown in panel A while reminders for the intervening word task and the subsequent face task are shown in panel B and C respectively. These screens served as a reminder as to the position that the participant's responding fingers should be in.

As noted, brief reminders were presented for 2 seconds before the intervening task began and again for 2 seconds before the target sequence began. This served as a reminder to the participant that the next part of the trial required a different response and that they were to move their fingers into the appropriate response position (for faces, participants responded 'left' or 'right' according to which face was targeted (if at all); whereas for the word task they responded 'up' for word and 'down' for non-word in Experiment 7a and "up" for above centre of the screen and "down" for below centre of the screen for Experiment 7b). The response keys were arranged so as to be spatially congruent to the response to be made (see Figure 5.2 above).

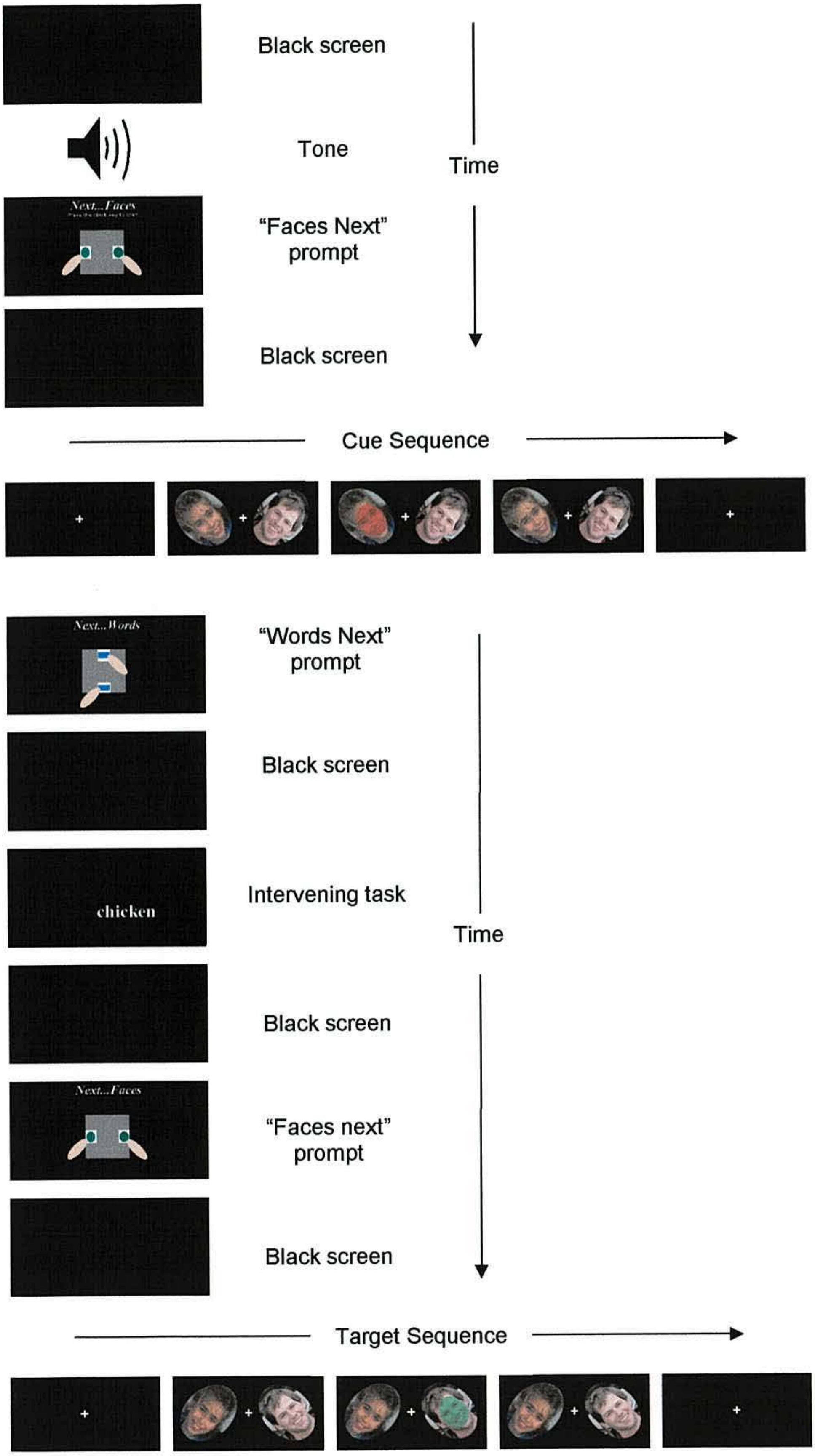


Figure 5.3 – Showing the main procedure for the Experiments 7a and 7b.

Design

The experimental design was identical to that of experiments 6a and 6c. However, by inserting the word task between the cue and target sequences, the inter-stimulus-interval between the presentation of the cue and target faces is now 11.4 seconds as opposed to the 3.8 seconds of experiments 6a and 6c.

Experiment 7a – lexical intervening task

Participants

Twenty-eight undergraduates from the University of Wales, Bangor participated for course credit (26 females, 2 males, mean age 21.9 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness. Fourteen participants were randomly assigned to each experimental group (upright-upright or upright-inverted).

Apparatus, Stimuli, Procedure & Design

Experiment 7a used the same face cueing procedure as that of Experimenting 6a and 6c. Half of the participants were presented with faces that were upright in the cue and upright in the target (as in Experiment 6a). The other half of the participants were presented with faces that were upright in the cue and inverted in the target (as in Experiment 6c). The intervening word task was a lexical decision where participants had to determine if the word string presented near the centre of the screen were a real or non-word.

Experiment 7b – spatial intervening task

Participants

