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Inhibition of return is mediated by object identity

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CONTENTS

Abstract

In complex environments it is important that action is directed towards relevant information. This thesis investigates the role of objects in inhibitory mechanisms of visual attention. It is critical for humans and other animals to search the environment efficiently. Posner and colleagues (1984, 1985) demonstrated that inhibition of the return (IOR) of attention ensures the movement of attention to new locations. Subsequent research suggested that this inhibition could be associated with objects and that object-based representations support efficient visual search over long delays and intervening events. The present series of experiments investigated the role of object-based representations in IOR. The results confirmed previous work showing long-term IOR for faces, and also demonstrated, for the first time, long-term IOR for non-face objects. Long-term IOR occurred even when cues and targets were identical, suggesting that this effect is due to retrieval of object-based inhibition, not mismatching perceptual information. These results suggest that inhibitory processing states associated with objects can be encoded into memory, and subsequently retrieved when the object reappears. Further experiments found that IOR is mediated by object identity but not object category. IOR over short intervals was associated with the identity of realistic objects, as well as the identity of meaningless shapes, but there was no evidence to suggest that IOR could be associated with an object's category. Long-term IOR was also associated with object-identity and not with object category. However, no long-term IOR was observed for identical meaningless shapes, which suggests that memory encoding and retrieval of IOR can only occur if the inhibition is associated with the identity of meaningful objects. The final experiments provided further evidence for the role of object-based representations in IOR by showing that IOR can be influenced by action-related properties of objects. Taken together, the results of this research show that IOR can be relatively long lasting and is mediated by complex identity-based representations of objects.

Chapter 1 – Introduction

The visual environment is highly complex, and it is impossible for the brain to process all the information it receives. Therefore, coherent behaviour in this complex environment depends on the ability to select a goal-relevant object out of many other irrelevant objects. To achieve this, selective attention mechanisms are necessary, and much research has focused on the way in which these mechanisms operate.

The allocation of attention was originally thought to be purely spatial, and the analogy of a spotlight or a zoom lens was used to describe the movement of attention around the visual field (e.g. Broadbent, 1958; Eriksen & Eriksen, 1974; Eriksen & Yeh, 1985; Posner, Snyder, & Davidson, 1980). The central idea of this approach is that attention is oriented to the spatial location of a cue. If the cue is valid (indicating the target location), then responses to a target at that location are faster compared to when the cue is invalid (i.e. the target appears at an uncued location). According to the spotlight metaphor, target detection is facilitated at the cued location because it is within the beam of the attentional spotlight, whereas detection is impaired at uncued locations due to the time taken for attention to move away from the cued location.

However, subsequent research showed that attention can be allocated to objects in a scene, rather than spatial locations. For example, Duncan (1984) presented participants with brief displays containing a box with a line drawn through it. Both the box and the line could vary in two ways: the box was either short or tall and had a gap in its left or right side, whereas the line was either dotted or dashed and leaned to the left or right. When participants were asked to judge two of these features, they were less accurate when the features belonged to separate objects than when the features belonged to the same object. This cannot be explained by a space-based model of attention, because both objects overlapped so that the distance between features was equal regardless of whether they appeared on the same object or on different objects. A number of studies have since confirmed that attention can operate according to an object-based model (see Scholl, 2001, for a review).

Further work showed that space-based and object-based attention can simultaneously influence behaviour. Egly, Driver, and Rafal (1994) asked participants to detect a target that could appear at one of the four ends of two adjacent rectangles. A cue indicating the most likely target location was presented shortly before the target appeared. Participants were faster to detect targets at the cued end of a rectangle than at the uncued end of the same rectangle; this was assumed to reflect space-based attention, as the cue and target appeared on the same object. In addition, target detection at the uncued end of the cued rectangle was faster than target detection at the uncued end of the uncued rectangle; this was thought to indicate object-based attention, because the distance between the cue and target was equal in both conditions. Subsequent studies have also shown evidence for object-based and space-based effects using variations of this paradigm (e.g. Abrams & Law, 2000; Lamy & Tsal, 2000; Pratt & Sekuler, 2001; Vecera & Farah, 1994).

Inhibition of return

Although visual orienting cues facilitate visual processing under some circumstances, as described above, there are some situations in which coherent behaviour may require inhibition of attention at the cued location. When searching a complex visual environment for a particular object, it is important that attention does not return to previously examined objects. For example, a predator searching for prey must move attention between different animals in a herd until it finds a suitable victim. If attention repeatedly returned to previously examined objects then the animal would fail to find food, resulting in starvation. Therefore, it is likely that efficient inhibitory search mechanisms have evolved to aid this search process.

Such a mechanism was demonstrated by Posner and Cohen (1984) using a paradigm in which participants were presented with a central square at fixation flanked by two peripheral squares, and were instructed to make rapid keypress responses to a target. Shortly before the target was presented, a peripheral cue consisting of a brief illumination of one of the boxes appeared. This procedure is illustrated in Figure 1. When the interval between the onset of the cue and the onset of the target was short (less than 200 ms), reaction times were faster to targets at the cued location compared to the uncued location, suggesting that attention was automatically oriented to the cued location, thereby facilitating processing of the target. However, when the cue-target interval was long (300 ms or more), participants were slower to detect targets at the cued location compared to the uncued location.

Posner, Rafal, Choate, and Vaughan (1985) proposed that after attention had been oriented to a location, it was then inhibited from returning to that location shortly afterwards. They named this effect *inhibition of return* (IOR), and suggested that it would facilitate foraging behaviour by preventing attention from returning to previously examined locations, hence motivating search of new locations.

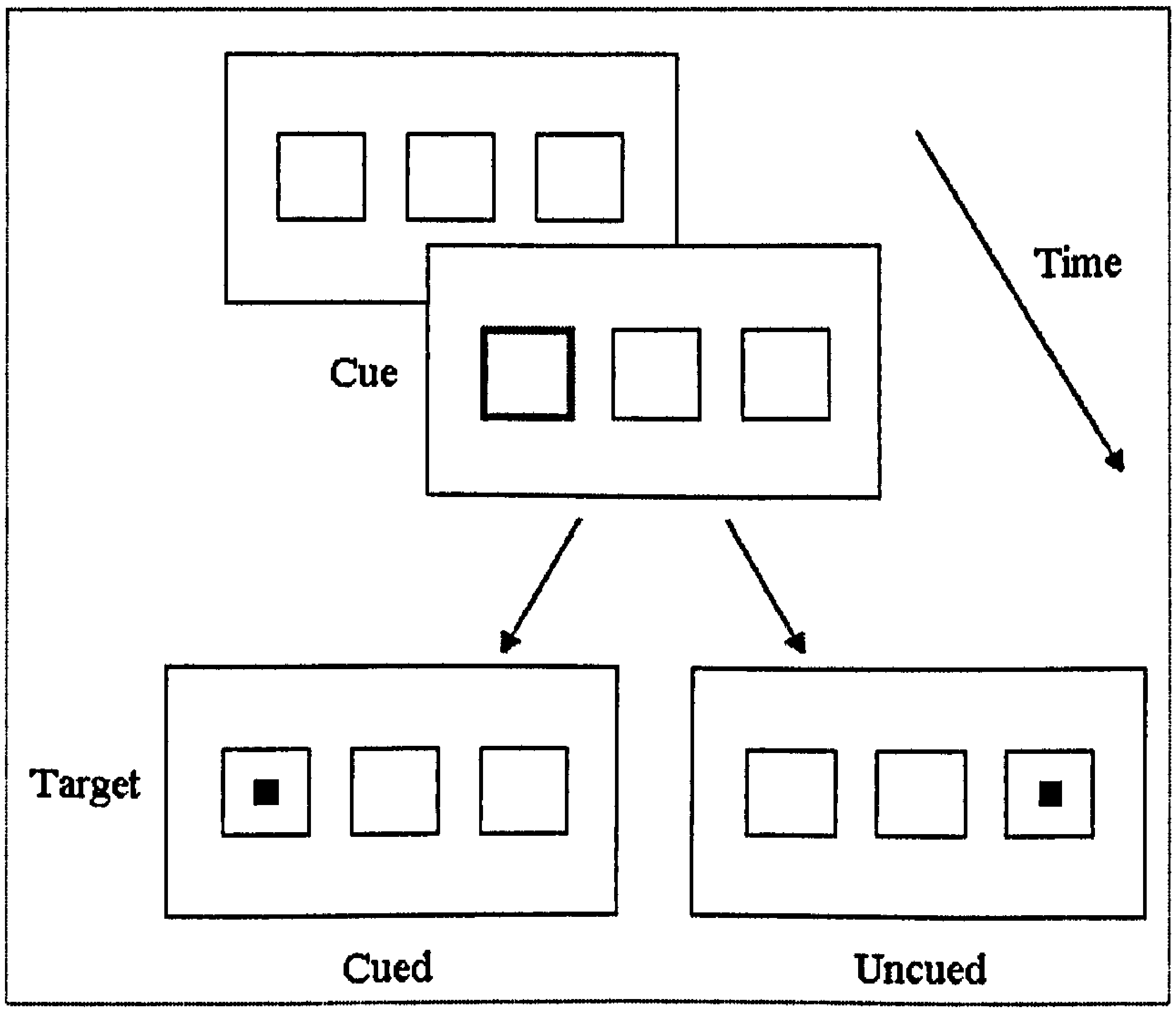

Figure 1: An example of a typical IOR procedure (adapted from Posner & Cohen, 1984). When the interval between the cue and target is short (less than 200 ms), responses to the target are faster at the cued location than at the uncued location. When the cue-target interval is long (300 ms or more), responses are slower at the cued location compared to the uncued location; this demonstrates IOR.

Since its discovery, IOR has been observed many times using a range of different procedures (see Klein, 2000, for a review). For example, IOR has been found using single keypress responses (e.g. Reuter-Lorenz, Jha, & Rosenquist, 1996), choice keypress responses (e.g. Maylor, 1985), reaching responses (e.g. Howard, Lupiáñez, & Tipper, 1999; Tanaka & Shimojo, 1996), and eye-movement responses (e.g. Abrams & Dobkin, 1994b; Pratt, 1995). This effect has also been observed when the task involves target identification (e.g. Chasteen & Pratt, 1999; Cheal, Chastain, & Lyon, 1998; Pratt, Kingstone, & Khoe, 1997), colour discrimination (e.g. Law, Pratt, & Abrams, 1995; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997), and localisation (e.g. Maylor, 1985). As well as recording response times, researchers have measured IOR using psychophysical methods (e.g. Handy, Jha, & Mangun, 1999), electrophysiological methods (e.g. McDonald, Ward, & Kiehl, 1999; Prime & Ward, 2004), and reach trajectories (e.g. Howard et al., 1999). Furthermore, IOR is not restricted to the visual modality, and this effect has been observed for tactile stimuli (e.g. Poliakoff, Spence, O'Boyle, McGlone, & Cody, 2002), auditory stimuli (e.g. Schmidt, 1996; Spence & Driver, 1998b), and cross-modal stimuli (e.g. Spence & Driver, 1998a; Spence, Nicholls, Gillespie, & Driver, 1998).

The inhibitory processes underlying IOR can be accounted for by a neural network model of inhibition developed by Houghton & Tipper (1994; see also Houghton, Tipper, Weaver, & Shore, 1996). In this model, perceptual inputs create object representations, which contain all the features of the object. These representations are compared against an internal template that contains the features of the target (e.g. the small square in Figure 1). Perceptual inputs that match the template receive excitatory feedback, whereas inputs that mismatch (e.g. the illumination of the placeholder box in Figure 1) receive inhibitory feedback. In an IOR paradigm, excitatory feedback initially increases the activation of all the features of the cue. However, because the cue does not match the target template, inhibitory feedback decreases the activation of all the features of the cue. This inhibitory processing builds over time, so that if the target signal appears in the cued item more than 300 ms after the cue signal, the activation of the cue representation will be below resting levels, and will therefore take longer to reach response threshold than the representation of an uncued item, thus demonstrating IOR.

The time course of facilitation and inhibition in IOR has been shown to be influenced by temporal properties of the cue and target. For example, Collie et al. (2000) found that IOR only occurred at long cue-target intervals when there was no temporal overlap between the cue and the target, and no IOR was observed when the cue remained visible until target offset. In contrast, facilitation only occurred at short cue-target intervals when the duration of the cue overlapped with the target. This suggests that excitation is maintained for the duration of the cue, and this excitation declines when the cue disappears, allowing inhibition to be observed at the cued location.

Subsequent work revealed that facilitation and inhibition can exist simultaneously. Wascher and Tipper (2004) used event-related potentials (ERPs) to measure brain activity during an IOR task. Cues could be either briefly presented, or continually presented until target offset. The behavioural results found facilitation at short cue-target intervals and IOR at longer cue-target intervals when cues were transient, whereas no IOR was observed for sustained cues. For sustained cues a negative ERP component was increased, compared to when cues were only briefly presented. This increase was assumed to reflect excitation for sustained cues, which is consistent with the idea that excitation is maintained for the duration of the cue. However, in both the sustained and transient cueing conditions, inhibition of all cued targets was revealed by a reduction in the amplitude of the P1 component for cued relative to uncued targets. These results suggest that neural inhibition and facilitation can co-occur, but in the behavioural effects IOR may be masked by excitation processes.

Object- and location-based IOR

As with other studies of attentional processes, it was proposed that IOR was not necessarily only associated with spatial representations. Tipper, Driver, and Weaver (1991) suggested that inhibition might be associated with objects, as search typically involves attention moving around candidate objects rather than empty locations. In support of this idea, Tipper et al. (1991) showed that if a previously cued object moved to a new location, detection of targets in the cued object was impaired. A substantial amount of work has since confirmed that IOR can be associated with an object-based representation (see Grison, Kessler, Paul, Jordan, & Tipper, 2005, for a review).

Further research (Tipper, Jordan, & Weaver, 1999; Tipper, Weaver, Jerreat, & Burak, 1994b) revealed that IOR can be associated with both locations and objects simultaneously (see also Gibson & Egeth, 1994). When a cued object moved to an uncued location, participants were slower to detect the target when it appeared in the cued object, compared to when it appeared in an uncued object and location (the control condition). However, response times were also slower when the target was presented in an uncued object that had moved into the cued location, compared to the control condition. This demonstrated a purely *spatial* IOR effect. In contrast, most other studies arguing for location-based IOR, such as Posner and Cohen (1984), contained a confound between object- and location-based effects, because the cue and the target appeared in a static object. Indeed, the IOR effects observed by Posner and Cohen (1984) were relatively large (approximately 40 ms), compared to the experiment described above, in which the confound was removed. In the above experiment, the sum of the object- and location-based IOR effects (approximately 25 and 15 ms, respectively) produced an overall IOR effect of around 40 ms, which suggests that the large IOR effects observed by Posner and Cohen (1984) reflect both location- and object-based inhibition.

The combined effects of location- and object-based inhibition were examined further by Jordan and Tipper (1998, 1999) using a paradigm which allowed purely spatial IOR effects to be compared to combined object- and location-based IOR effects while holding the physical features of the stimulus display constant. In the object condition, cues and targets were presented in Kanisza squares, formed by aligning the contours of 'pacman' figures. In the objectless condition, the 'pacman' figures were simply re-oriented, so that no objects were apparent. IOR effects were larger when the Kanisza squares were cued (42 ms) than when the empty locations were cued (18 ms). This is consistent with the previous findings that inhibition of object- and location-based representations is additive.

Tipper, Weaver, and Houghton (1994a) suggested that inhibitory mechanisms of attention may act on different representations depending on the goals of the task. Tipper et al. (1994) presented participants with stimuli that had three properties: colour, identity, and location. A target was specified by colour, and participants had to respond to either the location of the target or the identity of the target while ignoring a distractor object. When the task involved location, inhibition was associated with the location of the distractor. However, when the task involved identity, inhibition was associated with the identity and location of the distractor. These findings suggest that inhibitory mechanisms of attention are flexible, and can adjust according to the nature of the task.

Consistent with this idea, other work has shown that the type of representation engaged in IOR tasks may depend on the nature of the task and the salience of the objects. For example, when cues and targets appeared in simple, sparse stimulus displays that were fixed in orientation, there was no difference in the magnitude of IOR for objects compared to empty locations (McAuliffe, Pratt, & O'Donnell, 2001). In contrast, when cues and targets appeared on salient objects that varied in orientation, the results replicated previous findings, showing that IOR was larger when objects were present compared to when no objects were shown (Leek, Reppa, & Tipper, 2003). Furthermore, this object-based IOR effect was larger when cues and targets were separated by an internal part boundary compared to when they appeared on the same internal feature. The finding that IOR can be modulated by the internal structure of an object suggests that object- and location-based IOR are independent processes that have different functional characteristics.

Neural properties of IOR

There is evidence to suggest that object- and location-based IOR may be mediated by different neural processes. Posner et al. (1985) proposed that IOR is mediated by processing in the superior colliculus (SC). The SC is involved in the control of saccadic eye-movements (e.g. Goldberg & Wurtz, 1972; Mohler & Wurtz, 1977; Sparks, 1978), and research suggests that IOR is generated by the programming of saccadic eye-movements (Abrams & Pratt, 2000; Kingstone & Pratt, 1999; Rafal, Calabresi, Brennan, & Sciolto, 1989).

Evidence for the role of the SC in IOR is provided by research showing that damage to the SC reduces IOR (Posner et al., 1985; Sapir, Soroker, Berger, & Henik, 1999), whereas damage elsewhere along the tectopulvinar pathway does not impair IOR (Sapir, Rafal, & Henik, 2002). Also, IOR interacts with the "gap effect", which is mediated by processing in the SC (Dorris & Munoz, 1995; Munoz & Wurtz, 1995a, 1995b; Schiller, Sandell, & Maunsell, 1987; Sparks & Mays, 1983). The gap effect is when the removal of a central fixation stimulus prior to the onset of a peripheral target causes faster saccades to the target compared to when the fixation stimulus remains visible. When this task is combined with an IOR task, the gap effect is smaller for saccades to previously cued targets relative to uncued targets, suggesting that IOR is also mediated by the SC (Abrams & Dobkin, 1994a).

Other work has shown that IOR depends on the direct pathway from the retina to the SC. The SC receives greater inputs from the temporal hemifield than the nasal hemifield, and this asymmetry is not found in retinal projections to the cortex (Lewis, Maurer, & Milewski, 1979). In correspondence with these asymmetric pathways to the SC, IOR effects are larger when cues appear in the temporal hemifield than when they appear in the nasal hemifield (Berger & Henik, 2000; Rafal, Henik, & Smith, 1991; Rafal et al., 1989; Sapir et al., 1999; Simion, Valenza, Umiltá, & Dalla Barba, 1995). Furthermore, IOR occurs even when visual processing cannot be mediated by cortical visual pathways. For example, IOR has been observed in newborn infants, even though visual processing at that age is mediated by the retinotectal pathway through the SC (Simion et al., 1995; Valenza, Simion, & Umiltà, 1994), and IOR has also been found in the hemianopic field of a patient with damage to the primary visual cortex (Danziger, Fendrich, & Rafal, 1997).

However, more recent research suggests that the inhibition in IOR may be produced by a number of brain structures. The SC receives inputs from cortical areas including the parietal lobe and the frontal eye fields (Shipp, 2004). Dorris, Klein, Everling, and Munoz (2002) suggested that, although the SC is involved in IOR, the inhibition may be generated in brain regions upstream of the SC, such as the parietal cortex. Consistent with this idea, patients with damage to the parietal lobe do not show IOR for stimuli presented in the ipsilesional visual field (Vivas, Humphreys, & Fuentes, 2003). In addition, research using functional magnetic resonance imaging (fMRI) has found that IOR is associated with increased activation in several cortical regions, such as the frontal eye fields and the supplementary eye fields (Lepsien & Pollmann, 2002), and the dorsal premotor area and the superior parietal cortex (Rosen et al., 1999). These findings are consistent with recent work using transcranial magnetic stimulation (TMS), in which stimulation over the right frontal eye field reduced IOR for stimuli in the ipsilesional visual field (Ro, Farnè, & Chang, 2003). Finally, event-related potential studies of IOR have shown a reduction in the amplitude of the P1 component for previously cued stimuli (McDonald et al., 1999; Prime & Ward, 2004), and P1 is generated in extrastriate cortex (e.g. Clark & Hillyard, 1996; Di Russo, Martínez, Sereno, Pitzalis, & Hillyard, 2002). Taken together, these findings suggest that IOR is mediated by a number of different brain structures.

Recent work has shown that the way that IOR is generated may depend on the type of task used to examine IOR. Sumner, Nachev, Vora, Husain, and Kennard (2004) used stimuli that were only visible to short-wave sensitive cones (S cones) in the retina. S cones do not project to the SC (de Monasterio, 1978; Schiller & Malpeli, 1977), so these stimuli were invisible to the retinotectal pathway. The cue was either a brightness change, as in the traditional IOR paradigm, or a colour change that was only visible to S cones. The S cone stimuli produced a similar magnitude of IOR to the luminance cues, even though they were invisible to the SC. This shows that the SC is not necessary for the generation of IOR. However, this IOR for S cone stimuli was only observed when the task involved a manual keypress response. When the task required eye-movements towards the targets, no IOR was observed for S cone stimuli. Sumner et al. (2004) suggested that the traditional IOR effect (e.g. Posner & Cohen, 1984) is mediated by both retinotectal and cortical pathways, and the retinotectal pathway is only necessary for saccadic IOR. These results suggest that a number of different pathways may be involved in attentional orienting.

Tipper et al. (1994b) suggested that object-based IOR requires cortical processing, as the SC does not process object-based information. Rather, object recognition processes occur in cortical areas (Kanwisher, Woods, Iacoboni, & Mazziotta, 1997b; Malach et al., 1995). Furthermore, Tipper et al. (1991, 1994a) observed IOR for moving objects, and neurons in the SC cannot efficiently encode speed and direction of motion; these analyses are carried out in cortical areas such as the medial temporal lobes (Gross, 1991; Schiller & Stryker, 1972). Abrams and Dobkin (1994b) found location-based IOR in eye-movements (that are mediated by the SC), as participants were slower to make saccades to previously attended locations. In contrast, when a cued object moved to a new location, no object-based IOR was observed in eye-movements. This is consistent with the idea that, whereas the SC is involved in location-based IOR, object-based IOR may be mediated by cortical neural structures.

Further support for this idea comes from the study of "split-brain" patients; that is, patients who have damage to the corpus callosum which isolates the two cortical hemispheres. Tipper et al. (1997b) found that split-brain patients showed object-based IOR when the cued object moved within the same visual field (the same cortical hemisphere), but showed no IOR effects when the object moved into the other visual field (the contralateral hemisphere). Control subjects showed IOR effects in both situations. These findings suggest that cortical processing plays a critical role in object-based IOR.

IOR in working memory

As described above, object-based and location-based IOR appear to be independent processes that can be mediated by different neural pathways. Therefore, it is likely that the temporal properties of the object- and location-based processes underlying IOR are different. Previous studies assumed that the inhibitory processes underlying IOR are transient (e.g. Maylor, 1985; Posner & Cohen, 1984; Reuter-Lorenz et al., 1996), and it has been suggested that there is no memory for inhibition in visual search (Horowitz & Wolfe, 1998, 2001, 2003). Because the spatial location of information can change over time, this proposal seems reasonable in terms of location-based IOR. However, the finding that inhibition can be associated with objects suggests that object-based representations may provide the basis for efficient search over time.

Indeed, to efficiently search complex environments it may be necessary to inhibit a number of previously examined items. In order for IOR to act on multiple items, inhibition associated with these items must be maintained in working memory, which is assumed to hold a small amount of information (approximately four items) that is required for ongoing behaviour (see Cowan, 2001). Klein (1988) found that, during serial search through displays containing multiple objects, targets presented at previously attended objects were harder to detect. This demonstrated, for the first time, the role of inhibition in a serial search task. Subsequent work showed that inhibition in serial search tasks can only be observed if the objects in the search array remain visible. When the objects were removed, then no inhibition was observed (Klein & MacInnes, 1999; Müller & Mühlenen, 2000; Takeda & Yagi, 2000), which provides further support for the idea that inhibition can be associated with object-based representations.

Further research examined IOR in working memory using multiple cueing paradigms, in which several locations were sequentially cued before the target appeared at either a previously cued location or an uncued location. Initial studies showed that, when three locations were cued before target onset, IOR was maintained at all three previously cued locations (Danziger, Kingstone, & Snyder, 1998; Tipper, Weaver, & Watson, 1996). However, there was a linear decline in IOR from the most recently cued location, indicating that IOR can only be maintained across a limited number of previously cued items.

This was confirmed in subsequent work by Snyder and Kingstone (2000). In this study the display consisted of eight outline boxes arranged in a circle around fixation. Up to six different boxes were cued, and then a target requiring a speeded key press response appeared in either a cued or an uncued box. The results showed a linear decline in IOR from the most recently cued location, with significant IOR effects for up to 5 previously cued items. This is consistent with the limits reported in working memory. This pattern of IOR in working memory has also been found to occur when very brief cues are used (Dodd, Castel, & Pratt, 2003) and when onset or offset cues are used (Birmingham & Pratt, 2005), which suggests that the linear decline in IOR in working memory is not influenced by the nature of the cue or the speed at which attention moves between the cued locations.

Recent work suggests that the maintenance of IOR in working memory can be facilitated by the presence of objects. Paul and Tipper (2003) presented participants with displays consisting of either no objects, identical objects (outline boxes), or salient objects (different coloured shapes) arranged around a central fixation point in an imaginary circle. Six cues were flashed in a location or object, and then a target requiring a rapid keypress response was presented in one of the previously cued items or in an uncued item. In the no objects condition there was a small overall IOR effect, but significant IOR effects were only observed for up to three previously cued locations. In contrast, when identical objects were cued, the overall IOR effect was greater, and IOR was significant up for up to four previously cued items. This shows that inhibition of non-distinct objects is held in working memory for longer than inhibition of empty locations (see also Birmingham & Pratt, 2005). Furthermore, when salient objects were cued, there was a larger overall IOR effect, and IOR was significant at the earliest cued location.

The finding that memory for inhibition is increased when objects are more salient is consistent with recent work by Samuel and Kat (2003), in which the duration of IOR varied according to the task. IOR effects were measured at varying intervals up to 3000 milliseconds in complex stimulus displays, and up to 4200 milliseconds in sparse stimulus displays. When sparse stimulus displays were used, IOR disappeared within three seconds. However, when complex stimulus displays and subtle cueing effects were used, robust IOR effects were present at a three second cue-target interval. These findings suggest that object-based representations facilitate the maintenance of inhibition in working memory.

Alternatively, it is possible that these object-based IOR effects reflect spatial re-orienting processes, rather than inhibition of objects. For example, Robertson (2004) found that IOR was only associated with moving objects when the movement was consistent with the rotation of a spatial reference frame. No IOR was observed when the objects moved in opposite directions or through a corner angle. Robertson (2004) also suggested that greater IOR can be observed for objects than for locations in static displays, because the presence of objects defines a spatial location more precisely. According to this view, objects simply provide landmarks that support location-based inhibition. In support of this idea, research has shown that memory for locations is influenced by the structure of spatial information (e.g. Hubbard & Ruppel, 2000; Huttenlocher, Hedges, & Duncan, 1991). Furthermore, Castel, Pratt, and Craik (2003) found that IOR was eliminated when the cue was followed by a task requiring spatial working memory, but an intervening task requiring nonspatial working memory did not disrupt IOR, which suggests that IOR is mediated by a spatial working memory system.

However, as noted previously, object-based and space-based representations may conjointly influence behaviour (Jordan and Tipper, 1998, 1999; Tipper et al., 1991, 1994b, 1999), and the type of representation used may depend on the demands of the task (Leek et al., 2003; McAuliffe et al., 2001). Indeed, IOR has been observed in visual search when the objects in the search display moved randomly and independently (Ogawa, Takeda, & Yagi, 2002). Therefore, it is possible that in some situations IOR may depend entirely on object-based representations. Because objects always occupy locations, previous multiple cueing studies showing object-based IOR in working memory contain a confound between space-based and object-based IOR (e.g. Paul & Tipper, 2003), and the IOR effects observed in these tasks do not provide any information about the relative influence of each type of representation.

Therefore, recent work has taken a different approach in an attempt to determine the role of objects in IOR. Tipper (2001) proposed that transient inhibitory states associated with objects may be encoded into long-term memory and subsequently retrieved when the object reappears. Visual search is not always completed within one processing episode, and it is sometimes necessary to stop a search and then resume it later. It is therefore possible that a link between inhibitory processes and long-term memory may have evolved. For example, a child searching for a ball in a neighbour's garden may have to break off the search and leave the garden when the neighbour's vicious dog appears. However, when the dog goes back into the house, the child may return to the garden to continue searching for the ball. At this point, it is proposed that at least two mechanisms enable the search to be resumed. First, the child consciously remembers looking for the ball (explicit recall). Second, upon re-entering the garden, prior inhibitory states are retrieved from long-term memory, in order to facilitate search by preventing the return of attention to previously examined objects.

Long-term IOR

Recent research by Tipper, Grison, and Kessler (2003) has demonstrated, for the first time, the existence of long-term IOR. Tipper et al. (2003) developed a paradigm that was designed to maximise memory encoding and retrieval of stimuli and associated inhibitory states. This study used face stimuli, because humans have been shown to process faces fluently (e.g. Bruce & Humphreys, 1994; Kanwisher, McDermott, & Chun, 1997a), and faces tend to be automatically encoded in episodic memory (e.g. Shah et al., 2001). Furthermore, the faces were unfamiliar, so that no prior memory representations could exist, and each face was seen only twice, once during cueing and once during target presentation. The cue and target stimuli consisted of semi-transparent red (cue) and green (target) oval shapes that were superimposed over the faces so that the faces appeared to turn briefly red or green. Faces presented to the left and right of fixation were alternated with scenes presented above and below fixation. This separation of faces by using scenes as a filler task was intended to facilitate encoding and retrieval of items and their associated inhibition, based on findings that spaced presentation of items leads to better memory encoding and retrieval than massed presentation (e.g. Melton, 1970). Stimuli were presented in the same order and in the same position in the cue and target blocks, in order to facilitate retrieval by reinstating the encoding context.

Participants were significantly slower to detect targets appearing on previously cued faces versus uncued faces at cue-target intervals of 3 minutes and 48 displays, and 13 minutes and 192 displays. Interestingly, these long-term IOR effects were only observed for faces presented in the left visual field (VF), and there were small facilitation effects for faces presented to the right VF. This hemispheric difference is consistent with research showing that faces are processed in the right hemisphere (e.g. Kanwisher et al., 1997a; Tong, Nakayama, Moscovitch, Weinrib, & Kanwisher, 2000). Tipper et al. (2003) suggested that faces presented to the left VF are allocated more processing resources during encoding than faces presented to the right VF, and this leads to more stable memory representations and associated inhibition for faces on the left compared to faces on the right. As a result, long-term IOR is more robust for faces on the left than for faces on the right. No long-term IOR was observed when cues and targets appeared at empty locations in scenes, which suggests that long-term IOR can only be observed when inhibition can be associated with an object.

Further work (Kessler & Tipper, 2004) using a similar procedure examined long-term IOR for faces in all four quadrants of the visual field. On each trial two faces were shown, either in the top-left and bottom-right VFs, or in the bottom-left and top-right VFs. Participants had to ignore a red cue and localise a green target using one of four keys, depending on which quadrant the target appeared in. There were 4.3 minutes and 80 intervening displays between the cue and the target. Significant long-term IOR was only found in the upper left visual quadrant. This supports Tipper et al.'s (2003) results, and also shows that memory for faces and associated inhibitory states is more robust in the upper VF. This is consistent with research showing that the upper VF is more concerned with object recognition than the lower VF, and visual search is faster when targets are in the upper VF (Previc, 1990; Previc & Blume, 1993). Of particular relevance to these experiments, Fecteau, Enns, and Kingstone (2000) found that search for faces is faster in the upper VF.

Kessler & Tipper (2004) also varied the location of the faces during the cue and target displays and the presentation time of the face prior to target onset. Faces could either remain static or they could change location within the left or right hemifield between cue and target displays (i.e. faces could move from top to bottom or vice versa). Also, faces in the target display appeared for either 500 ms or 1000 ms before target onset. When faces remained static, long-term IOR was observed at the 500 ms interval, but not at the 1000 ms interval, suggesting that retrieval of inhibition is fast and transient. Long-term IOR was still observed when the cued face moved to a new location, showing that the inhibition was associated with the identity of the face, and not with a location-based reference frame. However, these long-term IOR effects were smaller and only occurred at the 1000 ms interval, which implies that retrieval of inhibitory processes was slower and less efficient when the spatial configuration of the faces changed. Kessler & Tipper (2004) suggested that the time taken for retrieval of inhibitory states depends on the similarity between encoding and retrieval states. That is, when the cue and target displays were identical (in the static condition), retrieval of inhibition was relatively fast. In contrast, when the cue and target displays did not exactly match, because the configuration of the faces changed, retrieval was delayed. Importantly, the results show that retrieval of inhibitory states is transient, as the IOR observed for static faces at the 500 ms interval was no longer present at the 1000 ms interval.

This long-term memory encoding and retrieval of object-based inhibitory states cannot be explained by location-based theories of visual search (e.g. Robertson, 2004), as each cue was separated from its corresponding target by many intervening displays in which cues and targets were presented to the same locations. Therefore, the long-term IOR observed by Tipper and colleagues (Kessler & Tipper, 2004; Tipper et al., 2003) must reflect a purely object-based IOR effect. This effect cannot be explained by on-line inhibitory mechanisms, as maintenance of inhibition over long delays and intervening events would interfere with ongoing behaviour. As mentioned previously, research suggests that IOR can only be maintained in working memory for a limited time (e.g. Paul & Tipper, 2003; Samuel & Kat, 2003; Snyder & Kingstone, 2000). According to Tipper and colleagues, these long-term IOR effects occurred because the identity of the cued face was encoded into memory together with its associated inhibitory state. When the face reappeared, the previous processing episode was retrieved and the inhibition was reinstated, resulting in slower reaction times to previously cued faces relative to uncued faces.

In the neural network model of inhibition (Houghton & Tipper, 1994; Houghton et al., 1996), inhibitory feedback causes a temporary suppression of activation, in order to prevent an incorrect response. However, once the correct response has been made, this inhibition quickly decays to enable processing to continue without interference. According to Grison, Kessler, Paul, Jordan, & Tipper (2005), long-term IOR can be accommodated in a revised version of this model, in which an episodic memory sub-network, representing hippocampal processes, stores the activation patterns of the entire network (including both inhibitory and excitatory processes) as part of an episode. This episode is then retrieved in the presence of suitable retrieval cues, and the prior activation state of the network is reinstated. In this way, transient inhibitory processes enable successful search after a long delay, without interfering with ongoing behaviour.

The research described above suggests that objects play an important role in IOR. In particular, it appears that object-based representations enable successful search over time. However, there are some issues that require further investigation. Long-term IOR effects have only been observed in two studies, both of which used face stimuli (Kessler & Tipper, 2004; Tipper et al., 2003). These effects were small and only occurred in one visual field. Therefore, it is important to replicate these findings using other types of object stimuli. In addition, further work is necessary in order to confirm that long-term IOR effects reflect memory retrieval of inhibitory states, as suggested by Tipper and colleagues (Grison et al., 2005; Kessler & Tipper, 2004; Tipper et al., 2003), rather than memory retrieval of mismatching perceptual information (e.g. Park & Kanwisher, 1994; see Chapter 2). Finally, although object-based IOR has been observed in a number of studies, there has been little research into the type of object representation that is inhibited. That is, it remains unclear whether object-based IOR operates on the identity of an object or the basic-level category to which the object belongs. Furthermore, while previous studies of long-term IOR have used complex real-world stimuli, it is not clear whether meaningful objects are required for encoding and retrieval of inhibitory states; it is possible that such effects could also be observed using meaningless shapes. These issues will be addressed in the following chapters.

IOR and action affordances

It is also possible that inhibitory mechanisms of attention may be influenced by action-related properties of objects. Perception and action appear to be closely linked, and vision can be fluently converted to action in the absence of a conscious intention to act (see Milner & Goodale, 1995, for a review). For example, Simon (1969) showed that responses to a visual target were facilitated when the target location was spatially compatible with the location of the responding hand, even though location was irrelevant to the task. Furthermore, patients with damage to the frontal lobes may display "utilisation behaviour", in which they act automatically towards objects in the environment in ways that are appropriate for the objects but not relevant to the current task (Lhermitte, 1983). For example, when presented with a jug of water and a glass, patients may pour the water into the glass and drink it, while verbalising that they know they should not do this. It appears that perception of an object may lead to the automatic encoding of the action afforded by the object, even when no action is necessary.

Of most relevance to this thesis, Tucker and Ellis (1998) showed that the actions afforded by objects can influence behaviour in neurologically normal participants. Participants were presented with pictures of graspable objects and were asked to indicate, via a left hand or right hand key press, whether each object was upright or inverted. The objects were oriented to be compatible with either a left or a right hand grasp. Response times were faster when the grasp afforded by the object was compatible with the responding hand, compared to when the evoked action was incompatible with the response. These action affordance effects have since been confirmed in a number of studies (e.g. Ellis & Tucker, 2000; Phillips & Ward, 2002; Tucker & Ellis, 2001, 2004), and are associated with increased activation in the anterior parietal, dorsal premotor, and inferior frontal cortex (Grèzes, Tucker, Armony, Ellis, & Passingham, 2003). These results suggest that viewing an object can activate motor representations of the action associated with that object.

It is possible that the activation of motor representations could influence the magnitude of object-based IOR effects. As noted previously, in Houghton & Tipper's (1994) model of inhibitory mechanisms, selection of a target object is achieved by the excitation of inputs that match the target template and the inhibition of competing inputs that do not match the target. It is well established that competition among inputs for neural representation is partly driven by bottom-up factors, and stimuli that are more salient produce greater levels of activation (Desimone & Duncan, 1995). Therefore, an important property of Houghton & Tipper's (1994) model is that inhibition is reactive. That is, the amount of inhibition applied to an object is determined by the activation state of that object. Distractors that are highly salient produce greater activation, and therefore receive more inhibition than other less potent distractors. According to this model, objects which afford response-compatible actions should receive greater levels of inhibition than objects that afford incompatible actions.

Some evidence for the idea of reactive inhibition comes from research using reaching-to target-tasks. Initial studies found that distractors close to the hand interfered with response more than distractors that were further from the hand, even though they were equal distances from the target (Pratt & Abrams, 1994; Tipper, Lortie, & Baylis, 1992). Further work showed that the extent to which the hand deviates away from an irrelevant distractor is determined by the salience of the distractor (i.e. its proximity to the responding hand); the more potent the distractor, the greater the deviation (Howard & Tipper, 1997; Tipper, Howard, & Jackson, 1997a).

More recently, Tipper, Meegan, and Howard (2002) found that inhibitory effects of distractors were reduced when the direct path to the distractor was blocked. In this study the stimuli were lights on a button board, and participants had to reach out and press a button adjacent to the target light while ignoring a distractor light. Distractors that were more easily responded to (i.e. were closer to the responding hand) produced greater interference than those which were more distant or were on the other side from the responding hand, as is predicted by the Houghton and Tipper (1994) model of reactive inhibition. However, this effect was eliminated when a transparent obstacle was placed in front of the distractor, showing that these effects were not due to the spatial relationship between the distractor and the responding hand. Rather, these results suggest that inhibitory mechanisms of attention can operate according to action-based frames of reference.

Therefore, if IOR acts on object-based representations, then it should be modulated by action-related properties of objects. Indeed, IOR has been observed when the task involved reaching to targets (Chang & Ro, 2005; Howard et al., 1999; Tipper, Howard, & Houghton, 1998), showing that IOR can operate according to an action-based frame of reference. Other work has found increased Simon effects (faster RTs for spatially compatible responses than for incompatible responses) for cued targets compared to uncued targets in IOR tasks, even when location was irrelevant and the task required keypress responses to attributes such as colour or identity (Ivanoff, Klein, & Lupiáñez, 2002).

However, there has been no research into whether action-related properties of objects can influence IOR. In accordance with previous work (Ellis & Tucker, 2000; Grèzes et al., 2003; Phillips & Ward, 2002; Tucker & Ellis, 1998, 2001, 2004), the use of objects that afford actions should result in the activation of motor representations associated with those actions. This automatic response activation may increase the magnitude of the IOR effect, as stimuli that are more salient and interfere more with the task require greater levels of inhibition (Houghton & Tipper, 1994). The finding that IOR can be modulated by action affordances of objects would provide further evidence to support the view that IOR operates on object-based representations. Therefore, the final part of this thesis attempts to determine whether action affordances influence IOR effects.

Overview

The research reviewed in this introduction suggests that object-based representations may facilitate visual search over time and intervening events. The aim of the experiments reported in the following chapters was to examine how IOR is mediated by object-based representations. The first part of the thesis aims to confirm that inhibition associated with object-based representations can be encoded into and retrieved from memory. Chapter 2 attempts to confirm previous findings of long-term IOR for faces and to demonstrate long-term IOR for non-face objects. This chapter also investigates whether long-term IOR is due to memory retrieval of inhibitory attentional states or retrieval of mismatching stimulus features. To preview the findings of Chapter 2, long-term IOR was observed for faces and objects, and this effect could not be explained by a perceptual mismatch account. However, the results also revealed some interesting visual field differences in the pattern of IOR, which appeared to be inconsistent with previous work (e.g. Kessler & Tipper, 2004; Tipper et al., 2003). Therefore, Chapter 3 investigates whether the visual field asymmetries in Chapter 2 were caused by competition between faces and objects for processing resources. Second, this thesis investigates the level of object representation at which this inhibition operates (Chapter 4). That is, does object-based inhibition operate on basic-level category representations, or does it operate on specific, identity-based representations? This series of experiments also examines whether IOR can be associated with the identity of briefly presented meaningless shapes. Finally, Chapter 5 examines whether action-related properties of objects influence IOR.

Chapter 2 – Long term inhibition of return

The experiments reported in this chapter had two main goals. First, these experiments aimed to confirm the existence of long-term IOR. This effect has only been observed twice (Kessler & Tipper, 2004; Tipper et al., 2003), and appears to be a small, fragile effect that only appears in one visual field, so it is important to replicate these findings. The previous work found long-term IOR for naturalistic face stimuli, but did not investigate whether long-term IOR can be observed for other objects. However, recent work has suggested that faces are processed differently from other objects (Ro, Russell, & Lavie, 2001), and face processing is more automatic than object processing (Cauquil, Edmonds, & Taylor, 2000; Lavie, Ro, & Russell, 2003; Liu, Higuchi, Marantz, & Kanwisher, 2000), therefore it is important to confirm the existence of long-term IOR using other types of stimuli. The stimuli used in the current experiments consisted of common objects and faces. Whereas Tipper et al. (2003) separated out the face displays by cueing empty locations in scenes, these experiments used pairs of objects in the intervening task. Cueing objects rather than empty locations was expected to facilitate memory for inhibition, allowing long-term IOR to be observed for objects as well as faces.

Second, the experiments reported here investigated whether long-term IOR is due to memory encoding and retrieval of inhibitory attentional states, as suggested by Tipper and colleagues (Kessler & Tipper, 2004; Tipper et al., 2003). An alternative explanation for these long-term IOR effects can be provided by *feature mismatch theory* (Park & Kanwisher, 1994), which was developed to account for negative priming effects in terms of a memory retrieval mechanism. Negative priming refers to the increase in response time to a target (the probe) that has been an ignored distractor (the prime) on a previous trial (Neill, 1977; Tipper, 1985); this increased response time is widely assumed to reflect inhibitory mechanisms of attention (May, Kane, & Hasher, 1995; Tipper, 2001). However, according to feature mismatch theory, negative priming results from a lack of correspondence between the features of the prime distractor and the features of the probe target. Park and Kanwisher (1994) argue that in negative priming tasks participants try to match the target item to previously experienced items, and a partial match (for example, the same item in a different colour) impedes processing because the mismatching stimulus features must be resolved. This memory retrieval of mismatching perceptual information causes slowed response times when the target has previously been seen as a distractor.

Park and Kanwisher's (1994) theory could explain the long-term IOR effects observed in previous studies. Indeed, research showing long-term negative priming effects (DeSchepper & Treisman, 1996) formed the basis for Tipper et al.'s (2003) investigation into long-term IOR. In Tipper and colleagues' experiments (Kessler & Tipper, 2004; Tipper et al., 2003) the cued item was seen in red, however when it subsequently reappeared as the target it was green. Therefore, the long-term IOR effects observed in these experiments may be due to memory retrieval of mismatching perceptual information, rather than retrieval of inhibitory processes. That is, the slow response time to previously cued items in these experiments may reflect the time taken to resolve the mismatching stimulus information, rather than inhibitory attentional processes.

The current experiments used a paradigm similar to the one developed by Tipper et al. (2003). However, whereas Tipper et al. (2003) separated out the face displays by cueing empty locations in scenes, the current experiments used pairs of objects in the intervening task. Cueing objects rather than empty locations was expected to facilitate memory for inhibition, allowing long-term IOR to be observed for objects as well as faces. In order to facilitate the encoding and retrieval of object-based inhibition by separating stimulus presentation and reinstating encoding context, presentation of face displays alternated with presentation of object displays, and the sets of cue and target displays appeared in the same order. Large sets of unique stimuli were used, in order to avoid multiple representations of stimuli in episodic memory.

Because the materials used in these experiments were quite different to the sparse displays that have previously been used to investigate IOR (e.g. Posner & Cohen, 1984), a prior experiment was necessary to confirm the presence of standard IOR effects for these stimuli over short cue-target intervals with no intervening displays. Therefore, Experiment 1 was expected to show the standard IOR effect for faces and objects, indicating that these stimuli were suitable for investigating long-term IOR.

As mentioned above, an important goal of this chapter was to determine whether long-term IOR effects are due to the retrieval of prior inhibitory states, as suggested by Tipper et al. (2003), or the retrieval of mismatching stimulus features. Experiment 2a used mismatching red cues and green targets and Experiment 2b used matching cues and targets (either both red or both green). According to the inhibition theory, manipulating the cue-target match should not influence the magnitude of the IOR effect. In contrast, the mismatch theory predicts that long-term IOR effects should occur in Experiment 2a due to the mismatching cue and target signals, but no long-term IOR should occur in Experiment 2b.

Experiment 1

The aim of Experiment 1 was to replicate the standard IOR effect with a cue – target interval of 2000 milliseconds and no intervening displays using naturalistic face and object stimuli, with cues and targets that were similar to those used by Tipper et al. (2003). Faces appeared to the left and right of fixation and objects appeared above and below fixation. The task was to detect a green target signal presented over one of the two faces or objects. It was expected that response times would be slower to previously cued items compared to uncued items, thus revealing the basic short-term IOR effect. This result would indicate that the inhibitory processes underlying IOR are engaged when complex face and object stimuli are presented, suggesting that this paradigm is suitable for investigating the existence of long-term IOR.

Method

Participants

The participants were 16 undergraduate students (13 females, 3 males) from the University of Wales, Bangor, and their ages ranged from 18 – 25 years (mean age 19.5). All participants were right-handed with normal visual acuity, colour vision, and stereopsis, and they received course credit in return for their participation.

Apparatus and stimuli

Stimulus presentation and recording of response times were performed by the *E-prime* program (version 1.1, Psychology Software Tools, Inc.) running on a PC. The stimuli were presented on a 17 inch monitor, and a chinrest was used to keep participants at a distance of 57 cm from the monitor. A computer keyboard was located on a table within easy reach of the subjects. Keys 2, 4, 6, and 8 on the number pad of the computer keyboard were used to register the responses, and the 0 key was used to initiate trials.

The stimuli consisted of 280 colour face photographs and 280 colour object photographs. There were 280 stimulus displays, in which either two faces were aligned horizontally to the left and right of fixation, or two objects were aligned vertically above and below fixation. There were 35 female face pairs, 35 male face pairs, and 70 mixed face pairs, in which a male or a female face appeared equally often on the left and right. All faces were looking directly at the viewer, as eye-gaze can cause automatic orienting of attention (Driver et al., 1999; Friesen & Kingstone, 1998). Each left and right display subtended 12° of visual angle vertically and 18° horizontally, and each upper VF and lower VF display subtended 18° vertically and 12° horizontally. The cue and target signals were 4.3° horizontally by 5° vertically semitransparent red and green ovals that were overlaid on the faces and objects, leaving them visible. Examples of the cue and target displays for faces and objects are shown in Figure 2. Stimuli were presented on a black screen, and a central fixation point consisting of a white cross was present throughout each trial.

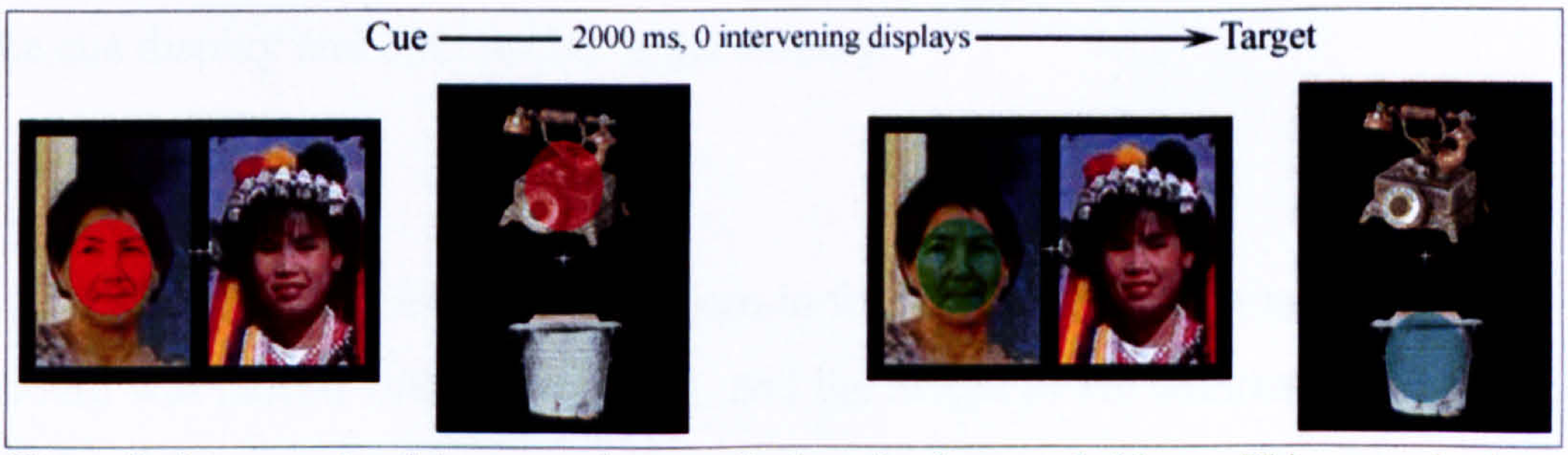

Figure 2: An example of the cue and target displays for faces and objects. This example shows the *cued left* condition for faces and the *uncued lower VF* condition for objects.