Twenty-eight undergraduates from the University of Wales, Bangor participated for course credit (26 females, 2 males, mean age 19.2 years). All participants had normal or corrected-to-normal visual acuity and no colour blindness. Fourteen participants were randomly assigned to each experimental group (upright-upright or upright-inverted).

Apparatus, Stimuli, Procedure & Design

Experiment 7b used exactly the same procedure as Experiment 7a except that the intervening word task was a spatial decision where participants had to determine if the word string was above or below the centre of the screen.

Results

Table 5.1 (below) shows the mean reaction times (RT), standard deviation (S.D.), errors, and actual IOR scores for experiments 7a and 7b. All data presented are for valid and invalid trials, catch trials were too few to warrant further analysis and are not discussed further. Trials on which errors occurred were excluded from analysis (all errors were non-significant). Figure 5.4 shows the actual IOR effect for the two experiments.

Table 5.1 – showing mean reaction times (RT, in milliseconds), standard deviation (S.D.), percentage errors and actual IOR effect for cued and uncued trials for experiments 7a and 7b. Errors are collapsed across the condition in which they (would have) occurred. Errors were: no response when there should have been one (a miss), a response when there should not have been one (false alarm) and, responding before the target onset (or no target for the invalid trials; anticipation).

	Experiment 7a – lexical word task				Experiment 7b – spatial word task			
	Upright-Upright		Upright-Inverted		Upright-Upright		Upright-Inverted	
Cue								
Inter-task	Lexical		Lexical		Spatial		Spatial	
Target								
	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued
Mean RT	354	362	361	374	384	386	404	404
S.D.	31	36	28	27	41	41	55	52
% errors	2.68%	0.89%	0.54%	0.71%	0.71%	1.43%	0.36%	0.54%
IOR effect	8		13		2		0	

As with the experiments of Chapter 4, side (left and right) was also included in the analyses but again, since there were no significant effects or interactions, is not discussed further.

Experiment 7a – lexical task

For the upright-upright target face condition, analysis in a one way within-subjects ANOVA found a significant effect of cueing [$F(1, 13) = 7.2, p < .02$] with the cued condition being longer than the uncued condition (362ms and 354ms respectively).