Design

This experiment used a repeated-measures factorial design with the independent variables *cueing* (cued or uncued), and *target location* (the left or right VF for faces or the upper or lower VF for objects). The experiment contained 256 trials in total, divided into four blocks of 64 trials each. Half of these trials displayed face stimuli and the other half displayed object stimuli. Presentation of a face display alternated with presentation of an object display. In each block there were 40 IOR trials (20 face trials and 20 object trials), in which the cue display required a 'no go' response and the target display required a 'go' response. In half of these trials the target appeared on a previously cued item, and in the other half the target appeared on an uncued item. In each cueing condition the target appeared equally often in both locations.

There were also 16 catch trials in each block; in 8 of these trials the cue display required a 'go' response and the target display required a 'no go' response, and in the remaining 8 trials both the cue and target displays required a 'no go' response. Half the catch trials displayed faces and the other half displayed objects. The purpose of the catch trials was to reduce the predictability of the 'no go – go' response sequence. The first 8 trials (4 face trials and 4 object trials) in each block were practice trials. In addition to the four experimental blocks, there was also a separate practice block consisting of 24 trials (half faces and half objects), of which 16 were IOR trials and 8 were catch trials.

The order of conditions and the order of the stimulus displays were randomised. Each stimulus display was only seen twice during the experiment, once as the cue display and once as the target display.

Procedure

Participants sat in a dimly lit room in front of the computer monitor. The keyboard was placed within easy reach, and the height of the chinrest was adjusted to a comfortable level. They were instructed to respond to green targets. They were also told to fixate on the fixation point throughout each trial, and to position their fingers on the correct keys on the number pad before each trial. For face displays participants had to press the 4 key with the left hand if the target appeared on the left, and the 6 key with the right hand if it appeared on the right; for object displays they had to press the 8 key with the right hand if it appeared in the upper VF, and the 2 key with the left hand if it appeared in the lower VF. The participants then completed the practice block, followed by the four experimental blocks. After each block participants had a 20 second break.

Before every trial, a picture display informed participants whether to expect faces or objects and instructed them to position their fingers on the keys accordingly. They then initiated the trial by pressing the 0 key with the thumb. A central fixation cross appeared for 300 ms, then the stimulus display appeared for 1000 ms, after which one item was overlaid by the cue signal for 200 ms. Then the original stimulus display was seen for a further 300 ms, followed by a blank screen for 700 ms. This was followed by the fixation cross for 300 ms, then the original stimulus display for 500 ms, after which the target signal was presented over one item for 200 ms. The original stimulus display then appeared for 300 ms, and then the screen remained blank for 700 ms. Participants had 1000 ms from the onset of the target signal to make a response. After responding, auditory feedback indicated whether the response was correct or incorrect. The cue-target interval was 2000 ms. The experiment lasted for approximately 35 minutes. The basic trial sequence is shown in Figure 3.

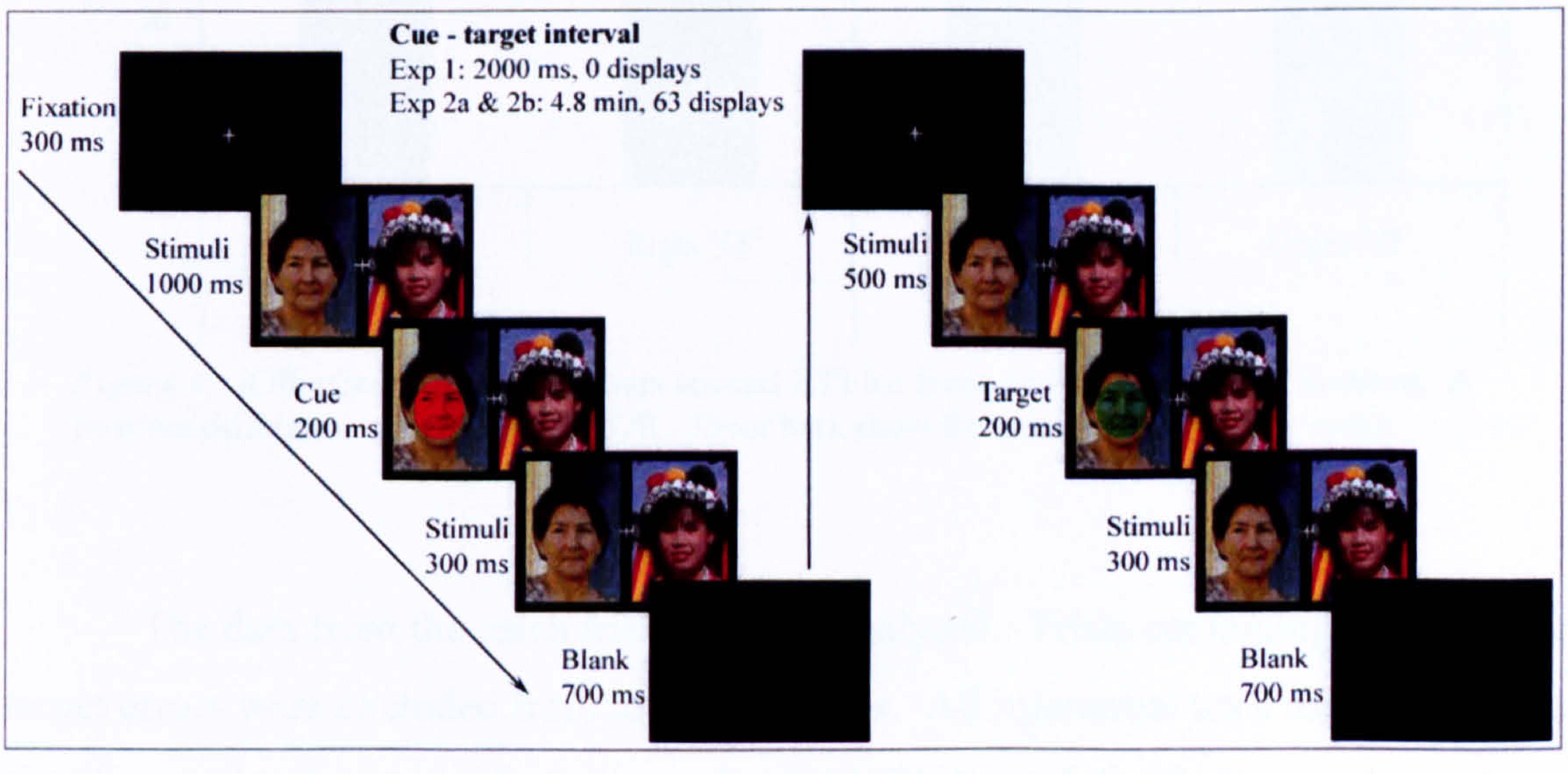

Figure 3: The sequence of events in a trial. This example shows the *cued left* condition for face stimuli in experiments 1 and 2a (mismatching cues and targets). The procedure for object stimuli was identical.

Results and discussion

Table 1 shows the mean reaction time (RT), standard deviation (SD), and percentage errors for each condition. Cue errors were responding to the 'no go' cue and target errors were either not responding, responding incorrectly, or responding too late (after 1000 ms) to the target. Figure 4 shows IOR effects (cued RT minus uncued RT) for faces and objects.

Table 1: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiment 1.

	Faces				**Objects**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Lower	Upper	Lower	Upper
Mean RT (ms)	405.75	387.44	352.50	346.88	423.44	419.56	370.41	375.56
SD (ms)	60.06	56.30	46.02	52.25	84.65	82.44	54.54	60.32
% cue errors	1.56	0.63	0.31	1.25	0.00	0.94	1.56	0.00
% target errors	1.25	0.63	0.94	0.31	2.50	3.13	3.44	2.19

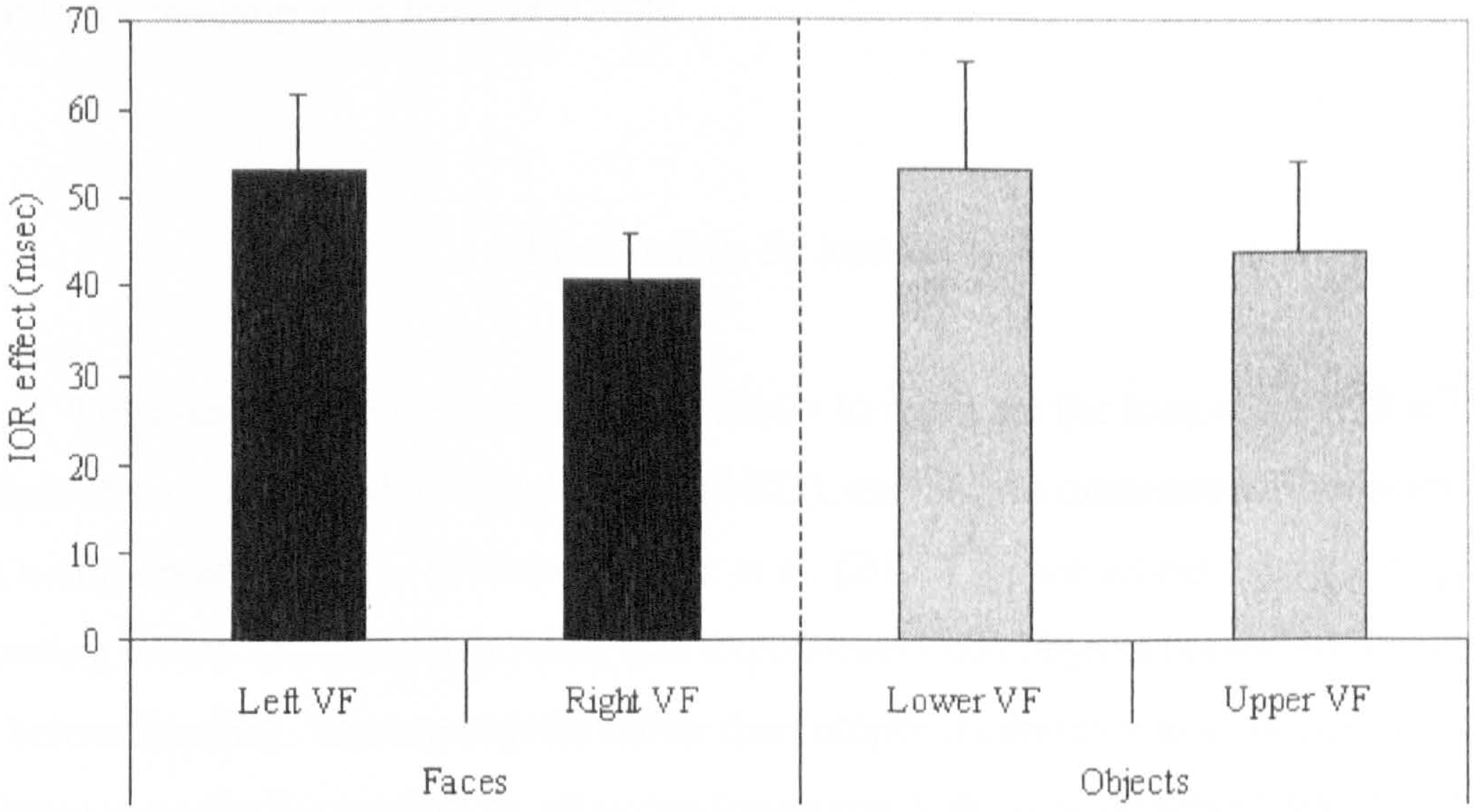

Figure 4: IOR effects (cued RT minus uncued RT) for faces and objects in each location. A positive difference score indicates IOR. Error bars show the standard error of the mean.

The data from the catch trials was not analysed. Trials containing either cue or target errors were excluded from the RT analysis. All inferential tests used a significance level of $p < .05$. Separate 2 x 2 ANOVAs with the factors *cueing* and *target location* were performed on median RTs and error rates for faces and objects.

Faces analysis

The RT analysis showed a significant main effect of cueing, $F(1, 15) = 77.59$, $p < .001$. There was also a significant main effect of location, $F(1, 15) = 5.46$, $p = .034$, with faster RTs on the right than on the left. However, there was no interaction between cueing and location, $F(1, 15) = 1.74$, ns. The error analysis found no significant effects.

Objects analysis

The effect of cueing was significant, $F(1, 15) = 22.90$, $p < .001$. However, there was no main effect of location, $F(1, 15) = 0.01$, ns, and no interaction between cueing and location, $F(1, 15) = 0.83$, ns. The error analysis found no significant effects.

These results show the standard IOR effect for faces on the left and right and for objects in the upper and lower visual fields. This indicates that this paradigm is suitable for investigating long-term IOR.

Experiments 2a and 2b

The aim of these experiments was firstly to replicate the long-term IOR effects for face stimuli observed by Tipper et al. (2003), and also to demonstrate long-term IOR using object stimuli. Whereas Tipper et al. (2003) separated out the face displays by cueing empty locations in scenes, this experiment cued objects presented above and below fixation. Cueing objects rather than empty locations was expected to facilitate memory for inhibition, allowing long-term IOR to be observed for objects as well as faces. The second goal of these experiments was to determine whether long-term IOR effects are due to the retrieval of prior inhibitory states or the retrieval of mismatching stimulus features, therefore the cue-target match was manipulated between subjects. In Experiment 2a (the mismatch condition), the cue signal was red and the target signal was green, whereas in Experiment 2b (the match condition) the cue and target signals were identical (see Figure 4). According to the inhibition theory, manipulating the cue-target match should not influence IOR. In contrast, the perceptual mismatch theory predicts that IOR effects should occur in the mismatch condition due to the mismatching cue and target signals, but no IOR should occur in the match condition.

Method

Participants

32 undergraduate students (16 in each experiment; 25 females, 7 males) aged 18 – 31 (mean age 20.4) from the University of Wales, Bangor participated in return for course credit or £5. All participants were right-handed with normal visual acuity, colour vision, and stereopsis.

Apparatus and stimuli

The apparatus and stimuli were identical to Experiment 1. However, in Experiment 2b the response rule was switched between the prime and probe displays, so that on IOR trials the cue signal matched the target signal (see Figure 5).

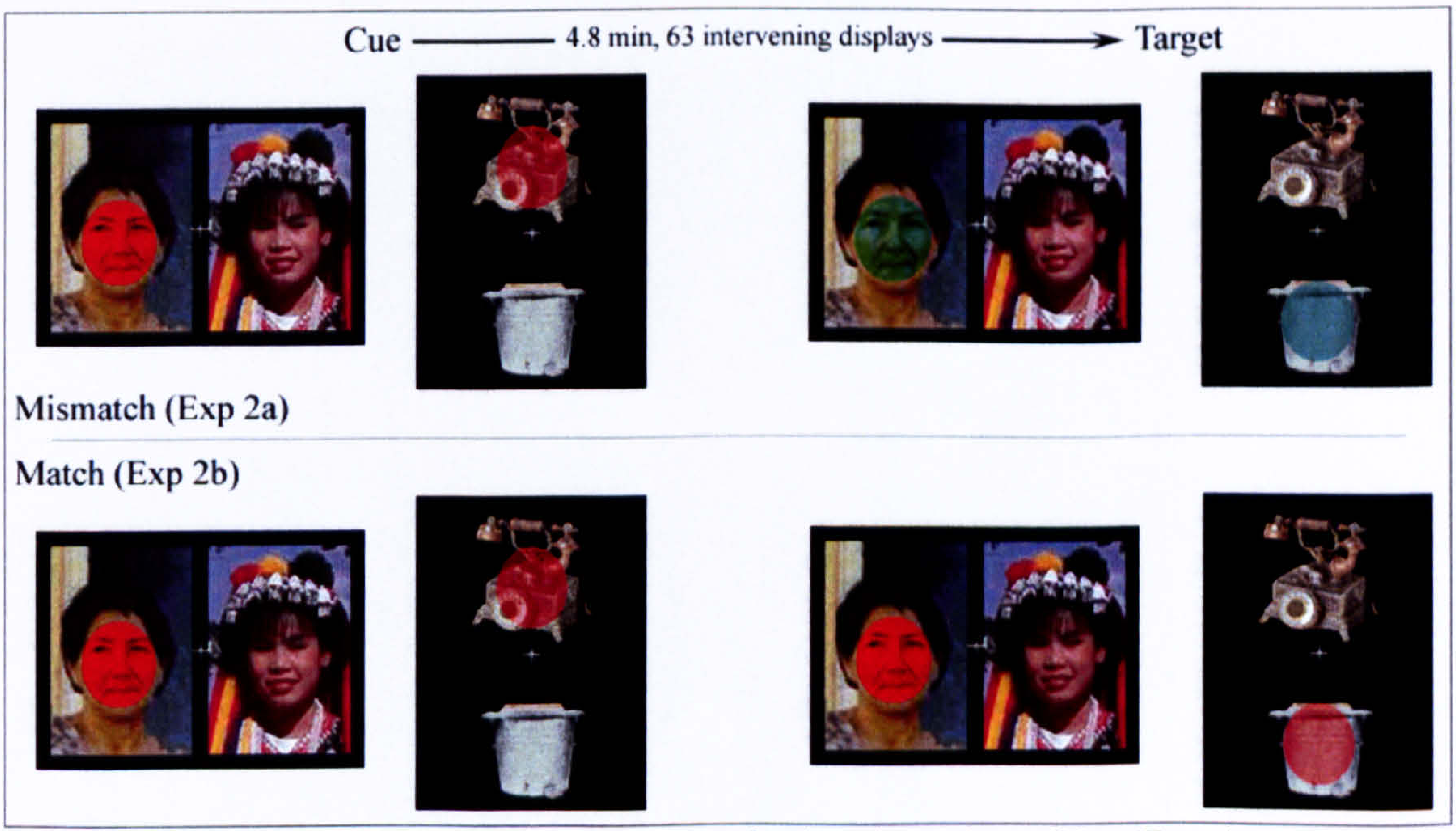

Figure 5: An example of the cue and target displays for the mismatch condition (Experiment 2a) and the match condition (Experiment 2b). This example shows the *cued left* condition for faces and the *uncued lower VF* condition for objects.

Design and procedure

The design and procedure were identical to Experiment 1, except that the cue and target displays were separated. That is, each block consisted of a set of 64 cue displays followed by a 20 second break and then 64 target displays (see Figure 6). The sets of cue and target displays were presented in the same order to reinstate the encoding context and to hold the SOA constant at 4.8 minutes and 63 displays. Half of the participants in Experiment 2b (matching cues and targets) responded to green (on catch trials) and ignored red in the cue display, and then responded to red and ignored green (on catch trials) in the target display. The other half did the opposite; that is, they ignored green and responded to red in the cue display, and ignored red and responded to green in the target display. So for half of the participants in the matching condition the cue and target signals on IOR trials were always red, and for the other half the cue and target signals were always green. In order to allow participants to become used to the new rule, the first 8 of each set of cue and target displays were practice trials.

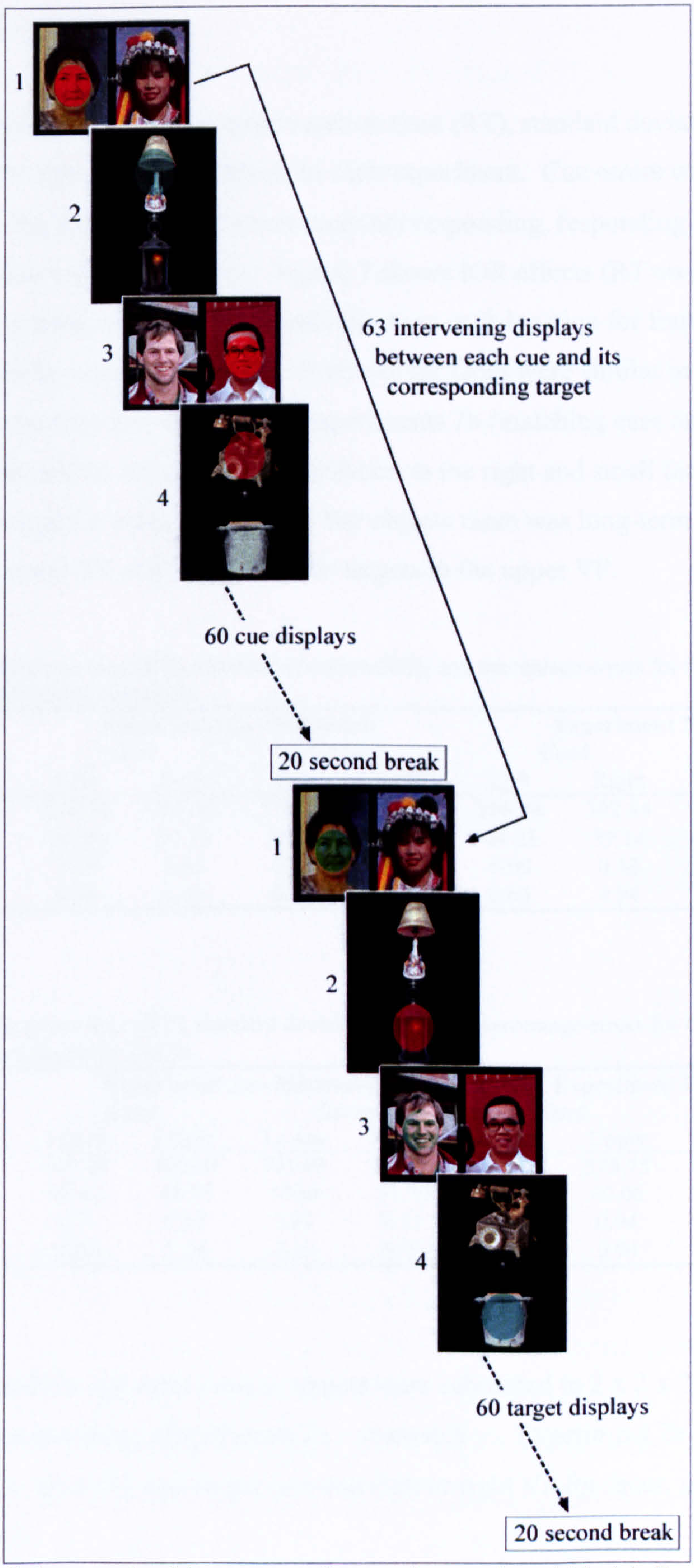

Figure 6: An example of the sequence of cues and targets in each block in Experiment 2a (mismatch). Each cue was separated from its corresponding target by 63 intervening displays and 4.8 minutes, during which cues and targets were presented in the same locations. The procedure for Experiment 2b (match) was identical.

Results and discussion

Tables 2 and 3 show the mean reaction time (RT), standard deviation, and percentage errors for faces and objects in each experiment. Cue errors were responding to the cue, and target errors were not responding, responding too late, or responding incorrectly to the target. Figure 7 shows IOR effects (RT on cued trials minus RT on uncued trials) for faces and objects in each location for Experiments 2a and 2b. As can be seen in Figure 7, IOR effects for faces were similar in Experiments 2a (mismatching cues and targets) and Experiments 2b (matching cues and targets). Long-term IOR effects were observed for faces on the right and small facilitation effects were found for faces on the left. For objects there was long-term IOR for targets in the lower VF and facilitation for targets in the upper VF.

Table 2: Mean response time (RT), standard deviation (SD), and percentage errors for faces in each condition in Experiments 2a and 2b.

	Experiment 2a - Mismatch				**Experiment 2b - Match**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	376.19	387.50	376.44	375.66	368.88	392.84	372.69	380.28
SD (ms)	42.40	51.15	38.42	56.17	44.03	59.14	46.33	37.82
% cue errors	1.25	0.63	0.63	0.31	0.00	0.63	0.94	0.31
% target errors	0.94	0.31	0.31	0.31	0.63	0.94	0.94	0.31

Table 3: Mean response time (RT), standard deviation (SD), and percentage errors for objects in each condition in Experiments 2a and 2b.

	Experiment 2a - Mismatch				**Experiment 2b - Match**			
	Cued		Uncued		Cued		Uncued	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Mean RT (ms)	401.09	380.09	391.88	387.09	415.53	378.75	413.28	379.22
SD (ms)	48.66	44.37	54.64	55.36	55.74	40.06	43.89	47.40
% cue errors	0.31	0.63	0.63	0.31	0.94	0.94	0.63	0.63
% target errors	5.63	1.56	2.19	0.31	4.38	0.94	1.88	1.88

Median RTs and error rates to targets were submitted to 2 x 2 x 2 ANOVAs with the factors *matching* (Experiment 2a - mismatch vs. Experiment 2b - match), *cueing* (cued or uncued), and *target location* (left or right VF for faces, upper or lower VF for objects).

Faces analysis

The RT analysis revealed a main effect of location, *F* (1, 30) = 4.60, *p* = .04, with faster RTs to targets on the left than on the right. Overall, RTs were slower to cued targets than uncued targets, and this difference almost reached significance, *F* (1, 30) = 3.39, *p* = .076. There was no main effect of matching, *F* (1, 30) < 0.01, *ns*, and matching did not interact with any other variable. There was a significant interaction between cueing and location, *F* (1, 30) = 4.27, *p* = .048 (see Figure 7). Planned comparisons revealed significant long-term IOR (12.2 ms) for cued versus uncued faces on the right, *F* (1, 30) = 7.01, *p* = .013, but not on the left, *F* (1, 30) = 0.23, *ns*. The error analysis found no significant effects.