For the upright-inverted target face condition, analysis in a one way within-subjects ANOVA found a significant effect of cueing [*F*(1, 13) = 8.2, p < .02] with the cued condition being longer than the uncued condition (374ms and 361ms respectively).

A combined analysis of face orientation (upright-upright vs. upright-inverted) was also undertaken for this lexical task which showed a significant effect of cueing [*F*(1, 1) = 15.0, *p* < .001] but interestingly no interaction of cueing by face orientation [*F*(1, 26) = 0.6, ns].

Experiment 7b – spatial task

For the upright-upright target face condition, analysis in a one way within-subjects ANOVA found *no* significant effect of cueing [*F*(1, 13) = 0.1, ns] with the cued condition being only slightly longer than the uncued condition (386ms and 384ms respectively).

For the upright-inverted target face condition, analysis in a one way within-subjects ANOVA found *no* significant effect of cueing [*F*(1, 13) = 0.0, ns] with the cued condition being identical to uncued condition (404ms).

A combined analysis of face orientation (upright-upright vs. upright-inverted) was also undertaken for this spatial task which showed no significant results.

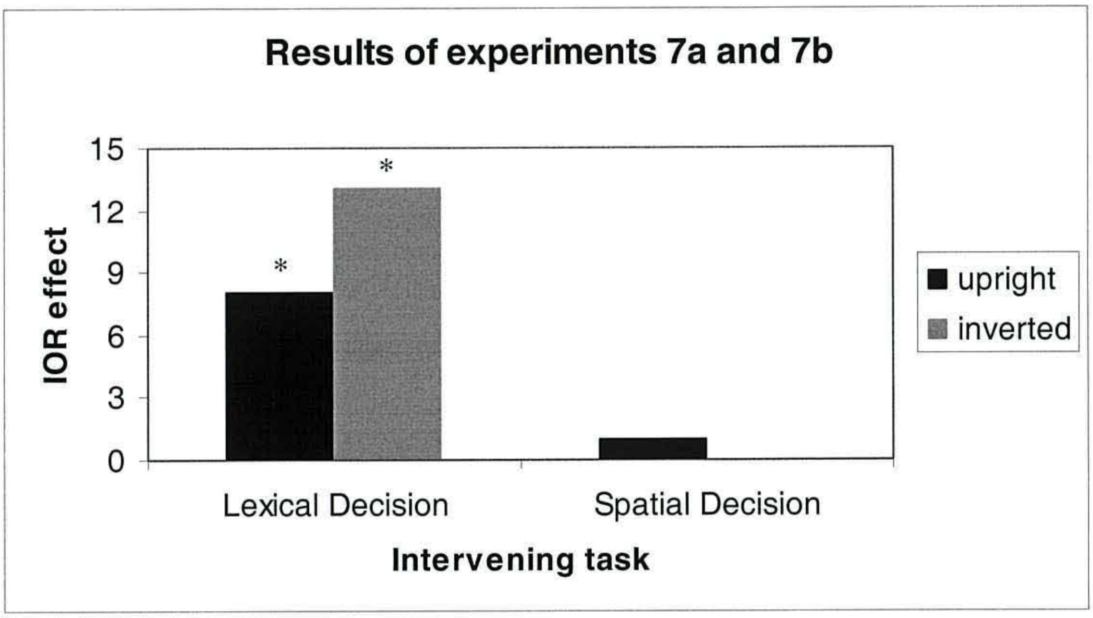


Figure 5.4 – showing the actual IOR effects for experiments 7a and 7b (bars marked with an asterisk denote statistical significance, *$p < .05$).

Combined analysis

To confirm the contrast between tasks where IOR was observed in the lexical decision but not in the spatial task, a combined analysis of Experiment 7a and 7b was undertaken which showed a significant effect of experiment (lexical vs. spatial) [$F(1, 1) = 10.3, p < .005$], cueing [$F(1, 1) = 7.7, p < .01$] and importantly, a significant interaction of cueing and experiment [$F(1, 1) = 6.0, p < .02$].