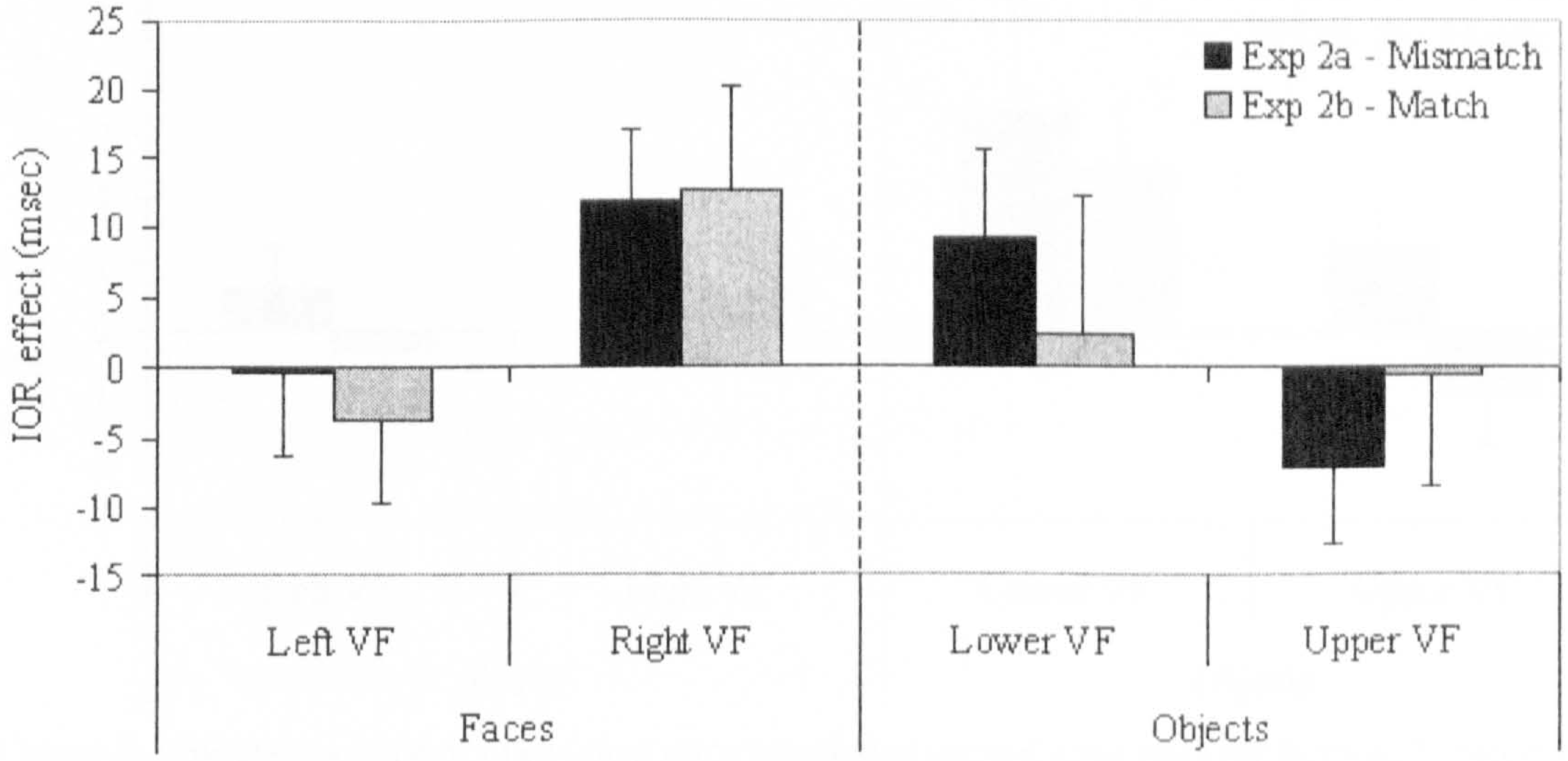

Figure 7: IOR effects (cued RT minus uncued RT) for faces and objects in Experiments 2a (mismatch) 2b (match). A positive difference score indicates IOR. Error bars show the standard error of the mean.

Objects analysis

The RT analysis revealed a highly significant effect of location, *F* (1, 30) = 19.35, *p* < .001; RTs were faster to targets in the upper VF than targets in the lower VF. However, there was no main effect of cueing, *F* (1, 30) = 0.07, *ns*, and there was no interaction between cueing and location, *F* (1, 30) = 1.40, *ns*. There was no main effect of matching, *F* (1, 30) = 0.18, *ns*, but there was a significant interaction between location and matching, *F* (1, 30) = 4.21, *p* = .049. Matching did not interact with cueing, *F* (1, 30) = 0.001, *ns*, or cueing and location, *F* (1, 30) = 0.71, *ns*.

The error analysis for objects revealed main effects of cueing, *F* (1, 30) = 7.44, *p* = .011, and location, *F* (1, 30) = 21.16, *p* < .001; participants made more errors to cued targets compared to uncued targets, and more errors to targets in the lower VF than in the upper VF. The error data also showed a significant interaction between cueing and location, *F* (1, 30) = 7.00, *p* < .013. Planned comparisons found significantly more errors to cued versus uncued targets in the lower VF, *F* (1, 30) = 9.04, *p* = .005 (see Figure 8), but not in the upper VF (*p* = .755). The error analysis showed no main effect of matching, *F* (1, 30) = 0.05, *ns*, and matching did not interact with any other variable.

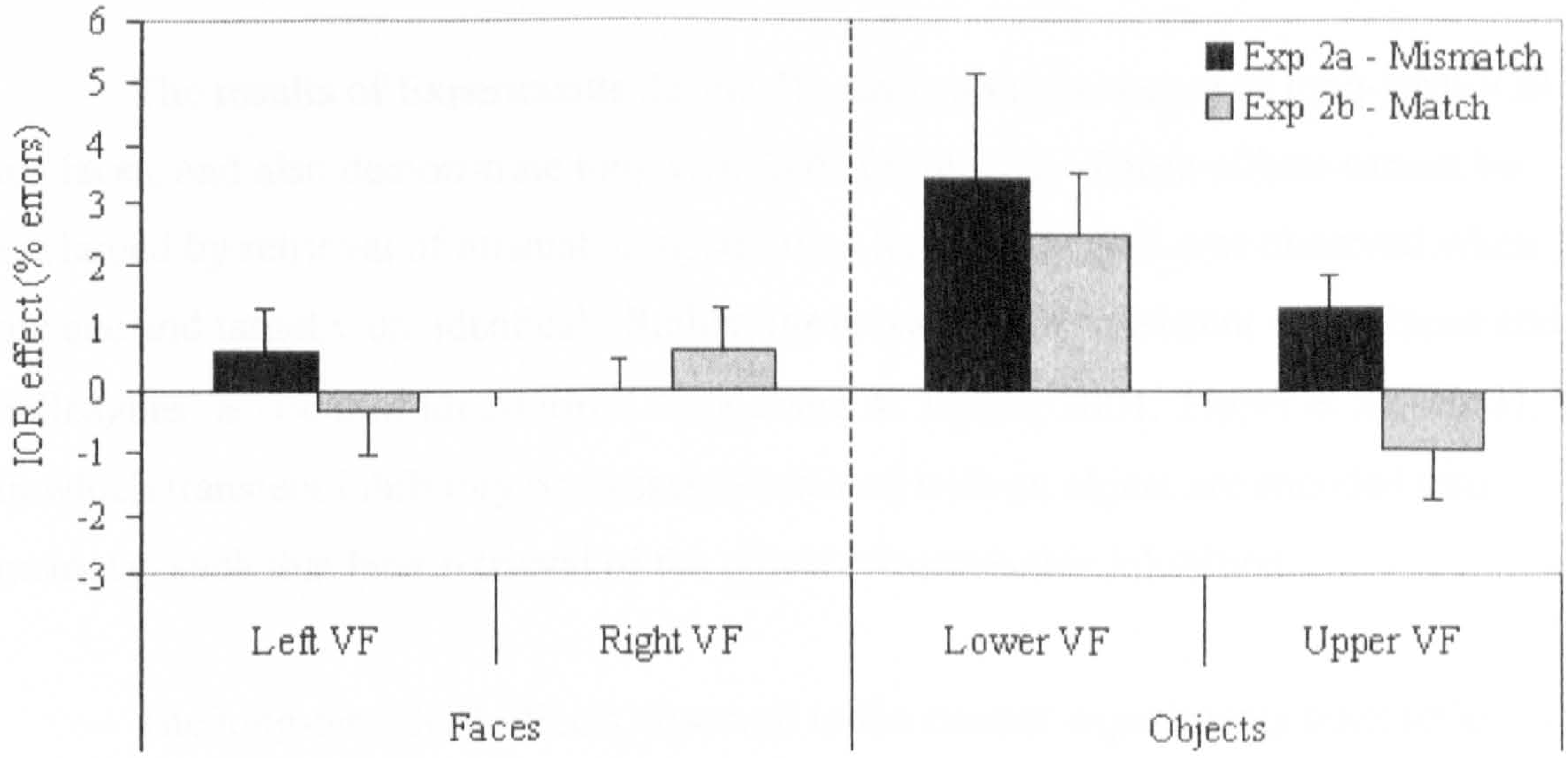

Figure 8: IOR effects in error rates (cued error rate minus uncued error rate) for faces and objects in Experiments 2a (mismatch) and 2b (match). A positive difference score indicates IOR. Error bars show the standard error of the mean.

The results show a small, but significant, long-term IOR effect for faces, with slower response times to faces that had been cued 4.8 minutes and 63 intervening displays previously, relative to uncued faces. This confirms previous findings of long-term IOR for faces (Kessler & Tipper, 2004; Tipper et al, 2003). Participants made more errors to previously cued objects compared to uncued objects. Although most studies of IOR have used RT measures, IOR has also been demonstrated using accuracy measures (e.g. Cheal et al., 1998; Handy et al., 1999). Therefore, the difference between cued and uncued error rates for objects in the current experiments can be assumed to reflect long-term IOR.

The main goal of these experiments was to determine whether these effects were due to retrieval of inhibitory processes, or retrieval of mismatching stimulus features. The long-term IOR effect for faces remained even when the cue and target were identical, which shows that this effect cannot be due to retrieval of mismatching perceptual information. Similarly, the IOR effect for objects was not influenced by manipulating the cue-target match. These results suggest that long-term IOR effects may be due to the encoding and retrieval of inhibitory states associated with cued objects.

General discussion

The results of Experiments 2a and 2b confirm the existence of long-term IOR for faces, and also demonstrate long-term IOR for objects. These effects cannot be explained by retrieval of mismatching stimulus features, as IOR was observed when the cue and target were identical. Rather, these results are consistent with Tipper and colleagues' account of long-term IOR (Kessler & Tipper, 2004; Tipper et al., 2003), in which transient inhibitory processes associated with an object are encoded into memory, such that later retrieval of the object reinstates this inhibition.

The long-term IOR effects observed in the current experiments must reflect a purely object-based form of IOR, as it is highly unlikely that location-based inhibition could be maintained over such long intervals and intervening events. Therefore, the results of this study disagree with Robertson's (2004) view that IOR acts on space-based representations. Rather, these results support previous findings showing that object-based representations facilitate efficient search over time (e.g. Paul & Tipper, 2003; Samuel & Kat, 2003; Tipper et al., 1996).

Long-term IOR for objects was only found in the lower VF. This is surprising because, as mentioned in Chapter 1, Kessler and Tipper (2004) found IOR for faces only in the upper VF, which is consistent with research showing that scanning and recognition processes are biased towards the upper VF. However, it is possible that the nature of the stimuli used in the current experiments led to the opposite pattern of IOR. The object stimuli consisted of a wide range of common objects, some of which were graspable and may have afforded action. According to Previc (1990), the upper VF projects more to ventral areas which have developed for search and recognition, whereas the lower VF projects more to dorsal areas which are specialised for reaching and manipulation of objects. Consistent with this idea, recent work has found stronger semantic priming effects for manipulable items presented in the lower VF compared to the upper VF, whereas the opposite pattern was found for non-manipulable items (Van Schie, 2003). Other work has shown that implicit recognition of an object's motor affordance biases visual attention more in the lower VF than in the upper VF (Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003).

Therefore, if some of the objects in the current experiments afforded actions, attention may have been biased towards manipulable objects in the lower VF, resulting in more robust memory representations and associated inhibition for these objects relative to manipulable objects in the upper VF. However, the set of object stimuli used in these experiments also included many non-manipulable objects, such as furniture. This may have reduced the overall IOR effects observed for objects in these experiments because, while cueing manipulable objects produced IOR effects in the lower VF and facilitation in the upper VF, cueing non-manipulable objects may have produced the reverse pattern.

It is interesting that the experiments reported here found long-term IOR for faces only in the right VF, whereas Tipper and colleagues (Kessler & Tipper, 2004; Tipper et al., 2003) found this effect only in the left VF. Tipper et al. (2003) suggested that the visual field asymmetry observed in their experiments was due to biased processing of faces in the right hemisphere. This assumption was based upon evidence that face recognition and episodic memory processing of faces are located in the right hemisphere (e.g. Kanwisher et al., 1997a; Zárate, Sanders, & Garza, 2000). However, the results of the current experiments suggest that these visual field differences may simply be due to a bias to attend to one of the faces in each pair, resulting in more efficient encoding and retrieval of that face and its associated inhibition. That is, retrieval of prior inhibitory processes may only occur in one visual field, but this varies across individuals, therefore the overall IOR effects may simply reflect variability in the sample. The visual field asymmetry observed for objects is consistent with this idea, as long-term IOR was only observed in the lower VF.

Alternatively, the different visual field asymmetries observed in the current experiments may reflect differences in the tasks. In Tipper et al.'s (2003) experiments the face displays were separated by scene displays, whereas the current experiments used objects instead of scenes. As mentioned previously, object-based IOR effects have been shown to be influenced by the type of task and the salience of the objects (e.g. Leek et al., 2003; McAuliffe et al., 2001; Paul & Tipper, 2003; Samuel & Kat, 2003). There is evidence to suggest that stimuli compete for neural resources, and this competition is biased by bottom-up factors such as stimulus salience and top-down factors such as task goals (Desimone, 1998; Desimone & Duncan, 1995; Kastner & Ungerleider, 2001). It is therefore possible that the use of object stimuli in the current experiments may have led to competition between faces and objects for processing resources, whereas the use of scenes in an intervening task (Tipper et al., 2003) did not produce competition.

Indeed, scenes and faces have been shown to be processed in distinct neural regions. For example, imaging studies have shown that viewing faces activates an area in the right fusiform gyrus (e.g. Kanwisher et al., 1997a; Tong et al., 2000), and viewing scenes activates an area in the posterior parahippocampal cortex (Epstein & Kanwisher, 1998). Deficits in face recognition arise from right-sided or bilateral lesions to the ventral visual association cortex (De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994), and deficits in navigation and memory for topographical materials have been observed following damage to the posterior parahippocampal cortex (Epstein, DeYoe, Press, Rosen, & Kanwisher, 2001). Therefore, because faces and scenes are processed in separate brain areas, there was no competition for processing resources in Tipper et al.'s (2003) experiments.

In contrast, research suggests that faces and objects are processed in overlapping brain areas. For example, Haxby et al. (2001) measured fMRI responses across a large area of ventral extrastriate cortex while participants viewed faces and different categories of objects. They found that the pattern of activity for each stimulus category was widely distributed across the ventral extrastriate cortex. Furthermore, the category that was being viewed could be identified by examining the pattern of response, even when the regions of maximal activity were excluded from the analysis. These findings suggest that faces and objects are represented in distributed and overlapping regions of ventral visual cortex. Therefore, it is possible that competition between faces and objects for processing resources caused the visual field asymmetries observed in the current experiments. This issue is addressed in the following chapter.

Chapter 3 – Visual field asymmetries in long-term inhibition of return

The experiments reported in Chapter 2 confirmed the existence of long-term IOR for face stimuli, and also found evidence of long-term IOR for object stimuli. It seems probable that these effects were caused by retrieval of inhibitory processes associated with previously cued objects and faces, as manipulation of the cue-target match did not influence IOR. However, long-term IOR was only observed for faces in the right VF, which contradicts previous research that found IOR only for faces on the left (Kessler & Tipper, 2004; Tipper et al., 2003). It is possible that retrieval of prior inhibitory processes only occurs in one visual field, but this varies across individuals, therefore the overall IOR effects may simply reflect random variability in the sample. However, this explanation is unlikely, as the pattern of IOR for faces observed previously by Tipper and colleagues was consistent across a number of experiments (Kessler & Tipper, 2004; Tipper et al., 2003).

As mentioned in the previous chapter, this reversal in visual field differences may be due to the use of objects rather than scenes in the intervening task. One means of attentional selection is competition among stimuli for neural representation (Desimone & Duncan, 1995), and it is possible that faces and objects were competing in this task. Although faces and objects were never present at the same time, there is evidence to suggest that competition between the two stimulus types could still occur. For example, neurons in the inferior temporal cortex and the superior temporal sulcus have been found to respond to a visual stimulus for longer than the physical duration of the stimulus (Keysers, Xiao, Földiák, & Perrett, 2001, 2005; Rolls, Tovee, & Panzeri, 1999). Furthermore, competition between sequentially presented stimuli has been observed. When a target stimulus is followed by a masking stimulus, the visibility of the target is reduced (e.g. Enns & Di Lollo, 2000; Felsten & Wasserman, 1980). According to Keysers and Perrett (2002), this masking effect is due to neural competition between old and new stimuli. In support of this idea, single neuron recordings in the temporal cortex have revealed that presentation of a mask shortly after the target reduces the quality and duration of the neural representation of the target (e.g. Keysers et al., 2001; Rolls et al., 1999).

It is possible that faces and objects were competing for processing resources in Experiments 2a and 2b because they are processed in the same brain regions, whereas the scenes in Tipper et al.'s (2003) study did not compete with faces for processing because scenes are processed in separate brain areas. Indeed, research suggests that faces and scenes are processed in anatomically distinct brain regions. For example, research using fMRI has shown that viewing faces activates an area in the right fusiform gyrus (Kanwisher et al., 1997a; McCarthy, Puce, Gore, & Allison, 1997; Tong et al., 2000), whereas viewing scenes activates an area in the posterior parahippocampal cortex (Epstein & Kanwisher, 1998). Deficits in face recognition arise from right-sided or bilateral lesions to the ventral visual association cortex (De Renzi et al., 1994), and deficits in navigation and memory for topographical materials have been observed following damage to the posterior parahippocampal cortex (Epstein et al., 2001).

In contrast, objects and faces are processed in overlapping brain areas (Haxby et al., 2001). Also, recent evidence suggests that the right fusiform cortex is involved in the encoding of precise object details to allow for the subsequent exemplar-specific recognition of objects (Garoff, Slotnick, & Schacter, 2005). Although some authors have suggested that face recognition proceeds separately from object recognition (e.g. Kanwisher, 2000; Kanwisher et al., 1997a), other work has shown that face-selective cortical areas are also used for expert perception of nonface objects (Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999). In addition, faces and objects can produce similar electrophysiological responses. The amplitude of the N170 ERP component is typically increased for faces relative to other objects (e.g. Bentin & Deouell, 2000; Eimer, 2000), and it has therefore been thought to indicate selective face perception processes. However, this enhanced N170 component is also produced by expert object recognition (Rossion, Curran, & Gauthier, 2002; Rossion, Gauthier, Goffaux, Tarr, & Crommelinck, 2002; Tanaka & Curran, 2001), which shows that similar neural processes mediate perception of both faces and objects.

Importantly, recent work suggests that the neural mechanisms underlying face and object recognition are functionally related. In an ERP study of face and object processing, Gauthier, Curran, Curby, & Collins (2003; see also Gauthier & Curby, 2005) found that, when presentation of faces alternated with presentation of cars, the amplitude of the N170 ERP component was increased for cars and reduced for faces in car experts relative to car novices, indicating that processing of cars by car experts interfered with face perception. Also, this interference was greater in the right hemisphere than in the left hemisphere. Similar results were reported in a subsequent study, in which expert recognition of novel, nonface objects interfered with face processing, causing a reduction in the N170 ERP component elicited by faces (Rossion, Kung, & Tarr, 2004). These findings show that the mechanisms for face and object processing are not functionally independent, and similar processes mediate both face and object perception. Furthermore, these results show that processing of objects can interfere with face processing, which is consistent with the idea that faces and objects were competing for processing in Experiments 2a and 2b.

The first goal of this chapter was to confirm the visual field asymmetries in IOR for faces observed in Chapter 2. In Experiment 3a, faces and objects were presented to the left and right VFs. If the same pattern of IOR for faces could be replicated in a slightly different paradigm, then this would rule out the possibility that the visual field asymmetries in IOR reflect random individual differences. In addition, Experiment 3b investigated long-term IOR for faces in the upper and lower VFs and objects in the left and right VFs. If faces and objects were competing for processing resources in this task, then the opposite pattern of IOR should be observed for each type of stimuli. That is, IOR for objects should occur in the left VF and IOR for faces should only be observed in the upper VF (recall that the previous experiments found IOR for faces in the right VF and objects in the lower VF). Such asymmetry in the pattern of IOR across the visual fields for faces and objects would provide further support for the idea that faces and objects were competing in this task.

Finally, and most importantly, this chapter directly examined whether the reversal in visual field differences in the current series of experiments compared to previous work was due to competition between faces and objects. The object displays from Experiment 2a were replaced with either scenes (Experiment 4a) or a blank screen (Experiment 4b). This meant that the pattern of IOR for faces on the left and right could be compared in terms of whether the intervening task contained *objects* (Experiments 2a and 3a) or *no objects* (Experiments 4a and 4b). When no objects were present, it was expected that the pattern of IOR for faces would be reversed compared to Experiments 2a and 3a, in which objects were present.

Experiments 3a and 3b

Experiment 3a was identical to Experiment 2a, except that objects appeared on the left and right (rather than in the upper and lower VFs) and the same response keys were used for objects and faces. It was assumed that this experiment would replicate the pattern of long-term IOR observed in the previous chapter; that is, IOR for faces in the right VF but not in the left VF. So there should be no differences in IOR effects for faces in Experiments 2a and 3a. Furthermore, if faces were competing with objects for processing resources in this task, then the opposite pattern of IOR should be observed for objects; that is, IOR for objects in the left VF but not in the right VF. Slightly brighter and less transparent shades of red and green were used for the cue and target signals in Experiment 3a to ensure that the IOR effects can be generalised to different cues and targets.

In Experiment 3b, faces appeared above and below fixation and objects appeared on the left and right of fixation. This manipulation was designed to confirm the results for objects in Experiment 3a, and also to investigate processing biases for faces in the upper and lower VFs. Because long-term IOR effects were observed for objects in the lower VF but not in the upper VF in Experiments 2a and 2b, the opposite pattern was expected for faces in Experiment 3b. This result would also be consistent with previous work showing greater IOR for faces in the upper VF compared to the lower VF (Kessler & Tipper, 2004).

Method

Participants

32 undergraduate students (16 in each experiment; 27 females, 5 males) aged 18 – 39 (mean age 21.6) from the University of Wales, Bangor participated in return for course credit. All participants were right-handed, with normal visual acuity, colour vision, and stereopsis.

Apparatus and stimuli

These experiments used the same apparatus as Experiment 1. The same face and object photographs were also used, but in Experiment 3a both faces and objects appeared on the left and right, whereas in Experiment 3b faces appeared above and below fixation and objects appeared on the left and right (see Figure 9). In Experiment 3b a male or female face appeared equally often in the upper or lower VF. Also, to ensure that the visual field asymmetry observed for faces in Experiments 2a and 2b cannot be due to the features of the faces, each face appeared on the opposite side in Experiment 3a. That is, a face which appeared on the left in Experiments 2a and 2b appeared on the right in Experiment 3a. Similarly, each object in Experiments 3a and 3b appeared in the opposite visual field in each experiment; so an object that appeared on the left in Experiment 3a appeared on the right in Experiment 3b.

Each left and right display subtended 12° of visual angle vertically and 18° horizontally, and each upper VF and lower VF display subtended 18° vertically and 12° horizontally. The cue and target signals were 4.3° horizontally by 5° vertically semitransparent red and green circles that were overlaid on the faces and objects, leaving them visible. Slightly brighter and less transparent shades of red and green were used for the cue and target signals in Experiment 3a to ensure that the IOR effects can be generalised to different cues and targets.