Analysis of intervening task

Individual analysis of the spatial and lexical intervening tasks showed no main effects or interactions. A combined analysis of the type of intervening task (lexical vs. spatial) showed a main effect with response times to the lexical task (718ms) being slower than the those to the spatial task (584ms) [$F(1, 53) = 71.41, p < .0001$].

General Discussion

The two experiments presented in this chapter have been a first attempt to use intervening tasks as a means of inferring the internal representations mediating IOR. This type of technique has been extensively employed in studies of working memory to dissociate memory for object-identity from memory for spatial location and such dissociation has indeed been found. To restate the original hypothesis: if inhibitory mechanisms are accessing a spatial based frame of reference, then the introduction of a spatial interference technique would obliterate memory of prior inhibitory states as shown in a decrease of the IOR effect. Conversely, if an object-based frame-of-reference were being accessed, then an object identity interference technique would disrupt the IOR effect. The results are relatively clear. Compare Figure 5.4 with the various predictions represented in Figure 5.1, panels A, B, and C. It is obvious that the obtained pattern of results is most similar to that of Panel B of Figure 5.1. Such a result demonstrates that the lexical decision task was unaffected (as demonstrated by the IOR effect being maintained in this task) whereas IOR in the spatial decision task was obliterated (it should also be noted that the lexical intervening task was significantly more difficult than the spatial intervening task adding further support to this notion). Therefore we can conclude that in this particular task, IOR is predominantly mediated by a spatial frame-of-reference. That is, attention is inhibited from returning to a spatial location, independent of the form of object presented there.

While the lexical decision showed no interference in the maintenance of inhibitory states, there also was no apparent effect of object identity. That is, there was no difference between the upright-upright and upright-inverted face condition. This is in direct contrast with the results observed in Experiments 6a and 6c described in Chapter 4 where there was a strong difference for upright-upright versus upright-inverted faces albeit with a shorter SOA. The decline in identity-based IOR shown in this chapter is perhaps due to the much longer interval between cue and target of over 11 seconds, perhaps suggesting that identity-based effects might not be maintained for this long whereas location-based effects might.

One point to note here is that, as mentioned, the SOA between cue and target was extended to over 11 seconds – this is the first time that traditionally-short-lived IOR effects have been demonstrated at such an extended cue-target SOA. While the purpose of these interference studies was to examine how inhibitory states might be maintained or disrupted, a control study where there is no interfering task and simply an extended SOA would be worthwhile to investigate the temporal limits of these IOR effects.

Summary

The experiments presented in this chapter tested a new procedure and technique for investigating the frames of reference mediating IOR. Using an intervening interference technique established in the working memory literature, the present chapter sought to investigate the frame of reference mediating inhibitory mechanisms as demonstrated by the IOR effect. A similar methodology as that of Chapter 4 was used where faces were presented in the upright and inverted orientations. In the present experiments however, an intervening lexical or spatial decision task was introduced between the cue and target face sequences. It was argued that a disruption of spatial representations (by the spatial intervening task) would abolish IOR whereas disruption of identity based representations (by the lexical intervening task) would not abolish IOR. This hypothesis was supported – IOR was found in the lexical but not the spatial task (that is, the spatial task abolished IOR). Not only does this result support the notion that IOR is mediated (in this instance) by spatial representations, but IOR was also found to last for over 11 seconds – a unique finding in itself.

General discussion

General Discussion

This thesis has described 11 experiments that have been concerned with the inhibitory mechanisms of attention that mediate search. Thus to efficiently search an environment for a target object, it is critical that attention does not perseverate and continually return to previously examined locations and objects. Inhibition seems to be an important and automatic mechanism that prevents this return of attention. As reviewed in the introduction, a critical issue that has been vigorously debated concerns the frame-of reference within which IOR functions. That is, whether attention is inhibited from returning to a spatial location, as originally proposed by Posner and Cohen (1984); or whether attention is inhibited from returning to objects, as originally proposed by Tipper et al (1991). The consensus view now seems to be that both location- and object-based IOR exist, although they may be determined by tasks demands.

If this inhibition is to be of use in search tasks, then it makes sense that more than one location or object should be inhibited. Although some researchers suggested that inhibition was a limited mechanism only applied to one location (Pratt & Abrams, 1995); or more extremely that there is no prior memory for previous places searched (Horowitz and Wolfe, 1998) the 6 experiments described in Chapters 2 and 3 confirmed that inhibition is present for more than one location.

These studies also investigated the role of objects in the maintenance of inhibition confirming previous ideas (e.g., Tipper et al., 1994) that when objects are inhibited the memory for the inhibition appears to be a little more stable. Thus in such serial cueing tasks, inhibition at the more distant points in time of 4- to 6-back cueing was only observed when objects were cued. However, there does seem to be an invariant limit to this inhibition as attempts to get more robust effects at these more distant points in time by presenting unique objects on every trial (Experiment 4a) failed. Thus like other studies of working memory, the limit seems to be around 4 or 5 items, with effects occasionally glimpsed at 6 items.

A further issue engaged in these experiments concerned the processes mediating these object-based effects. Two ideas were proposed. First, object representations are inhibited, and when the same object has to be subsequently re-processed, the inhibition associated with its representation slows down analysis. Similar ideas have been developed to account for the inhibitory processes revealed via negative priming procedures (see Tipper, 2001, for review). The second, and alternative explanation, is that the object-based representations themselves are not inhibited. Rather, objects, as compared to empty featureless environments, provide spatial landmarks. Thus objects divide space into meaningful structure, which facilitates the memory for *where* an event took place.

Experiment 5 tested this latter location-marker hypothesis. Markers were placed on the screen adjacent to where cues and targets were always presented. Importantly, objects were never cued, so inhibition was not associated with objects. Nevertheless, the IOR effects in this condition were equivalent to those observed when objects were cued (Experiment 1). Therefore it seems that much of the increased IOR effect when objects are cued is not caused by inhibition of object-based representations, but is due to the objects providing stronger location cues.

However, the data from Experiment 4b provided some, although not strong, evidence for the alternative hypothesis that object-based representations are associated with inhibition. In this study unique complex objects were presented on every trial. However, they were flashed briefly for 100ms, just as in the no object condition of Experiment 2 where grey squares were flashed. The rationale behind this experiment was that the object's identity would be associated with inhibition. Thus when that object was re-presented as the target, there would be some retrieval of this prior inhibition, and hence response times would be slowed. Indeed, in this study a significant effect was observed at the more distant point in time at 5-back cueing (similar to the effect observed in Experiment 4a).

Although not strong evidence, these findings lead to the tentative suggestion that there are two mechanisms mediating object-based IOR. Objects act as landmarks, facilitating the maintenance of spatial-based inhibition, and objects themselves can be associated with inhibition. The experiments in Chapter 4 were an attempt to test this latter idea that objects are inhibited, by developing a new paradigm. In these studies faces were used because they have the unique property that identification is seriously impaired when faces are inverted.

The prediction was that if the identity of a cued face was associated with inhibition, then impairing identification during cueing or retrieval while responding to the target, would reduce the level of inhibition. That is, in the former case IOR would be associated with various representations such as location, object files, plus object identity. Assuming additive effects of inhibition with these various forms of representation (as argued by Jordan & Tipper, 1998) the IOR effect would be larger when identity is encoded and subsequently inhibited.

The results described in Chapter 4, while preliminary in their findings, suggest that IOR might be associated with the identity of an object. Thus when object identity could be encoded in the cue and target display, IOR was larger than when faces were inverted during encoding of the cue or when inverted during processing of the target. Hence these data provide converging evidence to support the conclusion tentatively drawn from experiment 4b: increased inhibition when objects are cued is not solely due to objects providing spatial landmarks. Rather, an object's identity might also be associated with inhibition.