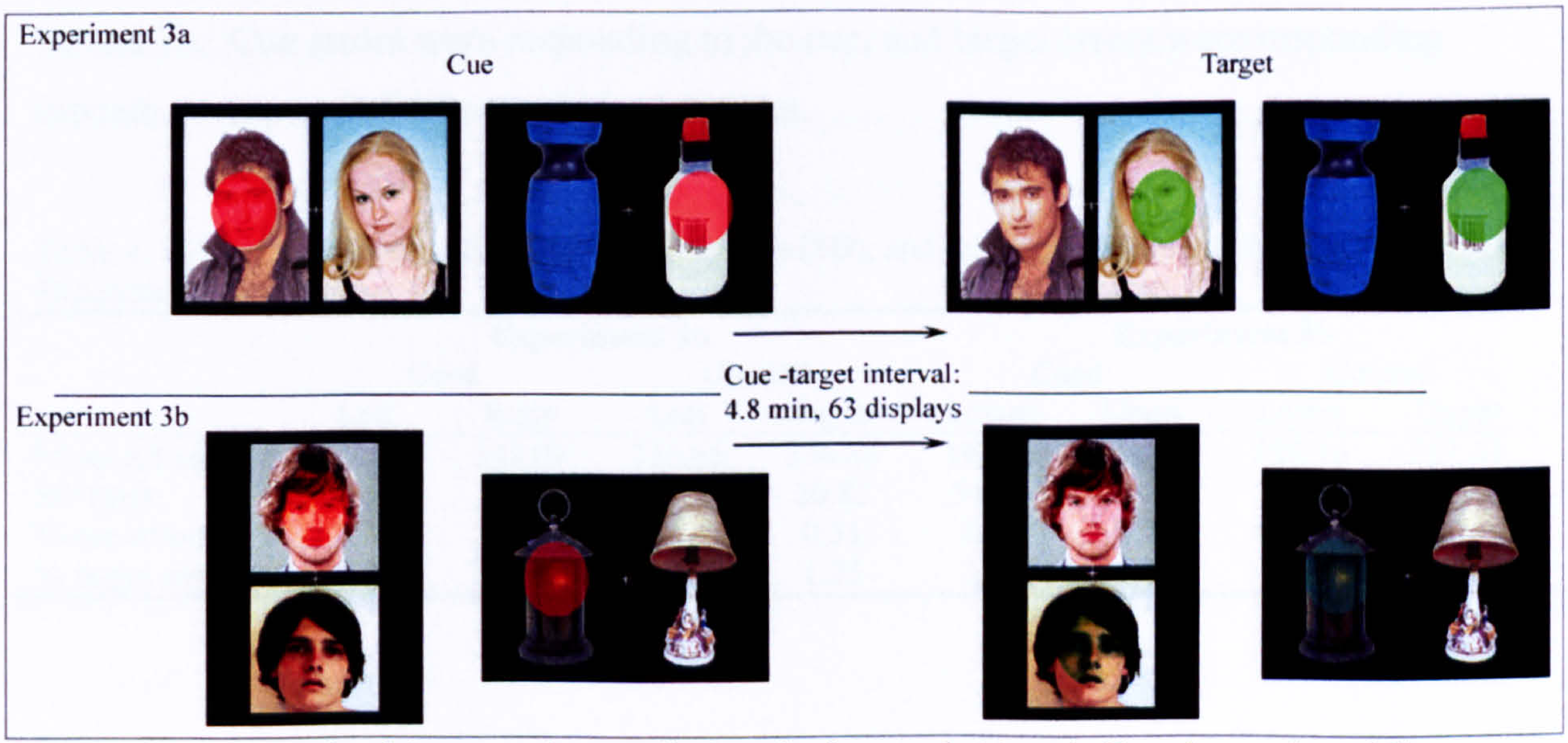

Figure 9: An example of the cue and target displays for faces and objects in Experiments 3a and 3b.

Design and procedure

The design and procedure was identical to Experiment 2a. Each experiment used a repeated-measures factorial design with the independent variables *cueing* (cued or uncued), and *target location*. In Experiment 3a the target location was the left or right VF for both faces and objects, and in Experiment 3b the target location was the upper or lower VF for faces and the left or right VF for objects. Participants in Experiment 3a were instructed to respond by pressing the 4 key with the left hand if the target appeared on the left face or object, and the 6 key with the right hand if it appeared on the right face or object. In Experiment 3b participants used keys 4 and 6 with the left and right hands for responding to targets appearing on objects, and they had to respond to faces by pressing the 8 key with the right hand if the target was in the upper VF and the 2 key with the left hand if the target appeared in the lower VF. In both experiments participants initiated each trial by pressing the 0 key with the thumb.

Results and discussion

Due to an error by the experimenter, one object display was shown twice in Experiment 3a. Therefore, response times to the second presentation of this object display were removed from the analysis. Tables 4 and 5 show the mean reaction times, standard deviations, and percentage errors for faces and objects in Experiments 3a and 3b. Cue errors were responding to the cue, and target errors were responding too late or responding incorrectly to the target.

Table 4: Mean response time (RT), standard deviation (SD), and percentage errors for faces in Experiments 3a and 3b.

	Experiment 3a				**Experiment 3b**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Lower	Upper	Lower	Upper
Mean RT (ms)	329.59	344.09	335.66	336.88	393.13	388.63	397.16	381.63
SD (ms)	16.57	25.45	28.25	20.85	54.86	71.38	57.68	60.77
% cue errors	0.31	0.31	0.63	0.31	1.25	1.25	0.00	0.31
% target errors	0.63	2.19	0.31	1.25	2.81	1.88	3.75	2.19

Table 5: Mean response time (RT), standard deviation (SD), and percentage errors for objects in Experiments 3a and 3b.

	Experiment 3a				**Experiment 3b**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	337.84	337.66	334.38	344.84	358.38	341.22	351.94	348.94
SD (ms)	19.08	20.20	18.39	25.47	36.65	36.28	36.83	45.24
% cue errors	0.00	0.31	0.00	0.31	0.94	0.63	1.25	1.25
% target errors	0.31	0.31	0.31	0.63	0.63	0.94	0.00	0.31

The data from the catch trials was not analysed, and trials containing cue or target errors were excluded from the RT analysis. Median response times (RTs) and error rates from Experiments 3a and 3b were analysed together with the data from Experiment 2a, in order to compare IOR effects as a function of the intervening task.

Faces on the left and right

Median RTs and error rates to targets were submitted to 2 x 2 x 2 ANOVAs with the factors *intervening task* (Experiment 2a – objects in the upper and lower VFs or Experiment 3a – objects in the left and right VFs), *cueing* (cued or uncued) and *target location* (left or right). The RT analysis found a significant main effect of intervening task, F (1, 30) = 13.24, p = .001, with faster RTs in Experiment 3a than in Experiment 2a, however the intervening task did not interact with any other variable. There was no main effect of cueing (F (1, 30) = 2.00, ns), or location (F (1, 30) = 1.69, ns), but there was a significant interaction between cueing and location, F (1, 30) = 4.61, p = .04. Planned comparisons found that RTs were significantly slower (9.5 ms) for cued versus uncued targets on the right, F (1, 30) = 8.36, p = .007 (See Figure 10). RTs were faster (3.2 ms) for cued versus uncued targets on the left, however this facilitation effect was not significant (p = .45). The error analysis found no significant effects.

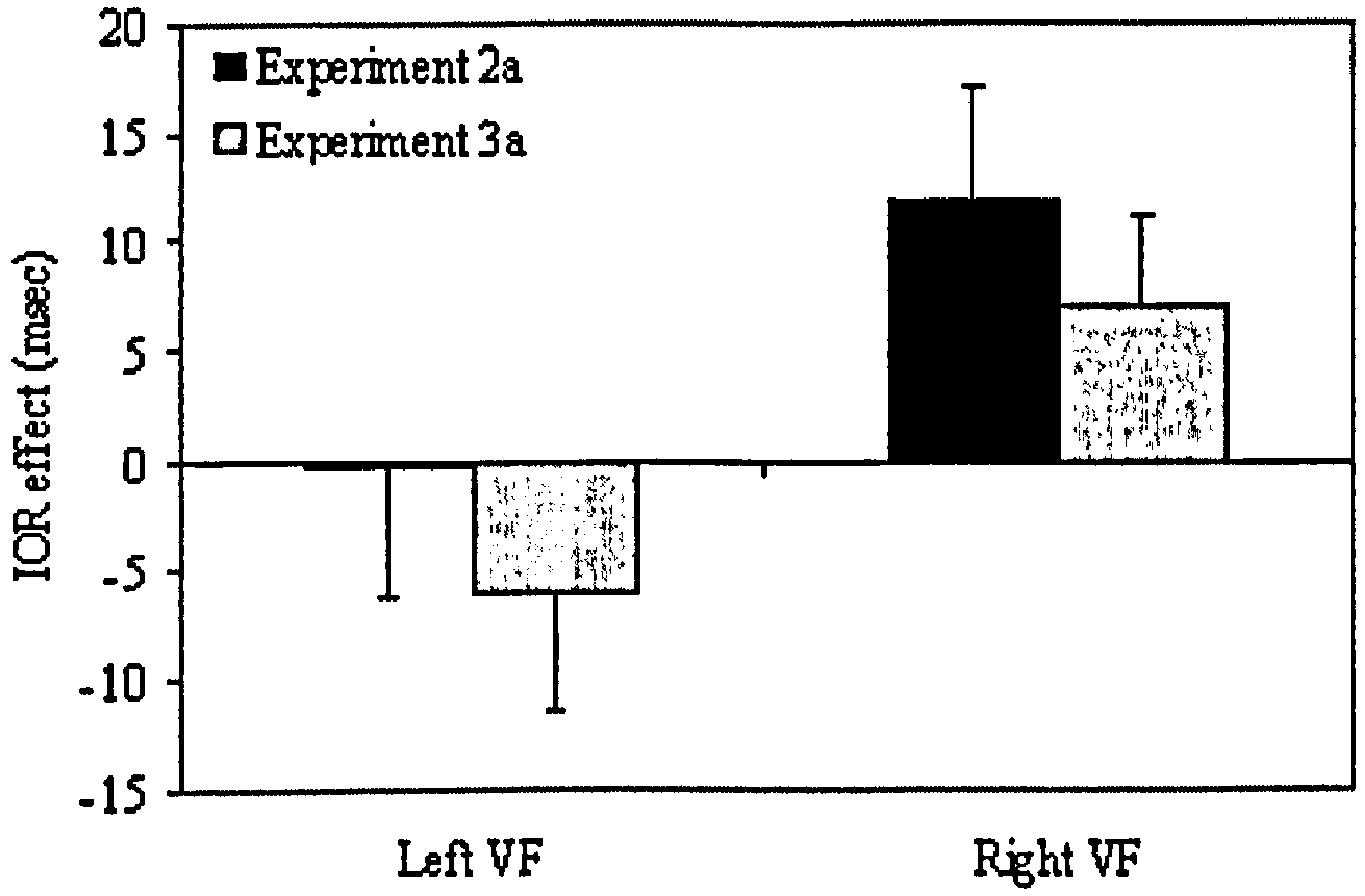

Figure 10: IOR effects (cued RT minus uncued RT) for faces in the left and right visual fields as a function of the intervening task (Experiment 2a – objects in upper and lower VFs or Experiment 3a – objects in left and right VFs). A positive difference score indicates IOR. Error bars show the standard error of the mean.

Faces in the upper and lower VFs

Median RTs and error rates to targets in Experiment 3b were submitted to 2 x 2 ANOVAs with the factors *cueing* and *location* (upper VF or lower VF). This analysis found no significant effects in RTs or error rates.

Objects on the left and right

Separate 2 x 2 x 2 ANOVAs with the factors *intervening task* (Experiment 3a – faces in the left and right VFs or Experiment 3b – faces in the upper and lower VFs), *cueing* (cued or uncued) and *target location* (left or right) were performed on median RTs and error rates. The RT analysis revealed a significant interaction between cueing and location, $F(1, 30) = 9.74$, $p = .004$. Planned comparisons found a marginally significant IOR effect (5.0 ms) for objects on the left, $F(1, 30) = 3.50$, $p = .071$, and a marginally significant facilitation effect (7.5 ms) for objects on the right, $F(1, 30) = 3.33$, $p = .078$ (see Figure 11). The error analysis found no significant effects.

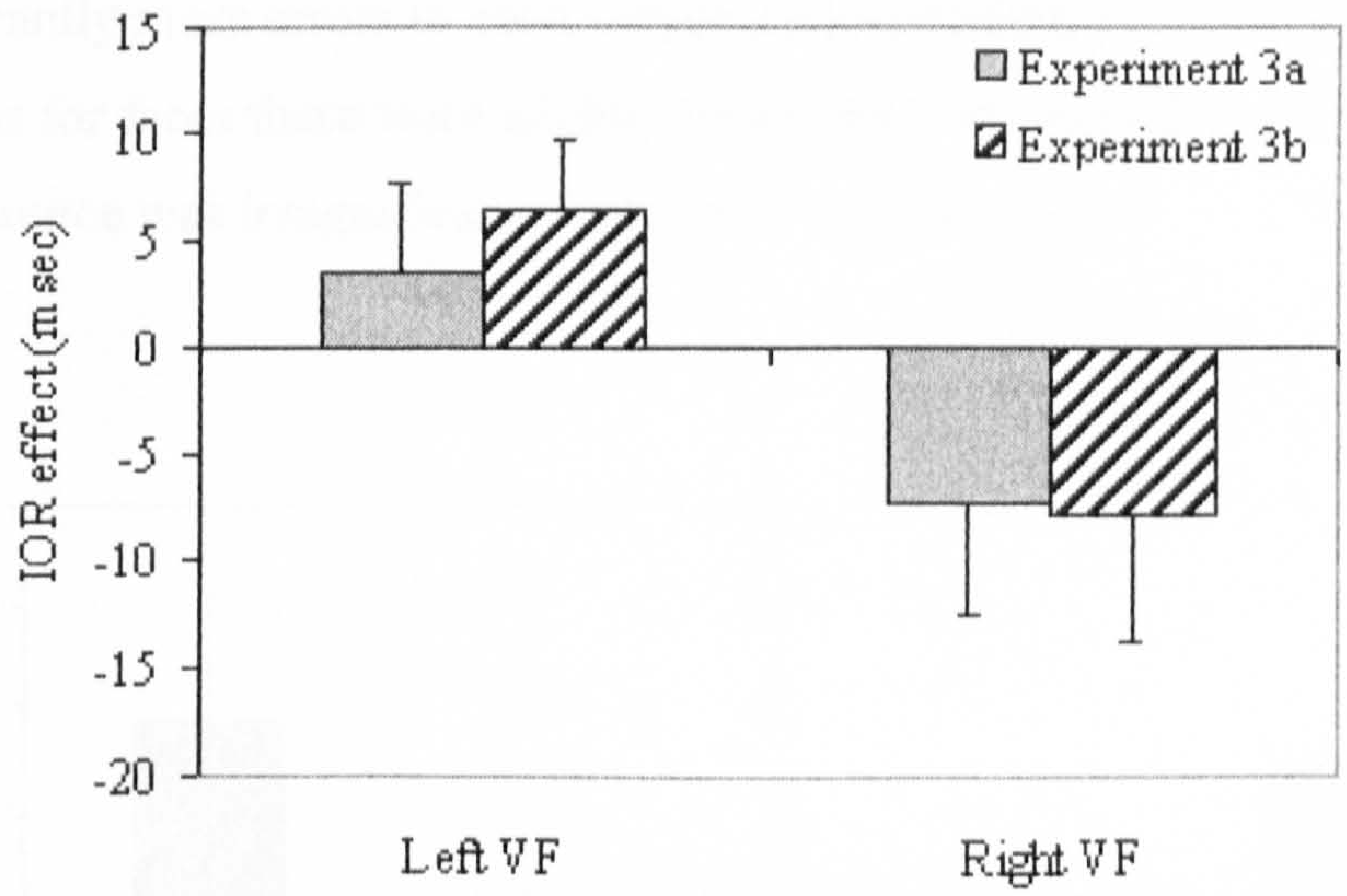

Figure 11: IOR effects for objects in the left and right visual fields as a function of the intervening task (Experiment 3a – faces in left and right VFs or Experiment 3b – faces in upper and lower VFs). Error bars show the standard error of the mean.

Faces and objects

Median RTs and error rates for faces on the left and right (Experiments 2a and 3a) and objects on the left and right (Experiments 3a and 3b) were submitted to 2 x 2 x 2 ANOVAs with the factors *stimuli* (faces or objects), *cueing* (cued or uncued), and *location* (left or right). The RT analysis revealed a significant 3 way interaction, *F* (1, 31) = 15.00, *p* = .001, revealing IOR for faces in the right VF (see Figure 10) and IOR for objects in the left VF (see Figure 11). The error analysis found no significant effects.

2 x 2 x 2 ANOVAs with the factors *stimuli* (faces or objects), *cueing* (cued or uncued), and *location* (upper VF or lower VF) were also performed on median RTs and error rates for faces in the upper VF and lower VF (Experiment 3b) and objects in the upper VF and lower VF (Experiment 2a). The RT analysis found a significant 3 way interaction, *F* (1, 30) = 6.11, *p* = .019, revealing IOR for objects in the lower VF and IOR for faces in the upper VF (see Figure 12). There was also a marginally significant main effect of location, *F* (1, 30) = 3.19, *p* = .084, with faster RTs to targets in the upper VF than in the lower VF. The error analysis showed that there were significantly more errors to targets in the lower VF than in the upper VF, *F* (1, 30) = 9.99, *p* = .004, and there was a significant interaction between stimuli and cueing, *F* (1, 30) = 9.42, *p* = .005. Planned comparisons showed that for objects there

were significantly more errors to cued versus uncued targets, $F(1, 15) = 7.83$, $p = .014$, whereas for faces there were slightly more errors to uncued versus cued targets, but this difference was insignificant, $F(1, 15) = 1.67$, $p = .22$.

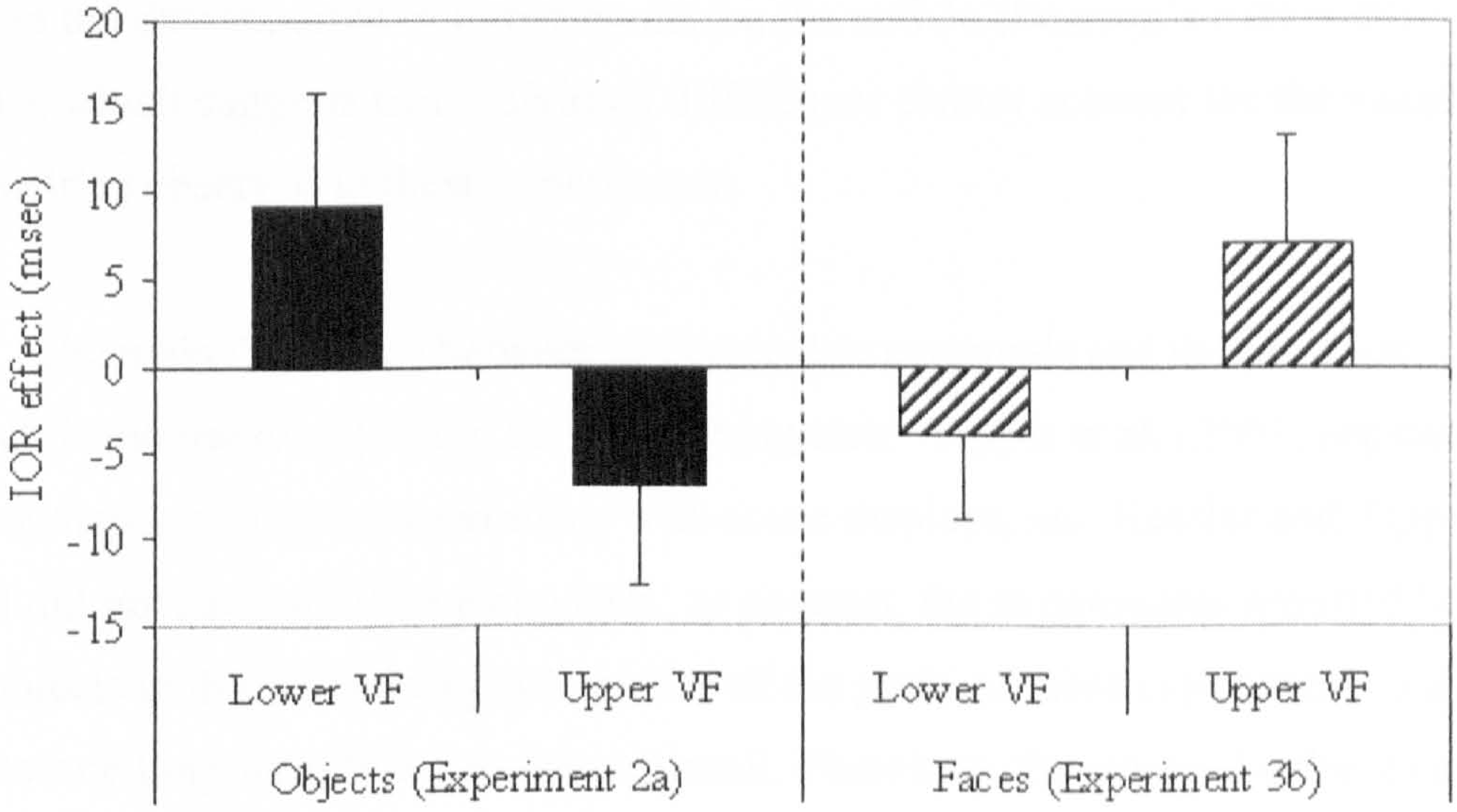

Figure 12: IOR effects (cued RT minus uncued RT) for faces (Experiment 3b) and objects (Experiment 2a) in the upper VF and lower VF. A positive difference score indicates IOR. Error bars show the standard error of the mean.

The results reveal the presence of long-term IOR for faces in the right VF, but not in the left VF, which is consistent with the results of Experiments 2a and 2b. This confirms the existence of long-term IOR for faces on the right when face displays alternate with object displays. Long-term IOR was observed for objects on the left and facilitation occurred for objects on the right. This visual field asymmetry is the opposite to that observed for faces, which provides further support for the notion that faces and objects were competing for processing resources in this task. IOR effects for faces and objects on the left and right were smaller when the stimuli in the intervening task also appeared on the left and right, compared to when the intervening task was in the upper and lower VFs. This is also consistent with the idea that faces and objects were competing for processing resources in this task.

It is unlikely that the visual field asymmetries in long-term IOR are due to individual differences in processing biases, because the pattern observed in previous studies has been highly consistent across a number of experiments (Kessler & Tipper, 2004; Tipper et al., 2003), and the opposite pattern has consistently been observed in experiments 2a, 2b, and 3a when objects were presented in the intervening task. Furthermore, if these visual field asymmetries for faces are due to random individual differences in hemispheric lateralisation, then the results should reveal a negative correlation between IOR on the left and IOR on the right. No such correlation was found in the data reported in Experiments 2a, 2b, and 3a (Pearson's r (N = 48) = -.12, $p = .40$), which suggests that individual differences cannot account for the visual field asymmetries observed in these experiments.

The main difference between the current experiments and the previous research is the use of objects in the intervening task. Tipper et al. (2003) separated the face displays in their experiments with scene displays, and Kessler and Tipper (2004) did not have an intervening task. In contrast, the experiments reported here used objects in the intervening task, as one of the goals of these experiments was to demonstrate long-term IOR for object stimuli. Therefore, the reason for the reversal of hemispheric differences may be because these experiments used object displays instead of scene displays in the intervening task. It is possible that faces and objects may compete for processing resources, whereas faces and scenes are processed separately in the brain and do not compete for processing.

Experiments 4a and 4b

The purpose of these experiments was to determine whether removing the objects from the display and replacing them with either scenes (Experiment 4a) or empty space (Experiment 4b) would cause the visual field differences in IOR to revert back to the pattern observed in previous studies that did not use objects in an intervening task (Kessler & Tipper, 2004; Tipper et al., 2003). If the reversal in hemispheric differences observed in the previous experiments was caused by competition between faces and objects, then the pattern of long-term IOR should be significantly different in Experiments 4a and 4b (no objects) compared to Experiments 2a and 3a, in which the intervening task contained objects. Therefore, there should be a three-way interaction between intervening task (*objects* or *no objects*), cueing, and location, with slower RTs to cued versus uncued targets on the right when the intervening task involved objects, and on the left when the intervening task contained no objects.

Method

Participants

The participants were 32 students (16 in each experiment; 23 females, 9 males) from the University of Wales, Bangor. Their ages ranged from 18 to 36 (mean age 23.1), and they were all right-handed with normal or corrected-to-normal colour vision. Participants received course credit or £5 for participating.

Apparatus and stimuli

The apparatus and stimuli for Experiment 4a were identical to Experiment 2a, except that the object displays were replaced with scenes (see Figure 13). There were 140 colour scene photographs, of which 70 were outdoor scenes and 70 were indoor scenes. Each scene display subtended 18° of visual angle vertically and 12° horizontally. A central fixation point consisting of a white cross in a black square (0.6° x 0.6°) was presented in the centre of each scene. The cue and target signals for faces were the same as those used in Experiment 2a. However, for scenes the cue signal was a white X in a black square and the target signal was a white O in a black square. The cue and target signals appeared in the upper or lower part of the scene, and the 2 and 8 keys of the numberpad were used to register the responses.

The apparatus and stimuli was the same for Experiment 4b, except that the intervening displays were replaced with a black screen containing a central white fixation cross. The cue and target signals that appeared on the black screen were identical to those used for the objects in Experiment 2a, except that they were slightly less transparent to make them easier to detect against the black background.

Design and procedure

The design and procedure were identical to Experiment 2a.