Finally, in Chapter 5 a new technique was examined. In these studies the effects of a concurrent task upon IOR effects was investigated. Such interference paradigms have been extensively investigated in studies of working memory, and it was felt that such approaches may help identify the representations mediating IOR. The results were relatively clear. It appears that in this particular task where the interval between cue and target was over 11 seconds, inhibition was accessing a purely spatial frame-of-reference. There were two pieces of data to support this conclusion. First, in contrast to the experiments described in Chapter 4, there was no evidence that inverting faces reduced the levels of inhibition. Second, only intervening tasks that required report of spatial information disrupted IOR effects. The more complex and difficult lexical decision task did not abolish IOR. Thus the use of intervening tasks has helped to isolate the form of IOR in this particular task, and perhaps more importantly, these experiments have confirmed that such interference procedures may be worth developing in future studies of inhibition.

Future studies

Naturalistic stimuli in n-back cueing procedures

In the sequential (6-back) cueing studies described in Chapters 2 and 3 it appeared that there is indeed an invariant limit to the capacity of such implicit working memory systems. That is, even when making each stimulus unique such that it was only experienced once when cued (Experiment 4a), there was no increase in the capacity for inhibition. However, these experiments examine orienting of attention in unstructured environments. That is, a random unrelated set of objects was presented on each trial. However, typical search in the real world is within highly constrained visual environments. For example, when searching one's office for a mislaid pen, the structure of the office is highly constrained in terms of personal experience (a place seen many times before) and by the general constraints of such an environment (offices contain predictable objects in predictable loci). If one were to study the orienting of attention in such highly constrained and semantically rich scenes, would memory for inhibition be more stable? This issue could be investigated using similar cueing techniques as those presented here but with 'real' objects cued in their 'real' environment. Taking the example of the office, cueing real items in their natural environment would perhaps yield stronger and more robust (longer lasting) IOR effects than those reported here (see Figure 6.1 below for a simplified example).

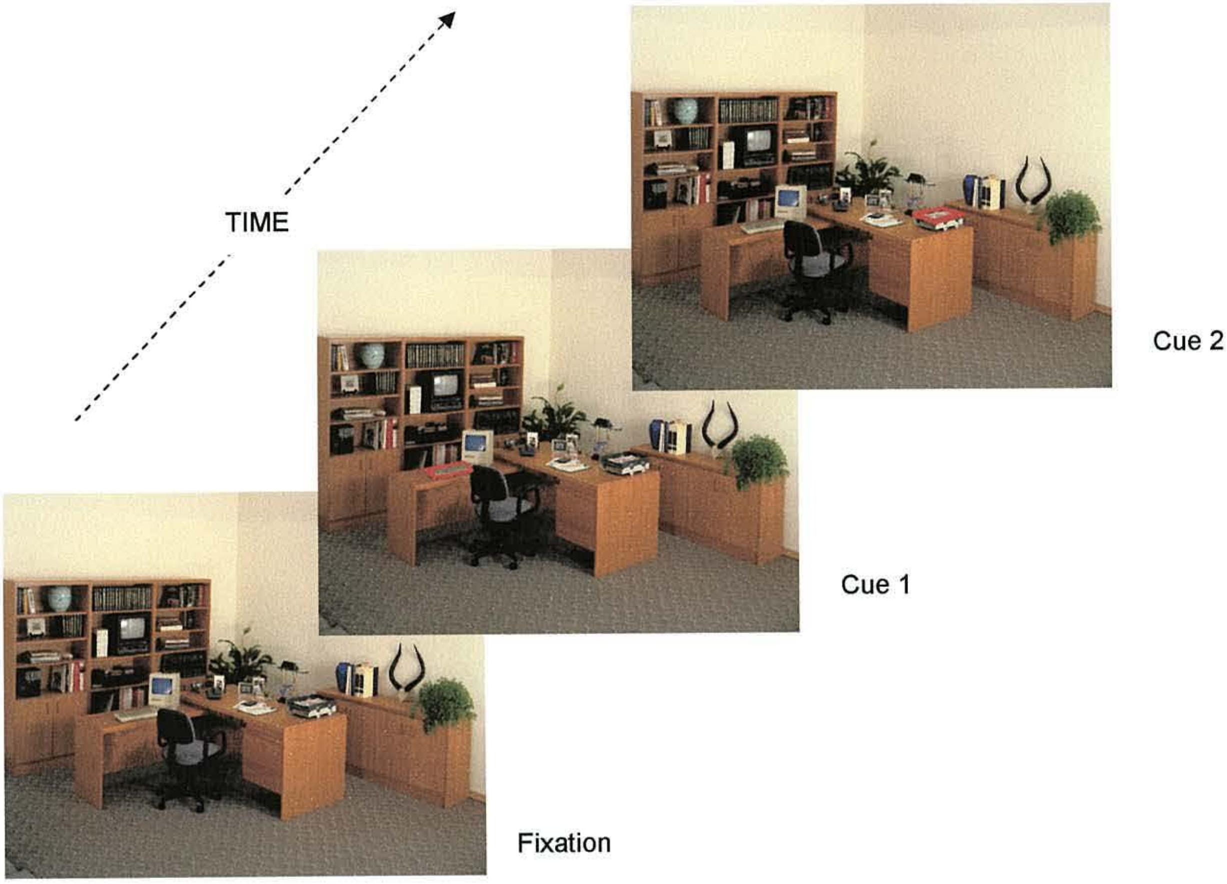


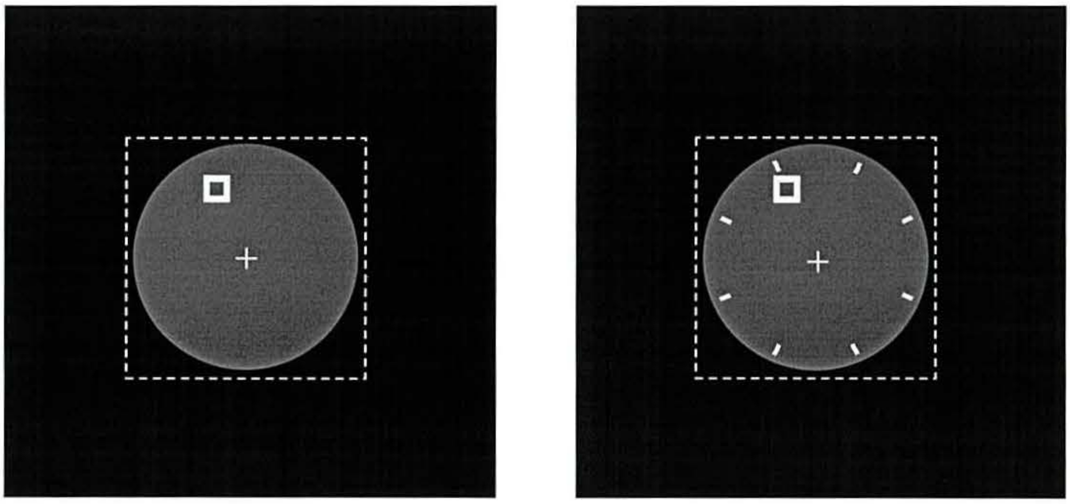
Figure 6.1 – showing an example of a hypothetical cueing procedure with naturalistic stimuli. In this example, a fixation screen and only two of six cues are shown. Cues are highlighted red objects – the computer keyboard for Cue 1 and the in-tray for Cue 2.