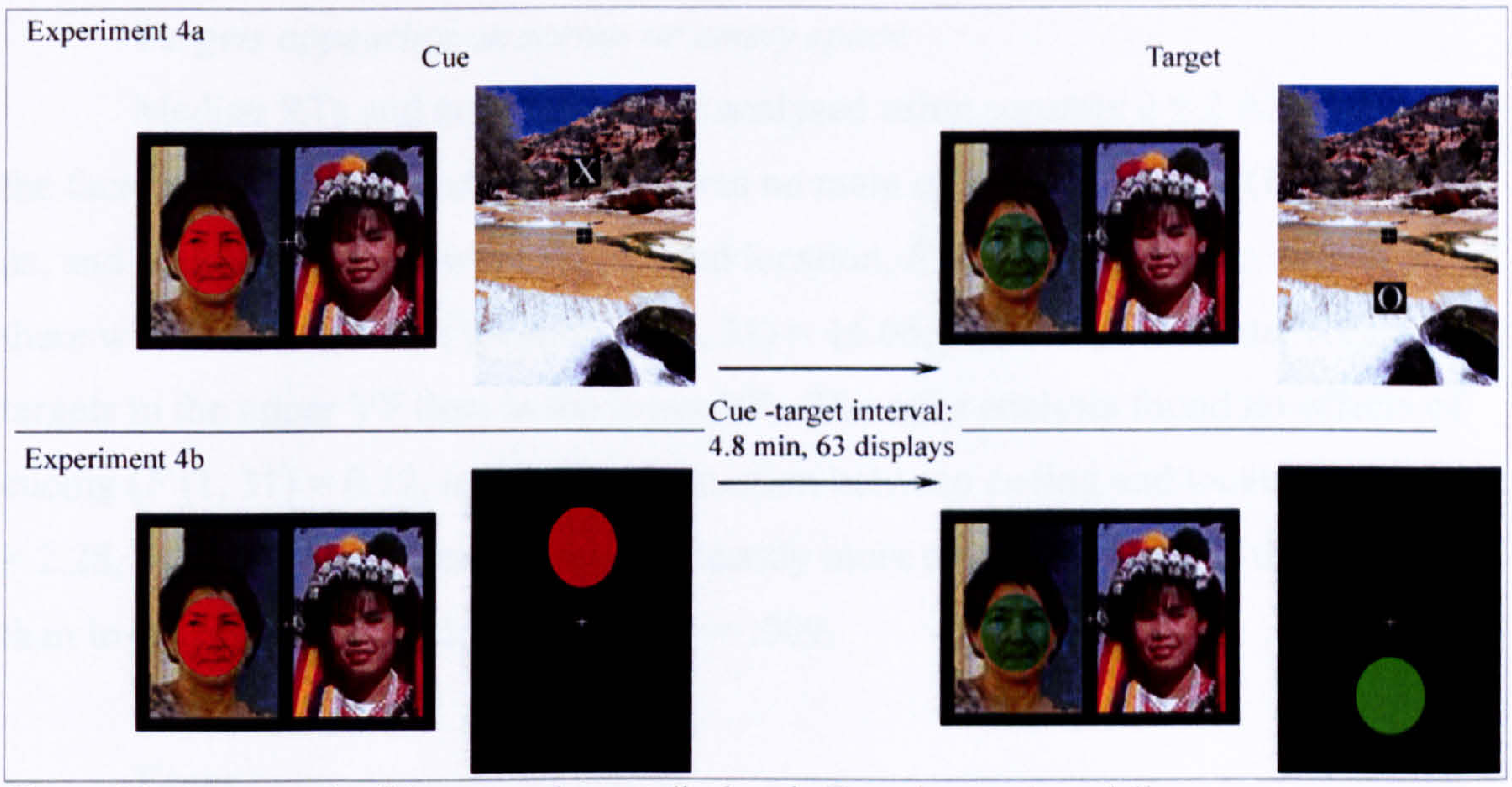

Figure 13: An example of the cue and target displays in Experiments 4a and 4b.

Results and discussion

Mean RTs, standard deviations, and error rates for each condition in each experiment are shown in Table 6 (faces) and Table 7 (scenes and blank screen). The data from the catch trials was not analysed, and trials containing cue or target errors were excluded from the RT analysis.

Table 6: Mean response time (RT), standard deviation (SD), percentage cue errors, and percentage target errors for faces in Experiments 4a and 4b.

	Faces – Experiment 4a				**Faces – Experiment 4b**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	353.34	349.03	351.09	353.22	332.16	310.63	330.66	315.22
SD (ms)	38.80	29.32	28.84	30.41	38.64	38.45	39.89	37.49
% cue errors	0.63	0.63	0.00	0.63	0.94	1.25	1.25	0.94
% target errors	1.25	0.31	0.94	0.63	0.00	0.00	0.00	0.94

Table 7: Mean response time (RT), standard deviation (SD), percentage cue errors, and percentage target errors for targets appearing on scenes or empty space in Experiments 4a and 4b.

	Scenes – Experiment 4a				**Blank screen – Experiment 4b**			
	Cued		Uncued		Cued		Uncued	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Mean RT (ms)	374.47	358.16	386.53	353.44	344.53	325.19	340.81	323.59
SD (ms)	33.68	37.61	39.79	32.68	36.59	48.00	37.76	40.79
% cue errors	1.88	0.63	1.56	1.25	0.00	1.25	0.00	0.31
% target errors	1.88	0.94	5.00	1.56	2.81	2.50	2.19	0.31

Targets appearing on scenes or empty space

Median RTs and error rates were analysed using separate 2 x 2 ANOVAs with the factors *cueing* and *location*. There was no main effect of cueing, F (1, 31) = 0.03, ns, and no interaction between cueing and location, F (1, 31) = 1.50, ns. However, there was a main effect of location, F (1, 31) = 16.06, $p < .001$, with faster RTs to targets in the upper VF than in the lower VF. The error analysis found no effects of cueing (F (1, 31) = 0.12, ns) and no interaction between cueing and location (F (1, 31) = 2.28, ns). However, there were significantly more errors to targets in the lower VF than in the upper VF, F (1, 31) = 7.74, $p = .009$.

Faces

Median RTs and error rates were submitted to separate 2 x 2 x 2 ANOVAs with the factors *intervening task* (objects - Experiments 2a and 3a, or no objects – Experiments 4a and 4b), *cueing*, and *location*. There was a significant main effect of intervening task, F (1, 62) = 5.03, $p = .028$, with faster RTs when the intervening task did not contain objects, supporting the idea that objects interfere with face processing. There was also a significant interaction between location and intervening task, F (1, 62) = 6.26, $p = .015$; RTs were faster to targets on the right when the intervening task did not contain objects, and RTs were faster to targets on the left when the intervening task contained objects.

Of most importance, there was a significant three-way interaction, F (1, 62) = 6.94, $p = .011$ (see Figure 14). When no objects appeared in the intervening task, RTs were slower to cued versus uncued targets on the left, and the opposite pattern was observed on the right. In contrast, when the intervening task contained objects, RTs were slower to cued versus uncued targets on the right, but not on the left. Planned comparisons revealed that the difference between cued and uncued RTs was only significant for faces on the right when the intervening task contained objects, F (1, 31) = 8.49, $p = .007$. There were no other significant effects. The error analysis found no significant effects of cueing (F (1, 62) = 0.19, ns), location (F (1, 62) = 0.42, ns), or intervening task (F (1, 62) = 1.05, ns), and no interactions.

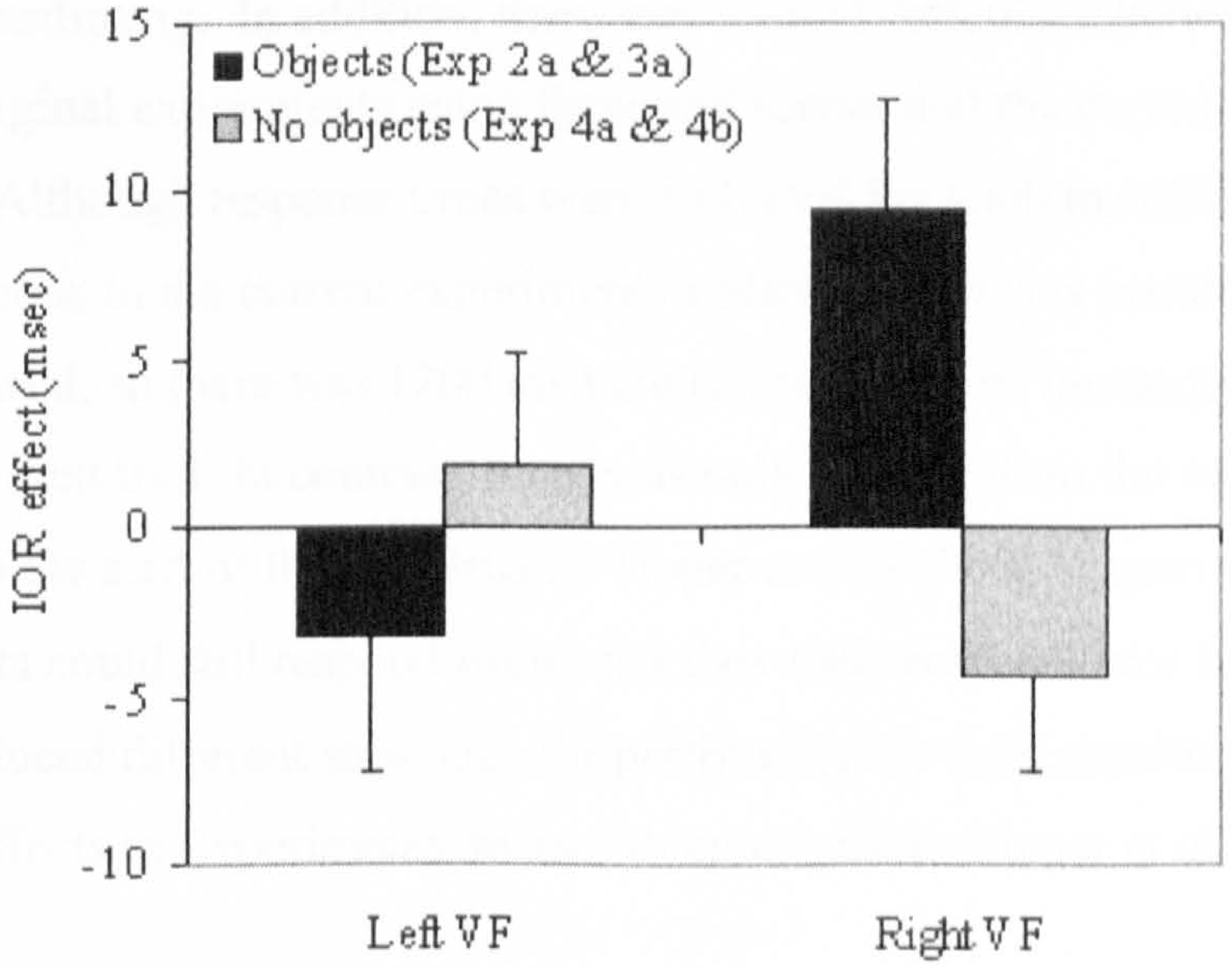

Figure 14: IOR effects (cued RT minus uncued RT) for faces as a function of intervening task (objects or no objects). A positive difference score indicates IOR. Error bars show the standard error of the mean.

The purpose of these experiments was to investigate whether the visual field differences observed in the previous experiments were due to the presence of objects in the intervening task. Indeed, the results revealed the opposite pattern of IOR when no objects were present (Experiments 4a and 4b) compared to when the intervening task contained objects (Experiments 2a and 3a), as shown by the three-way interaction between intervening task, cueing, and location. This suggests that competition between objects and faces led to the reversal in visual field differences in the previous experiments. No long-term IOR was observed when cues and targets appeared in scenes or empty space, which is consistent with the idea that object-based representations are necessary for the encoding and retrieval of inhibitory states.

IOR effects were much smaller in Experiments 4a and 4b than in Tipper et al.'s (2003) study, even though the experimental procedures were very similar. However, long-term IOR effects appear to be very fragile, and the small effects in these experiments may be due to differences in the participant sample compared to other experiments. For example, the data was collected at the end of term, when participants were under pressure to complete their course credits (which require them to take part in experiments). Many of the participants had done other experiments immediately before participating, which may have caused them to be tired and have difficulty concentrating. In addition, there was a small difference between Tipper et al.'s (2003) original experiments using faces and scenes and the current series of experiments. Although response times were collected for 1000 ms after target onset in both paradigms, in the current experiments a blank screen was presented for 700 ms between each trial, so there was 1200 ms between the onset of the target signal and the start of the next trial. In contrast, there was only 500 ms from the onset of the target signal to the start of the next trial in Tipper et al.'s (2003) experiment, meaning that participants could still respond even after they had received error feedback. This may have produced different strategies for performing the task, resulting in the smaller IOR effects in Experiments 4a and 4b compared to Tipper et al.'s (2003) study.

However, the results of the current experiments clearly show that the pattern of long-term IOR for faces was significantly different when objects were also present in the task, compared to when no objects were present, suggesting that faces and objects were competing for processing resources in this task.

General discussion

The experiments reported in this chapter provide further evidence that transient inhibitory states associated with the identity of a stimulus can be encoded into memory, such that later retrieval of the stimulus reinstates inhibitory processing. Long-term IOR was observed for faces in the right VF and small facilitation effects were seen in the left VF when face displays alternated with object displays. This replicates the results reported in Chapter 3, showing that the visual field differences in these experiments are not due to random individual differences.

However, when face displays alternated with scene displays this pattern was reversed; a trend towards long-term IOR occurred for faces in the left VF, while there was a small facilitation effect for faces in the right VF. The asymmetry in IOR for faces was significantly different when the intervening task contained scenes compared to when it contained objects. This suggests that objects compete with faces for processing resources, whereas scenes do not. These results are consistent with research showing that scenes and faces are processed separately in the brain (Epstein & Kanwisher, 1998), whereas object perception may recruit the same brain mechanisms as face perception (Gauthier et al., 2003; Rossion et al., 2004).

When faces appeared above and below fixation (Experiment 3b), there was a trend towards IOR in the upper VF and facilitation in the lower VF; this was significantly different to the pattern observed for objects (Experiment 2a), in which IOR occurred for objects in the lower VF and there was facilitation for objects in the upper VF. This provides further support for the idea that faces and objects were competing in these experiments. The results for faces are also consistent with previous work that found long-term IOR for faces in the upper VF but not in the lower VF (Kessler & Tipper, 2004).

It appears that long-term IOR only occurs in one visual field, as Experiments 2 – 4 and previous work (Kessler & Tipper, 2004; Tipper et al., 2003) have shown clear visual field asymmetries in long-term IOR. Previous studies of the standard IOR effect have observed IOR in both visual fields. However, recent work suggests that attentional biases can produce visual field differences in IOR. Spalek and Hammad (2005) found that English speaking participants, who read from left to right, showed larger IOR in the left VF than in the right VF, whereas Arabic participants, who read from right to left, showed the opposite pattern. This suggests that IOR is influenced by an attentional bias that is consistent with the direction of text reading.

When inhibition is retrieved from memory, the visual field differences in IOR are much more pronounced. This is probably because retrieval of object-based inhibitory states is dependent on prior encoding of the object. Objects that receive biased processing are likely to be better encoded and retrieved from memory than other objects. Tipper et al. (2003) and Kessler and Tipper (2004) suggested that the visual field asymmetry in long-term IOR for faces in their experiments was due to more efficient face processing in the right hemisphere than in the left hemisphere (e.g. Kanwisher et al., 1997a; McCarthy et al., 1997). However, the results of the current experiments show that these visual field differences in long-term IOR for faces are not fixed, and can change depending on the context in which faces are presented.

Indeed, in a further experiment using the same stimuli as their original long-term IOR experiments, Tipper et al. (2003) found that varying the onset asynchrony of the faces in the cue display produced a different pattern of IOR. When the right face appeared 150 ms before the left face, long-term IOR was only observed in the left VF, which replicated the results of their previous experiments. However, when the left face appeared first, this long-term IOR effect was eliminated, and there was a small facilitation effect in the left VF. These findings show that hemispheric biases for processing different kinds of stimuli can be reversed by certain experimental procedures. It appears that, as suggested by Tipper et al. (1994a), the mechanisms underlying long-term IOR are flexible and may operate differently depending on the nature of the task.

Experiments 2 – 4 also revealed evidence of excitatory processing, as facilitation effects were consistently observed in the opposite visual field to the one in which long-term IOR occurred, and this facilitation almost reached significance in Experiments 3a and 3b. This finding is similar to previous work (Kessler & Tipper, 2004; Tipper et al., 2003), which found small facilitation effects in the right VF. As mentioned in Chapter 1, both facilitation and inhibition can influence behaviour in IOR tasks (e.g. Collie et al., 2000; Wascher & Tipper, 2004). Furthermore, Kessler & Tipper (2004) showed that the time-course of the processes underlying long-term IOR depends on the efficiency of memory retrieval. As described in Chapter 1, when retrieval cues were efficient (i.e. the target display was identical to the encoding display and the target appeared in the dominant visual field), then inhibition was present at 500 ms, but had decayed by 1000 ms. In contrast, when retrieval cues were less efficient (i.e. the cued face appeared in a different location), IOR was less robust and retrieval of inhibition was slower, as IOR was only observed at 1000 ms. In the current experiments the stimuli in the target display always appeared for 500 ms before target onset, so the long-term IOR effects observed in these experiments only provide information about the excitatory and inhibitory processes happening at that particular point in time. It is possible that presenting the target after a longer interval (e.g. 1000 ms) would reveal a different pattern of IOR; for example, the previous facilitation in one visual field may become inhibition, whereas the IOR effect in the other visual field may disappear. Future work needs to measure response times at different intervals and use other measures, such as ERPs, to determine the exact processes that take place during retrieval of inhibitory states from memory.

The results of the current experiments found that processing was biased towards the right VF and upper VF for faces, and the left VF and lower VF for objects. However, the long-term IOR effects observed in these experiments were very fragile, and did not reach significance in every experiment. This may be because two objects or faces were present on each trial. It is possible that some of the displays contained one face or object that was more salient and captured attention, leading to some random variation in the visual field differences in IOR. This may have reduced the overall attentional biases observed for faces and objects.

Based on Tipper et al.'s (2003) methods for maximising memory encoding and retrieval, each face pair was deliberately designed to contain two very different, easily distinguishable faces. Therefore, attention may have been drawn to faces that were preferred by the participants; for example, attractive faces. Also, research has shown that emotion can influence attention. For example, during visual search, threatening faces are identified faster and more accurately than non-threatening faces (Lundqvist & Öhman, 2005; Ohman, Lundqvist, & Esteves, 2001; Tipples, Atkinson, & Young, 2002), and irrelevant faces displaying negative emotions interfere more with performance of a task than positive faces (Eastwood, Smilek, & Merikle, 2003; Vuilleumier, Armony, Driver, & Dolan, 2001). As the expression of the faces was not controlled in the current experiments, emotional influences on attention may have introduced random variability into the data, producing smaller long-term IOR effects. Similarly, the two objects in each display could be different kinds of object (e.g. a toy animal and a kitchen utensil), which may have produced a bias to orient towards one of the objects in each pair. For example, research has shown that graspable objects capture attention (Handy et al., 2003; Tucker & Ellis, 1998). As the expression of the faces and the action affordances of the objects were not controlled in the current experiments, these confounding factors may have introduced random variability into the data, producing smaller long-term IOR effects. To avoid such confounds, future work investigating long-term IOR for naturalistic stimuli should only present one object on each trial.

Chapter 4 – Does object-based IOR operate on identity or category?

The previous chapters have shown that inhibition associated with a specific object or face can be encoded into memory, and subsequently reinstated when the object reappears. These results suggest that inhibitory mechanisms of attention can act on object-based representations. However, an important issue concerns the level of object representation at which this inhibition operates. The previous findings demonstrating long-term IOR for face stimuli show that IOR can be associated with identity-based representations. This is because faces belong to the same object category, so retrieval of inhibitory processes would require memory for inhibition to be associated with a specific face identity, not the broad semantic category of faces.

Recent work has shown that IOR in working memory can be associated with identity-specific representations (Grison, Paul, Kessler, & Tipper, in press). A pair of faces was presented, and one of the faces was exogenously cued via a red semi-transparent circle. Nearly four seconds later, the same pair of faces appeared and a green target, requiring a rapid localisation response, appeared over the cued or the uncued face. The faces were either upright, so they could be easily recognised, or they were inverted, which is known to impair face recognition (Kanwisher, Tong, & Nakayama, 1998; Yin, 1969). Faces in the cue display were oriented anticlockwise 45° from vertical, whereas faces in the target display were oriented clockwise 45° from vertical. IOR was significantly larger when faces appeared upright in both the cue and target displays, compared to when faces were inverted in the cue display, the target display, or both the cue and target displays. Low-level object information and spatial location information were the same for all conditions, so the greater IOR for faces that were upright in the cue and target displays must reflect inhibition of object identity.

However, faces are usually processed at a subordinate level. From an evolutionary perspective, it is important to distinguish between friends and enemies, and there is evidence that humans are experts at subordinate face recognition (Gauthier & Tarr, 1997; Tanaka, 2001). In contrast, it is often unnecessary to make within-category distinctions for common objects, and objects are usually recognised at a basic level (Rosch, 1976). Therefore, when the task does not involve faces, inhibition may involve basic-level categories that are accessed by the ignored objects. This chapter investigates whether the inhibitory processes underlying IOR can also operate on abstract, semantic representations. That is, does IOR generalise to new, previously unseen objects that belong to a single category?

Evidence that inhibitory mechanisms of attention can be associated with the semantic properties of an object has been obtained using a negative priming paradigm (see Fox, 1995; May et al., 1995; Neill, Valdes, & Terry, 1995, for reviews of the negative priming literature). Of most relevance here, Tipper and Driver (1988) showed that negative priming transferred between semantically related objects (for example, from a picture of a dog to a picture of a cat) and between different forms of visual information (for example, from pictures to words depicting the same object). Similarly, other work has shown negative priming effects between semantically related words (e.g. Mari-Beffa, Fuentes, Catena, & Houghton, 2000). Tipper and Driver (1988) suggested that inhibition of the central representation of an ignored object spreads to related objects, so that subsequent processing of semantically related objects is also impaired.

Some authors have argued that the inhibitory mechanisms underlying IOR and negative priming are similar (Buckolz, Boulougouris, O'Donnell, & Pratt, 2002; Christie & Klein, 2001; Houghton & Tipper, 1994; Milliken, Tipper, Houghton, & Lupiáñez, 2000). Therefore, it seems reasonable to ask whether IOR can also operate on semantic, basic-level category representations. For example, if attention was repeatedly oriented, via a sudden onset cue, to the left side of members of a single object category, would the inhibition evoked by the cue become associated with the object category? If this were the case, then detection of a target appearing on the left side of a previously unseen member of the same category should be impaired, relative to target detection on the uncued side of the object.

Consider the following example. A picture of a chair is presented, and a sudden onset cue (which activates IOR) is flashed on the left side of this object. Shortly afterwards a different example of a chair is presented and again the left side of this object is cued. Is the inhibition of the left side of the object associated with the semantic class of objects (i.e., chair)? If inhibition can be associated with object category, then if a new (not previously seen) image of a chair were presented, detection of a target on the left side of this new stimulus would be impaired. Such an observation would be similar to the semantic category based negative priming effects described previously.

Therefore, there were two main goals of this chapter. First, the experiments reported here attempted to confirm that IOR can be associated with an object's identity, and that this identity-based inhibition can be retrieved at a later point in time. If IOR is identity-based, then IOR effects for targets presented to the left and right of fixation should be larger when the same object is presented in the cue and subsequent target display, compared to when different objects appear in the cue and target displays. In contrast, a purely spatial form of IOR that is unaffected by object-based representations would predict that IOR effects should be the same in these two conditions, as objects are irrelevant to location-based IOR. Furthermore, when the interval between a cue and subsequent target is relatively long (21 seconds and 5 intervening trials), IOR should be observed when identical objects are re-encountered at this later time. This would confirm the results of the previous chapters, and would also be consistent with recent findings that inhibitory processes associated with an object can be retrieved and reinstated when the object is re-encountered (Kessler & Tipper, 2004; Tipper et al., 2003).

Second, this chapter also investigated whether IOR can be associated with an object's category. If IOR can be associated with semantic representations, then IOR effects should be greater when different objects of the same category are repeatedly cued, relative to the baseline condition in which different, unrelated objects are cued. In addition, when the cue-target interval is long, and contains intervening trials, then inhibitory processes associated with the object category should be retrieved when a previously unseen member of that category is presented, revealing long-term IOR for categorically related objects. These would be striking results, because the target display in the categories condition contained an object that had not previously been encountered. Alternatively, if IOR cannot operate on semantic representations, then no differences should be observed between the IOR effects in the categories condition and the different objects condition, and no long-term IOR effects should be observed for object categories.

Experiments 5a, 5b, and 5c

In these experiments either identical objects (Experiment 5a), categories (Experiment 5b), or different objects (Experiment 5c) were presented (see Figure 15). Each object appeared three times. On the first two presentations, attention was oriented to the left or right of the object using an exogenous cue. Then on the third presentation, a target requiring a rapid localisation response appeared on the left or right. The interval between the second cue and the target was approximately 3 seconds with no intervening displays. The use of two successive cues differs from the standard IOR procedure, in which only one cue is presented, and this variation of the standard procedure was expected to increase the likelihood that IOR would become associated with basic-level categories.

Method

Participants

54 people (17 males and 37 females) participated in Experiments 5a, 5b, and 5c (18 in each experiment). The participants were either students at the University of Wales, Bangor or were residents of the Bangor area, and received £5 for participating. They ranged in age from 18 to 31 years (mean age 22.0), and they were all right-handed with normal or corrected-to-normal colour vision.

Apparatus and Stimuli

Stimulus presentation and recording of response times was performed by the *E-prime* program running on a PC. The stimuli were presented on a 17 inch monitor, and a chinrest was used to keep participants at a distance of 57 cm from the monitor. A computer keyboard was located on a table within easy reach of the subjects; the numberpad keys '4' and '6' were used to register the responses and the '0' key was used to initiate trials.

The stimuli consisted of 360 colour object photographs. There were 120 different categories of object, with three exemplars of each category. The cue and target signals were semi-transparent red (cue) and green (target) patches that were overlaid on the left or right side of the object. In Experiment 5a the same object appeared in the cue and target displays, in Experiment 5b the cue and target displays contained different exemplars of the same category, and in Experiment 5c unrelated objects appeared (see Figure 15). Because each set of cue and target displays in Experiments 5a and 5b contained objects of a similar size and shape, the objects in Experiment 5c were matched according to their size, and the cues and targets were placed in the same location for each set of cue and target displays. Stimuli were presented on a black screen, and a central fixation point consisting of a white cross was present throughout each trial.