Temporal limits of IOR

The number of items that can be held in working memory in IOR tasks now seems well established at 4 or 5 items as discussed above, but the temporal limits of IOR are as yet undetermined. The face identity experiments presented in Chapter 4 showed IOR effects lasting for over 3 seconds. This temporal dimension was further examined in the interference techniques of Chapter 5 where IOR effects of over 11 seconds were shown. These findings are considerably longer than those commonly reported. It would be prudent then to replicate this finding in further identity-based cueing techniques. As was discussed, it may be the case that in these tasks the very need for encoding higher level representations results in longer attentional traces (previous studies would require little identity encoding as basic geometric shapes are used). As such, it would be worthwhile establishing boundary conditions of the temporal limits of these effects. Given the long-term effects shown in negative priming (e.g. DeSchepper & Treisman, 1996, Neumann & Russell, 1992), it may well be the case that in IOR tasks longer lasting effects might be found (see also Tipper, 2001).

Objects acting as landmarks

As was developed in Experiment 5, adding landmarks to a display in which objects could appear briefly, increased the IOR effect relative to a condition where no objects and no landmarks were present (Experiment 2). It was suggested that these landmarks might act to support spatial memory. That is, the presence of these objects (in this instance, the landmarks) helped maintain IOR for objects that appeared briefly next to them. As was shown in Experiment 2 however, even without these permanent reference points (landmarks) there was still IOR associated with the brief appearance of objects on a blank display screen. It may be the case however that participants used other reference points with which to encode object-location in this task. For example, the edge of the display monitor on which the stimuli appear is always visible. One possibility of controlling for this would be by masking the display monitor and presenting the stimuli in a darkened room, thus removing all landmark reference points (see Figure 6.2 below).



A

B

Figure 6.2 – showing an example of a possible extension to the landmark study where the computer monitor (the dashed white outline) is hidden behind an occluding black surface. The computer screen (shown here in grey) is visible but there are no external environmental landmarks visible (e.g. corner of the monitor). Panel A shoes the no objects condition; panel B shows the no objects + landmarks condition.

Given the importance being placed here on the role of objects as landmarks, this would seem to be an important study to conduct.

Long-term IOR?

The work presented in this thesis and elsewhere has shown that inhibitory states in an IOR cueing paradigm can last over several intervening items and over several seconds. In these instances, it is reasonable to conclude that these inhibitory states are being maintained on-line in an analogue to working memory. However, as discussed in Chapter 4, recent findings in the Negative Priming (NP) literature have proposed the rather radical idea that entire attentional processing ‘episodes’ might be retrieved and reinstated after considerably longer periods of time. For example, DeSchepper and Treisman (1996) showed that representations of meaningless shapes could last without decrement across 200 intervening trials and with a temporal delay of up to one month! As proposed here, memory in IOR tasks is transitory and maintained on-line with invariant limits in the number of items that can be stored; the temporal limits are less well-defined. Given that both negative priming and inhibition of return are assumed to be accessing similar underlying inhibitory mechanisms, it may be the case that similar long-term retrieval of IOR might be shown over extended time and number of items. This idea was touched upon in Chapter 4 and would be worthy of future studies.

Conclusion

This thesis has concerned itself with the role of object-based representations and how they might influence inhibitory mechanisms demonstrated via the inhibition of return paradigm.

Significant Achievements:

1. There do indeed appear to be invariant limits to the capacity of inhibition. That is, no more than 4 to 6 items (locations or objects) can be inhibited.
2. The stability of inhibition is influenced by the presence of objects. There are two mechanisms mediating this object advantage: First, objects provide landmarks that support spatial memory; and second, object identity can be associated with inhibition.
3. New techniques have been developed. Firstly, IOR has been demonstrated using naturalistic stimuli in a serial cueing procedure (previous studies have examined simple grey outline boxes). Secondly, a traditional IOR paradigm has been extended using faces as the underlying objects with which inhibition

can become associated. Thirdly, an intervening task procedure, previously developed to study working memory, has been applied to the study of IOR.

These findings have important implications for further research in this area, both in terms of theory development, and the development of new experimental techniques. Such future work developing these approaches would provide a useful tool for revealing the mechanisms and frames-of-reference mediating attentional search processes.

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