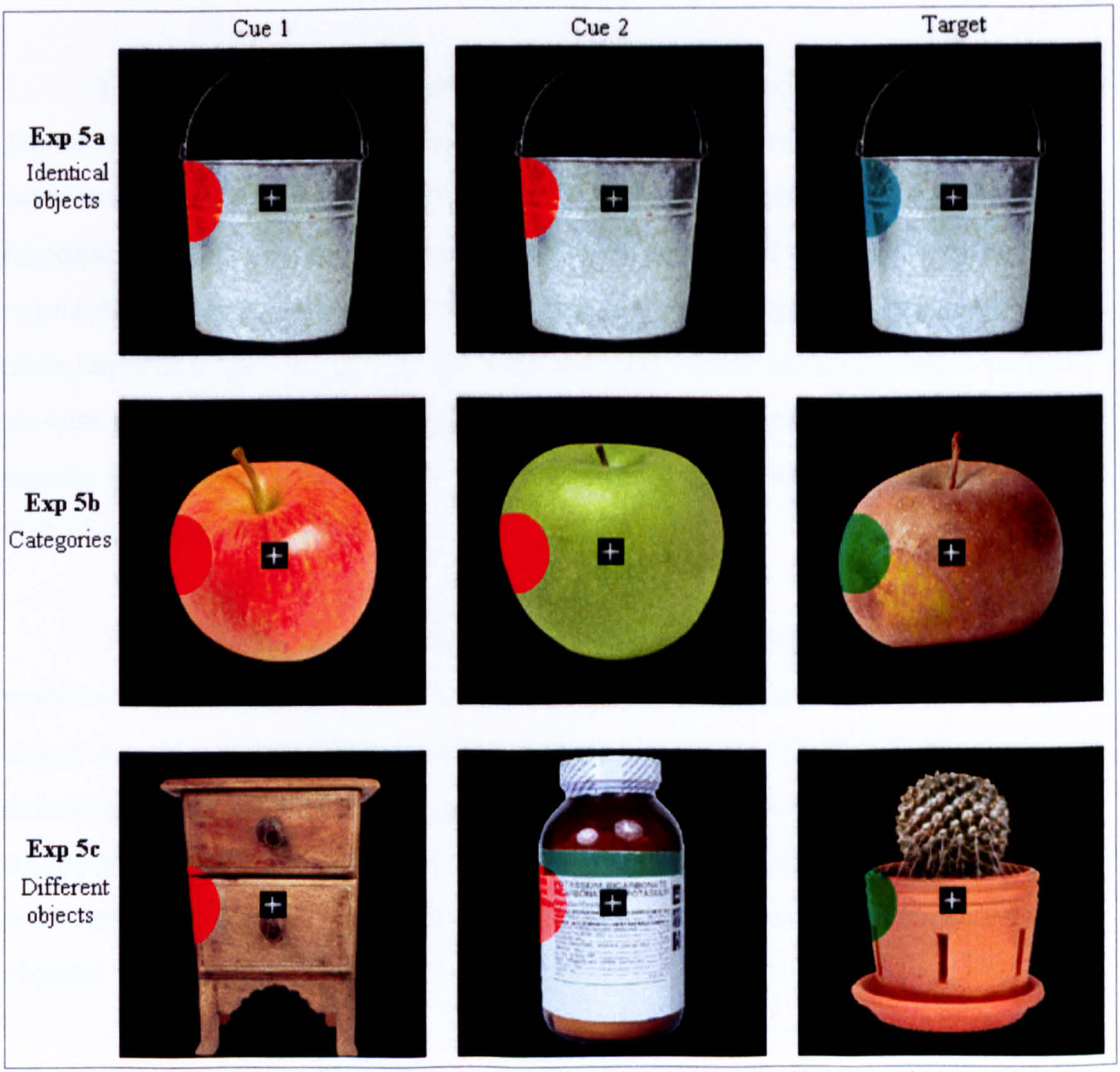

Figure 15: Cue and target stimuli for Experiments 5a (identical objects), 5b (categories), and 5c (different objects). This example shows the *cued left* condition for each experiment.

Design

Each experiment used a repeated-measures design with the independent variables *cueing* (cued and uncued) and *target location* (left and right). In each experiment there were 80 cueing trials, in which the 'no go' red cue was presented on the same side of the object in both of the two cue displays. This was then followed by a target display. On half of the cueing trials the green target appeared on the same side of the object as the two previous red cues (i.e. the cued condition), and for the other half of the trials the target appeared on the opposite side of the object from the two previous red cues (i.e. the uncued condition). In each cueing condition the target appeared equally often in the left and right visual field.

In order to reduce the predictability of the 'no go – no go – go' response sequence, in which the 'no go' cues always appear on the same side, there were 40 catch trials in each experiment. 16 of these catch trials required a 'go – go – no go' response (i.e. both cue displays required a 'go' response and the target display required a 'no go' response), 8 catch trials required a 'go – go – go' response, 8 catch trials required a 'go – no go – no go' response, and 8 catch trials required a 'no go – go – no go' response. For each type of catch trial the cues and targets appeared equally often on the left and right. There was also a practice block consisting of 8 IOR trials and 4 catch trials.

The order of conditions and the order of the stimulus displays were randomised. In Experiment 5a (in which three identical objects were shown), each object was seen by one third of participants. In Experiment 5b (in which 3 different exemplars of the same category were shown), the order of the 3 objects was counterbalanced across participants. In Experiment 5c (in which unrelated objects were shown), presentation of each exemplar of a category was separated by 39 other objects.

Procedure

Participants sat in a dimly lit room in front of the computer monitor. The keyboard was placed within easy reach, and the height of the chinrest was adjusted to a comfortable level. They were instructed to fixate on the fixation point throughout each trial, and to press the '4' key with the left hand if the green target appeared on the left and the '6' key with the right hand if it appeared on the right. They were also asked to refrain from responding if the stimulus was red (the cue), and were told to initiate each trial by pressing the 'start key' ('0' on the numberpad) with the thumb. They then completed the practice block, followed by the main experiment. The experiment was divided into two blocks of 60 trials each, with a 30 second interval between the blocks. There were no intervening items between the cues and the target, and the interval between the second cue and the target was approximately 3 seconds (this time interval can only be approximated, as participants took varying lengths of time to initiate each trial).

The sequence of events in a trial was as follows. A display appeared instructing participants to position their fingers correctly and press the 'start key'. For cue displays, a central fixation cross appeared for 300 ms, then the object appeared for 1000 ms, after which one side of the object was overlaid by the red cue signal for 200 ms. Then the original object was seen for a further 300 ms, followed by a blank screen for 700 ms. RT and error data were recorded for 1000 ms from the onset of the cue signal. Participants were then prompted to press the 'start key' again, and this cue sequence was then presented for a second time. Participants then pressed the start key again to begin the target display. The procedure for the subsequent target display was identical, except that the stimulus display appeared for 750 ms instead of 1000 ms.

The reason for choosing this 750 ms interval was to keep the procedure similar to the one that would be used in subsequent experiments (6a and 6b) that examined long-term IOR for categories and identical objects. Based on Kessler and Tipper's (2004) observation that retrieval of inhibition is slower when retrieval cues are less efficient, it was expected that inhibition associated with a category may take longer to retrieve than inhibition associated with identical objects. Therefore, stimuli in these experiments were presented for slightly longer before the target appeared, compared to the previous experiments.

Participants had 1000 ms from the onset of the green target signal to respond. After responding, participants received auditory feedback indicating whether the response was correct or incorrect. The experiment lasted for approximately 25 minutes. Figure 16 shows the basic trial sequence for Experiment 5b (in which categories were shown in the cue and target displays).

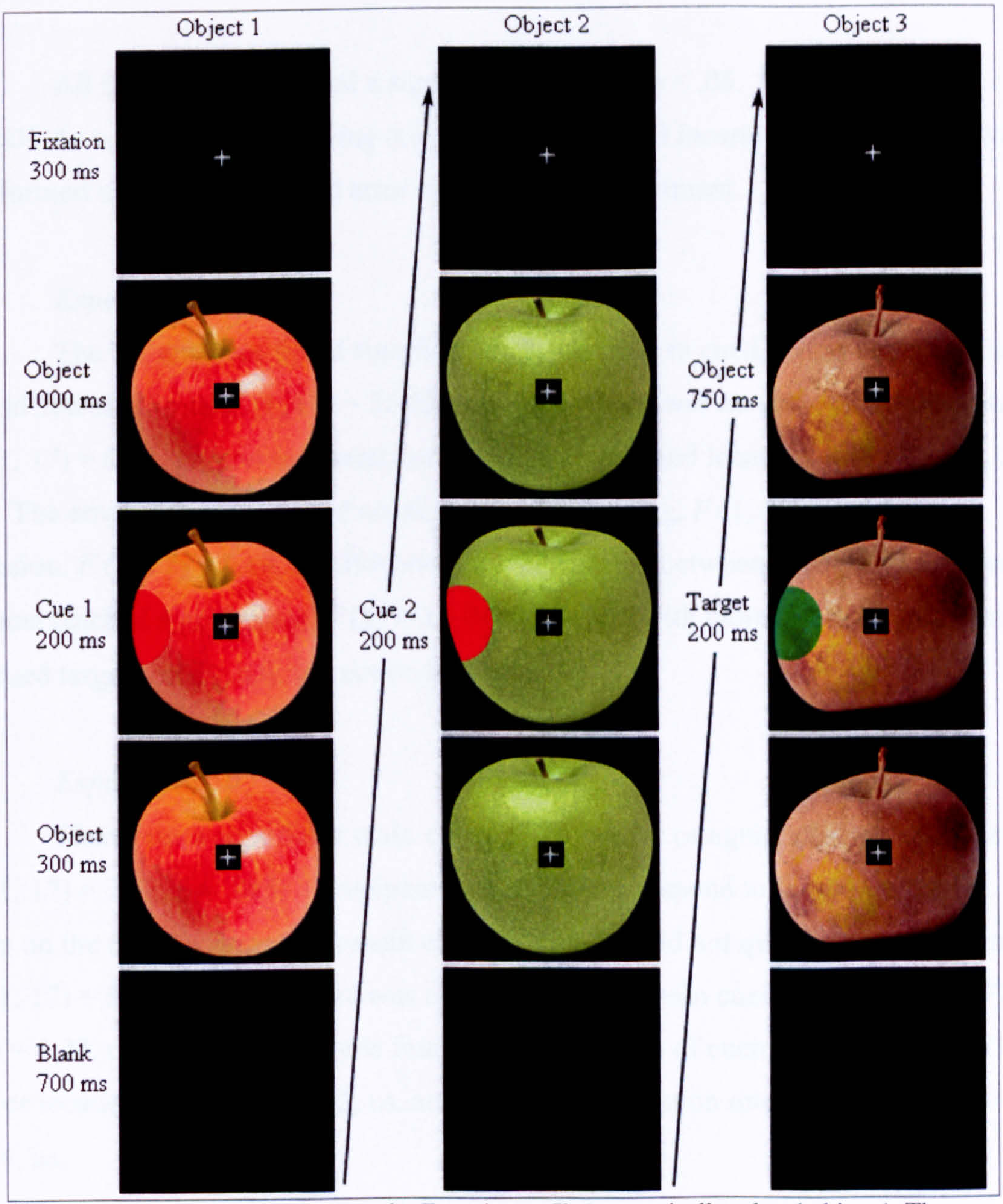

Figure 16: The basic trial sequence for Experiment 5b (categorically related objects). The procedure for Experiments 5a (identical objects) and 5c (unrelated objects) was identical.

Results and discussion

The data from the catch trials was not analysed, and data for trials containing cue or target errors was removed from the RT analysis. Cue errors were responding to the cue, and target errors were not responding, responding too late (after 1000 ms), or responding incorrectly to the target. Table 8 shows the mean RTs and error rates for each condition, and IOR effects (cued RT minus uncued RT) are shown in Figure 17.

All inferential tests used a significance level of $p < .05$. Separate 2 x 2 ANOVAs with the factors *cueing* (cued and uncued) and *location* (left and right) were performed on median RTs and error rates for each experiment.

Experiment 5a

The RT analyses found significantly slower RTs to cued versus uncued targets for identical objects, $F(1, 17) = 26.53$, $p < .001$. There was no main effect of location, $F(1, 17) = 0.43$, ns, and no interaction between cueing and location, $F(1, 17) = 0.14$, ns. The error analysis revealed no main effects of cueing, $F(1, 17) = 2.08$, ns, or location, $F(1, 17) = 0.19$, ns. However, the interaction between cueing and location almost reached significance, $F(1, 17) = 3.73$, $p = .07$, with more errors to cued versus uncued targets on the left, but not on the right.

Experiment 5b

There was a significant main effect of cueing for categorically related objects, $F(1, 17) = 7.37$, $p = .015$. Participants were faster to respond to targets on the left than on the right, however this main effect of location did not quite reach significance, $F(1, 17) = 3.50$, $p = .08$. There was no interaction between cueing and location, $F(1, 17) = 0.22$, ns. The error analysis found no main effects of cueing, $F(1, 17) = 0.65$, ns, or location, $F(1, 17) = 0.32$, ns, and no cueing x location interaction, $F(1, 17) = 0.74$, ns.

Experiment 5c

Cueing was significant for unrelated objects, $F(1, 17) = 6.21$, $p = .023$. There was no main effect of location, $F(1, 17) = 1.84$, ns, and no interaction between cueing and location, $F(1, 17) = 0.44$, ns. The error analysis showed a significant main effect of location, $F(1, 17) = 7.39$, $p = .02$, with more errors on the right than on the left. There was no main effect of cueing in error rates, $F(1, 17) = 0.80$, ns, but the cueing x location interaction was almost significant, $F(1, 17) = 3.40$, $p = .08$, with more errors to cued versus uncued targets on the right, but not on the left.

Table 8: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiments 5a, 5b, and 5c (0 intervening trials).

	Experiment 5a – Identical objects				**Experiment 5b – Categories**				**Experiment 5c – Unrelated objects**			
	Cued		Uncued		Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	439.67	445.44	406.89	408.58	396.39	408.86	383.08	398.42	409.97	413.78	395.81	405.42
SD (ms)	79.06	85.08	65.71	72.18	55.54	55.50	67.68	66.10	40.96	39.25	32.95	39.38
% cue errors	0.56	0.28	0.28	0.69	0.97	0.83	0.42	0.69	0.56	0.83	0.14	0.83
% target errors	3.61	1.94	1.39	2.22	2.22	1.67	0.83	1.94	0.83	3.89	1.39	1.94

Combined analysis of Experiments 5a, 5b, & 5c

Median RTs and error rates were submitted to a 3 x 2 x 2 ANOVA with the factors *experiment* (5a, 5b, and 5c), *cueing*, and *location*. Analysis of errors found no significant main effects or interactions. The RT analysis revealed a highly significant effect of cueing, $F(1, 51) = 39.40, p < .001$. A significant effect of location was also obtained, $F(1, 51) = 5.28, p = .03$, with faster response times to targets on the left versus right. Importantly, there was no main effect of experiment, $F(2, 51) = 1.15$, ns), showing that the different forms of object condition (identical, category, and unrelated) did not affect target detection abilities. Most importantly, there was a significant interaction between cueing and experiment, $F(2, 51) = 6.34, p = .003$. No other interactions were significant.

IOR effects for the three experiments were compared using three independent-samples t-tests. A significance level of $p < .017$ was used for each of these tests, in order to keep the overall significance level at $p < .05$. The IOR effects for identical objects were significantly larger than the IOR observed for categorically related objects, $t(34) = 2.85, p = .007$, and unrelated objects, $t(34) = 2.90, p = .007$ (see Figure 17). In contrast, the IOR effects for categorically related versus unrelated objects were not significantly different ($p = .92$).

One explanation for the larger IOR effects in Experiment 5a compared to 5b and 5c may be that the reaction times to uncued targets varied between experiments. To rule out this possibility, RTs in the uncued condition were compared using a 3 x 2 ANOVA with the factors experiment and location. There was no main effect of experiment, $F(2, 51) = 0.41$, ns, showing that the larger IOR effects for identical objects must be due to slowed RTs in the cued condition.

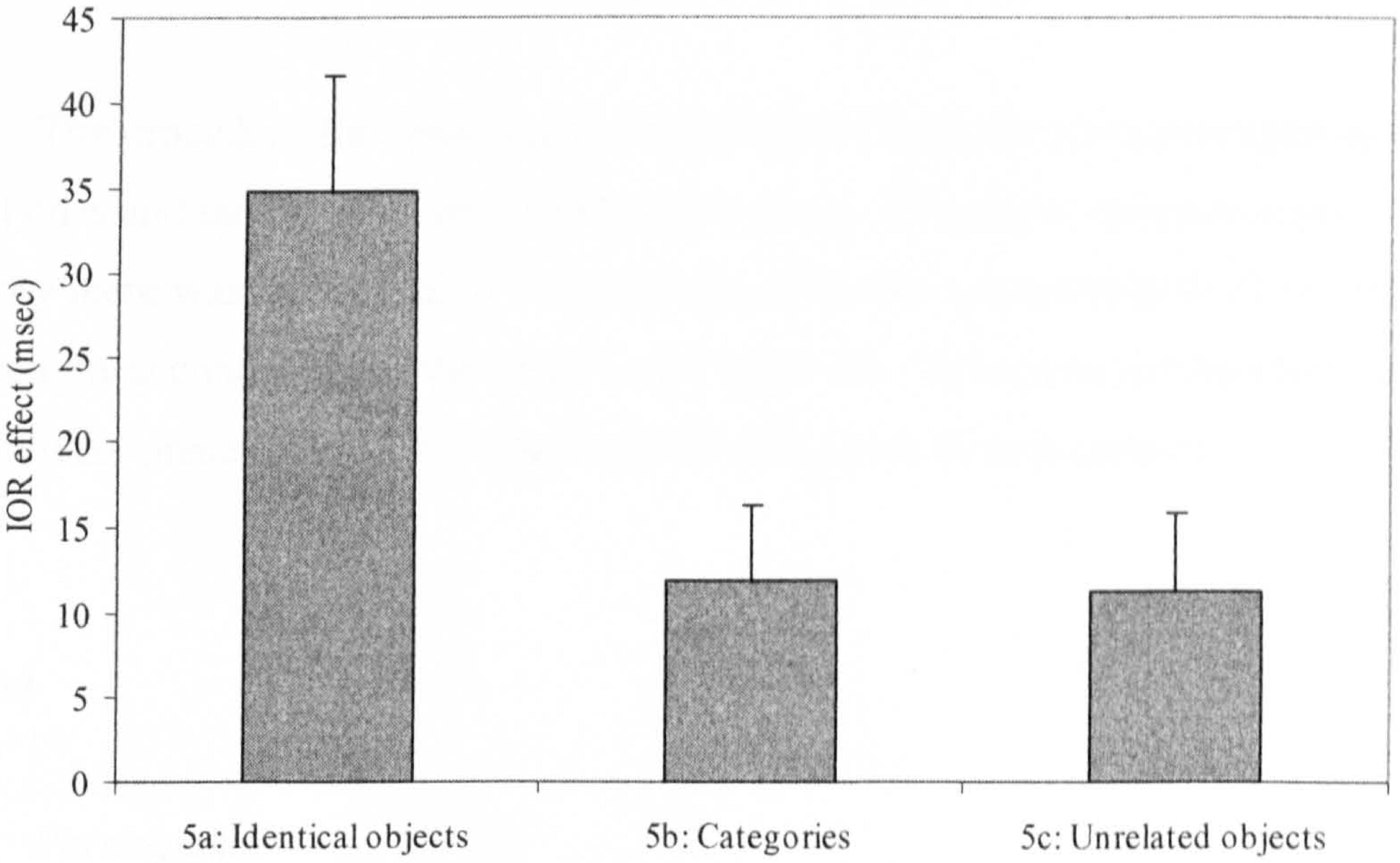

Figure 17: Summary of IOR effects (cued RT minus uncued RT) for Experiments 5a, 5b, and 5c (short cue-target interval). A positive difference score indicates IOR. Error bars show the standard error of the mean.

The finding that IOR effects were significantly larger for identical objects (Experiment 5a) than for different, unrelated objects (Experiment 5c) shows that IOR effects can be associated with objects. The small IOR effects observed for different objects must reflect spatial IOR, whereas the large IOR effects seen for identical objects reflect the combination of location- and identity-based IOR. These results are consistent with previous research showing that IOR is not purely location-based (e.g. Jordan & Tipper, 1998; Tipper et al., 1994b).

An important goal of this chapter was to investigate whether IOR can operate on semantic representations. There were no significant differences in the magnitude of IOR observed for categories (Experiment 5b) and different objects (Experiment 5c), and IOR effects were significantly smaller for categories than for identical objects (Experiment 5a). This result suggests that IOR cannot be associated with an object's category; rather, it operates on identity-specific representations.

Experiments 6a and 6b

The procedure for these experiments differed from the previous experiments, in that cues and targets were presented in sets of six. Therefore, for each object or category there was an interval of 5 intervening trials and approximately 21 seconds between the second cue and the target (see Figure 18). In Experiment 6a identical objects were presented and in Experiment 6b categories were presented.

Method

Participants

There were 36 participants in Experiments 6a and 6b (18 in each experiment, 17 males and 19 females), ranging in age from 18 to 37 years (mean age 25.2). The participants were either students at the University of Wales, Bangor or were residents of the Bangor area. All participants had normal or corrected-to normal colour vision and were right-handed. They received £5 for participating.

Apparatus and Stimuli

The object stimuli and the apparatus were the same as those used in Experiments 5a, 5b, and 5c. In Experiment 6a the same object appeared in the cue and target displays, and in Experiment 6b categorically related objects appeared in the cue and target displays.

Design and procedure

The design and procedure were identical to Experiments 5a, 5b, and 5c, except that cue and target displays were presented in sets of six, so that there were 5 intervening items and approximately 21 seconds between the first and second cue and between the second cue and the target. The length of this interval varied slightly between participants, due to differences in the time it took them to initiate trials, however there was always exactly 5 intervening items between each presentation of an object or category. Figure 18 shows a typical trial sequence in Experiment 6a (identical objects).

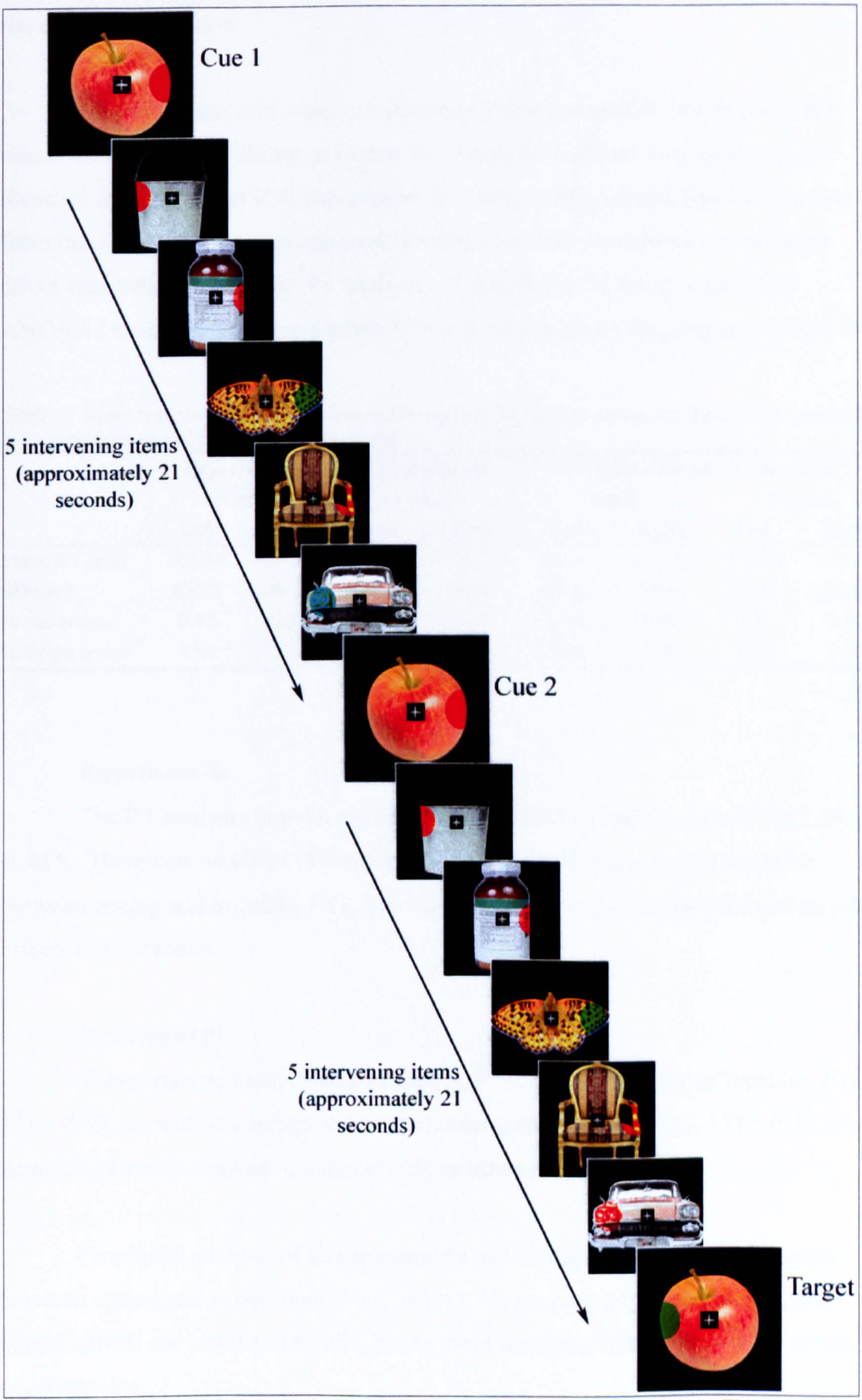

Figure 18: A typical trial sequence in Experiment 6a (long-term identical objects). This example shows the *uncued left* condition. The procedure for Experiment 6b (long-term categories) was identical.

Results and discussion

Mean RTs and error rates are shown in Table 9, and IOR effects (cued RT minus uncued RT) are shown in Figure 19. Small IOR effects were observed for identical objects, but no IOR was present for categorically related objects. The data from the catch trials was not analysed, and data for trials containing cue or target errors was removed from the RT analysis. Separate 2 x 2 (*cueing* x *location*) ANOVAs were conducted on median RTs and error rates for Experiments 6a and 6b.

Table 9: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiments 6a and 6b (5 intervening trials).

	Experiment 6a – Identical objects				**Experiment 6b – Categories**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	405.78	406.92	401.61	398.31	436.31	436.92	433.22	439.47
SD (ms)	63.33	59.21	67.15	50.58	67.36	73.66	68.43	65.10
% cue errors	0.42	0.28	0.56	1.25	0.14	0.00	0.42	0.97
% target errors	1.94	1.94	0.56	1.67	1.94	1.39	2.78	1.39

Experiment 6a

The RT analysis found a significant main effect of cueing, *F* (1, 17) = 7.34, *p* = .015. There was no effect of location, *F* (1, 17) = 0.05, ns, and no interaction between cueing and location, *F* (1, 17) = 0.21, ns. The error analysis showed no main effects or interaction.

Experiment 6b

There were no main effects of cueing, *F* (1, 17) = 0.003, ns, or location, *F* (1, 17) = 0.39, ns, and no interaction between cueing and location, *F* (1, 17) = 0.29, ns. Analysis of errors showed no main effects or interaction.

Combined analysis of Experiments 6a and 6b did not detect an interaction between cueing and experiment, *F* (1, 34) = 1.31, ns, probably because long-term cueing effects are small and fragile, hence there was insufficient power to detect such an interaction.

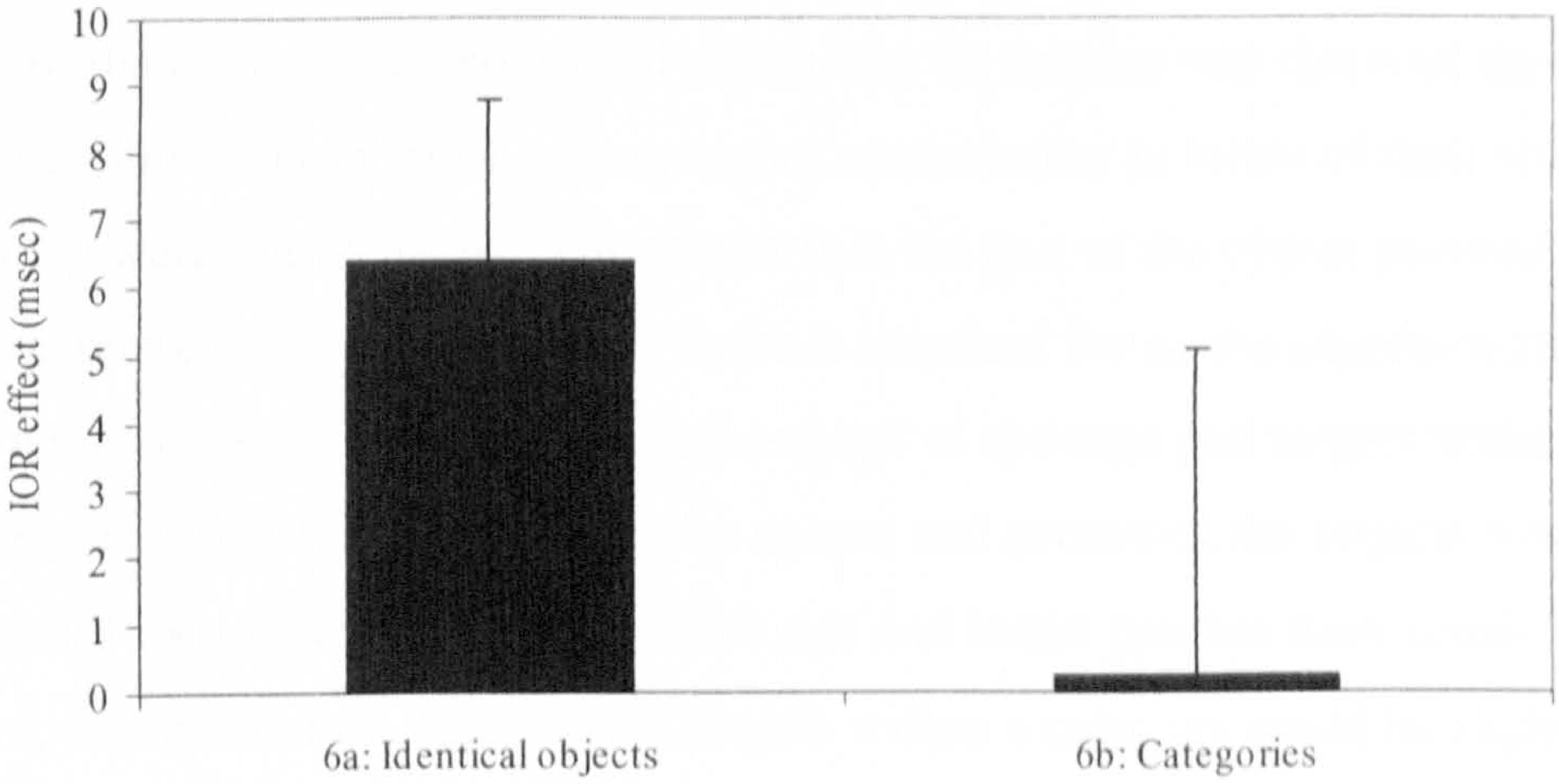

Figure 19: Summary of IOR effects (cued RT minus uncued RT) for Experiments 6a and 6b (long cue-target interval). A positive difference score indicates IOR. Error bars show the standard error of the mean.

Experiment 6a (identical objects) attempted to confirm the results of Chapters 2 and 3 and previous work demonstrating long-term IOR (Kessler & Tipper, 2004; Tipper et al., 2003). There was a significant IOR effect when the cue and target were separated by 21 seconds and 5 intervening trials, which is consistent with findings showing that IOR associated with an object's identity can be encoded into memory and later retrieved when the object is re-encountered. These long-term IOR effects must reflect identity-based IOR, as each cue was separated from its corresponding target by 5 intervening trials, in which cues and targets were presented to the same locations.

No long-term IOR was observed for categories (Experiment 6b), which suggests that IOR cannot be associated with semantic representations. This is consistent with the results obtained in Experiment 5b. It appears that IOR can operate on object-based representations, but these representations are identity-specific and inhibition does not spread to semantically related items.

However, a possible confound in Experiments 5 and 6 may be the contrast between the cues and targets for the category objects and the identical objects. The cues and targets used in these experiments were semi-transparent patches through which the colour and texture of the object could be seen. These patches were circular in shape, but only the part of the circle that covered the object was visible, so the size and shape of the cues and targets varied depending on the size and shape of the object. Although the three exemplars of each category were similar in terms of their shape and size, they were not identical. This meant that the part of the object covered by the semi-transparent cue and target patches was not identical for all the objects within a category, which caused small changes in the shape of the cues and targets within each category (see Figure 20). Furthermore, the colour and texture of the objects within a category could vary widely and, because the cue and target patches were semi-transparent, this meant that the cues and targets within a category could be slightly different shades of red or green and have different textures.

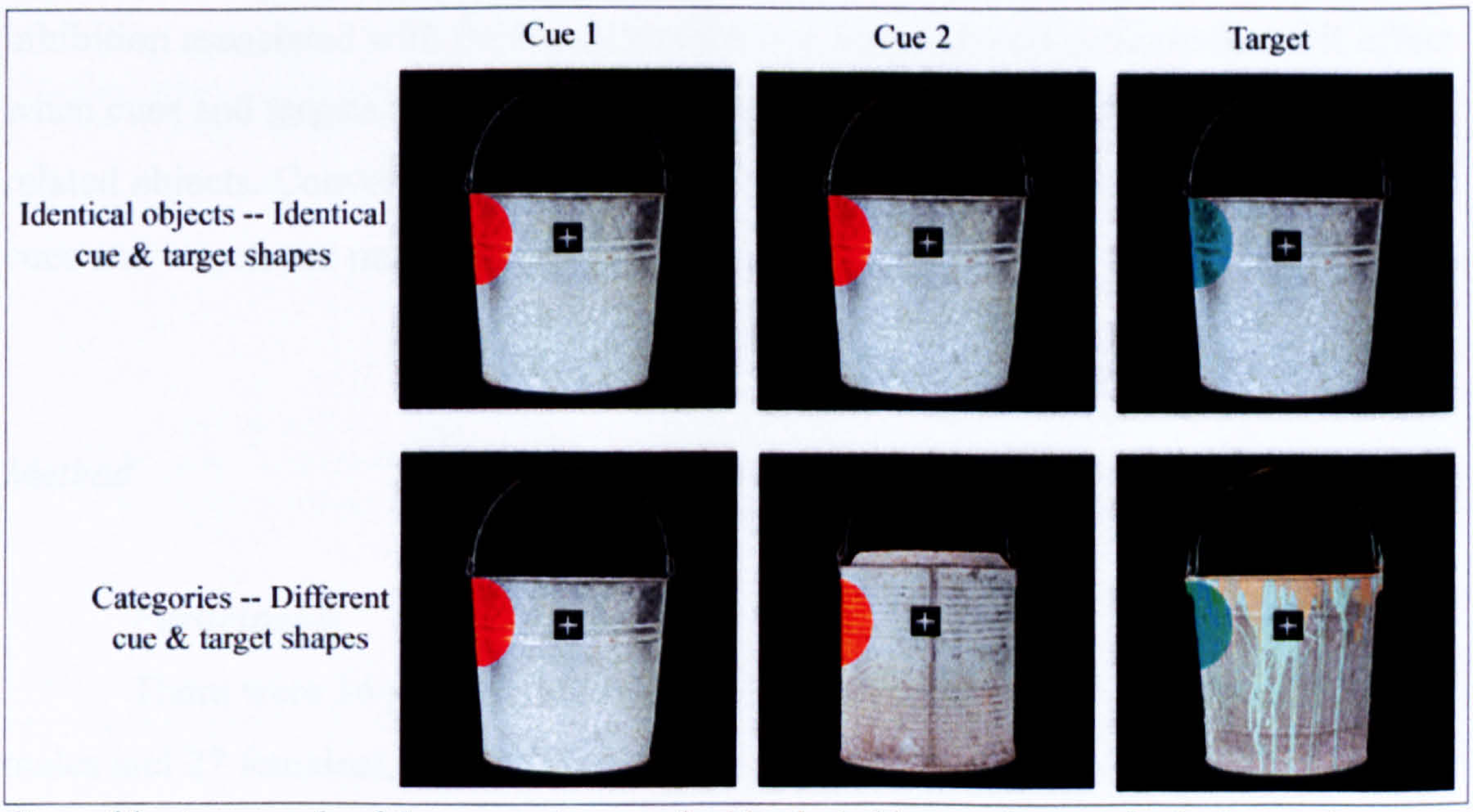

Figure 20: An example of the cues and targets for identical objects and categories in the previous experiments. Cues and targets that appeared on identical objects (top row) were identical, except for the different cue (red) and target (green) colours. In contrast, cues and targets that appeared on categories (bottom row) varied slightly in terms of shape, size, and texture.

So the cues and targets varied within-categories in terms of their shape, size, colour, and texture. In contrast, cues and targets in the identical objects condition were identical, apart from the different cue and target colours (red and green). Therefore, it is possible that the larger IOR observed for identical objects compared to categories in the previous experiments was due to the identity of the cues and targets, and the objects may not influence the magnitude of the IOR effect.

Experiments 7a and 7b

These experiments attempted to determine whether the objects in Experiment 5a contributed to the magnitude of the IOR effect or whether the results of the previous experiments were due to the identity of the cues and targets. In Experiment 7a, the cues and targets were different, but they appeared on identical objects. Conversely, in Experiment 7b, the cues and targets were identical, but they appeared on categorically related objects. If IOR is mediated by the identity of meaningful objects then the results should be similar to Experiments 5a and 5b; that is, larger IOR for identical objects than for categories. However, if the physical properties of the cues and targets played a role in the larger IOR for identical objects observed in the previous experiments, then a different pattern of data should emerge. That is, inhibition associated with the identity of the cue shape should increase the IOR effect when cues and targets are identical, even when they are presented on categorically related objects. Conversely, IOR effects for identical objects should be reduced if the cues and targets are not physically identical.

Method

Participants

There were 36 participants in Experiments 7a and 7b (18 in each experiment, 9 males and 27 females), ranging in age from 18 to 35 years (mean age 23.7). The participants were either students at the University of Wales, Bangor or were residents of the Bangor area, and they were all right-handed with normal or corrected-to-normal colour vision. They received £5 for participating.

Apparatus and Stimuli

These experiments used the same apparatus as the previous experiments. In Experiment 7a the stimulus displays consisted of the identical objects from Experiment 5a, and the cue and target patches were taken from Experiment 5b (categories). This meant that the same object was presented three times, but on each presentation the cues and targets varied slightly in terms of their shape, size, shade of red or green, and texture. In Experiment 7b the categorically related objects from

Experiment 5b were presented, but the cue and target patches were taken from Experiment 5a (identical objects). So three different categorically related objects were presented, but the two cues were identical, and the size, shape, and texture of the target matched the cues. Figure 21 shows examples of the stimuli in Experiments 7a and 7b.

Design and procedure

The design and procedure were identical to Experiments 5a and 5b.

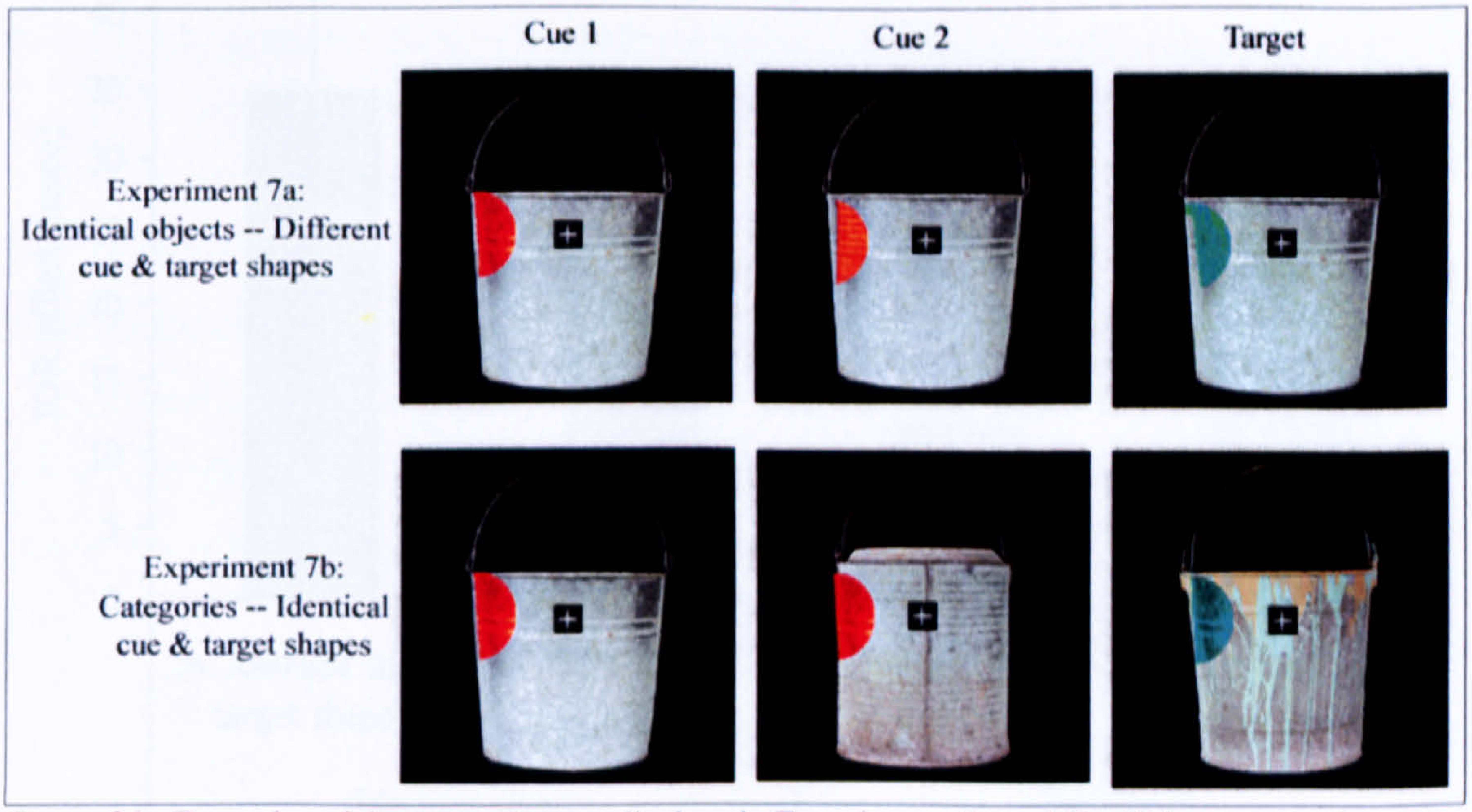

Figure 21: Examples of the cue and target displays in Experiments 7a and 7b. This example shows the *cued left* condition in each experiment.

Results and discussion

Table 10 shows mean RTs and error rates for each condition in Experiments 7a and 7b. Figure 22 shows IOR effects in these experiments compared to Experiments 5a and 5b. As shown in Figure 22, IOR effects for Experiments 7a and 7b were of a similar magnitude. Catch trials were not analysed and trials containing cue or target errors were excluded from the RT analysis.

Table 10: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiments 7a and 7b.

	Experiment 7a – Identical objects, different cue & target shapes				**Experiment 7b – Category objects, identical cue & target shapes**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	397.83	386.08	376.14	365.92	415.11	399.31	391.61	374.47
SD (ms)	95.95	91.85	99.19	86.77	92.70	89.31	91.48	85.16
% cue errors	0.42	0.83	0.56	0.97	0.83	0.28	0.28	0.14
% target errors	4.17	2.22	0.56	1.39	0.83	3.06	1.39	2.78

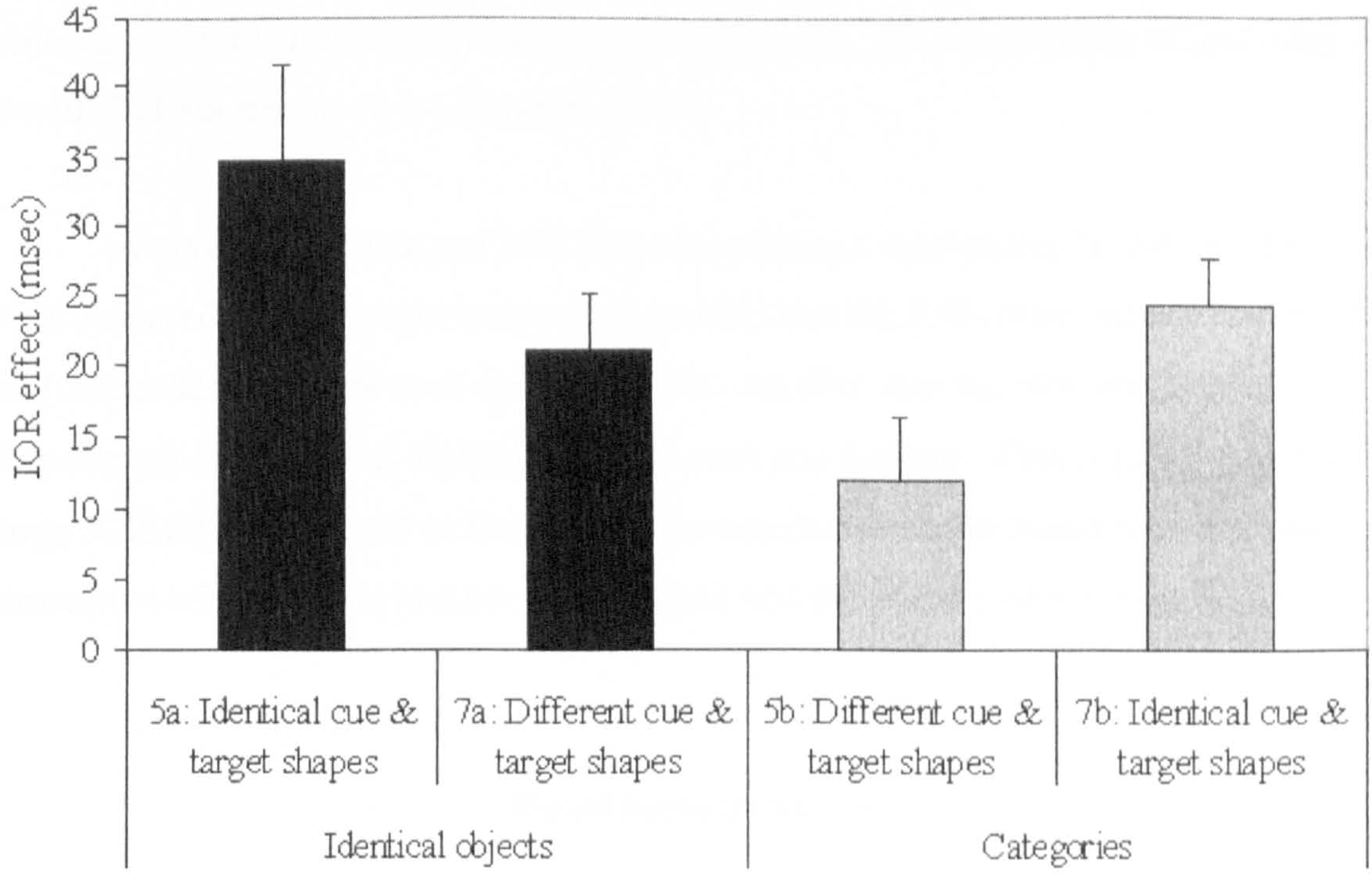

Figure 22: IOR effects (cued RT minus uncued RT) for Experiments 5a, 5b, 7a, and 7b. Error bars show the standard error of the mean.

2 (experiment – 7a and 7b) x 2 (cueing) x 2 (location) ANOVAs were performed on median RTs and error rates. The RT analysis found a significant main effect of cueing, *F* (1, 34) = 70.12, *p* < .001. There was also a significant main effect of location, *F* (1, 34) = 10.96, *p* = .002, with faster RTs to targets on the left. There was no main effect of experiment, *F* (1, 34) = 0.21, ns, and no interaction between cueing and experiment, *F* (1, 34) = 0.36, ns. There were no other significant main effects or interactions. The error analysis found a significant main effect of cueing, *F* (1, 34) = 5.57, *p* = .024. There was also a significant interaction between cueing and experiment, *F* (1, 34) = 6.52, *p* = .015, with more errors to cued versus uncued targets

in Experiment 7a, F (1, 17) = 8.28, p = .01, but not in Experiment 7b, F (1, 17) = 0.04, ns. There were no other significant effects in the error data.

IOR effects for Experiments 5a (identical objects, identical cues and targets), 5b (category objects, different cues and targets), 7a (identical objects, different cues and targets), and 7b (category objects, identical cues and targets) were compared using a one-way ANOVA. There was a significant main effect of experiment, F (3, 68) = 3.82, p = .014. Planned comparisons revealed that IOR was greater when cues and targets were identical than when cues and targets were different for both identical objects, p = .047 (Experiment 5a vs. Experiment 7a), and categorically related objects, p = .077 (Experiment 5b vs. Experiment 7b).

A similar magnitude of IOR was observed in Experiments 7a and 7b. The IOR observed in these experiments was greater than the IOR observed in Experiment 5b (categories, different cues and targets), but smaller than the IOR observed in Experiment 5a (identical objects, identical cues and targets). This suggests that the large IOR effect observed in Experiment 5a was due to object-based IOR that was associated with both the identity of the object and the identity of the cue.

Experiments 8a and 8b

Experiments 7a and 7b showed that the larger IOR for identical objects compared to categories in Experiments 5a and 5b was partly due to the identity of the cue and target shapes. This suggests that IOR can be associated with the identity of meaningless shapes. This is consistent with the work of Deschepper and Treisman (1996), which showed that inhibition in a negative priming task could be associated with the identity of meaningless shapes. Experiments 8a and 8b examined whether IOR could be associated with the identity of the cue shapes in the absence of any objects. These experiments were identical to Experiments 5a and 5b, except that the objects were removed from each stimulus display, leaving just the cue and target shapes. If the larger IOR effects in Experiment 5a compared to Experiment 5b were partly due to the identity of the cues and targets, as suggested by the results of Experiments 7a and 7b, then the same pattern of IOR should be observed when the objects are removed; that is, larger IOR when the cue and target shapes are identical (Experiment 8a), compared to when they are different (Experiment 8b). This would be a remarkable result, as these meaningless shapes only appeared for 200 ms.

Method

Participants

There were 36 participants in Experiments 8a and 8b (18 in each experiment, 11 males and 25 females), ranging in age from 20 to 35 years (mean age 25.5). The participants were either students at the University of Wales, Bangor or were residents of the Bangor area, and they all had normal or corrected-to-normal colour vision and were right-handed. They received £5 for participating.

Apparatus and Stimuli

This experiment used the same apparatus as the previous experiments. The stimulus displays were identical to Experiments 5a and 5b, except that the objects were cut out of the displays, leaving just the cue and target shapes (see Figure 23).

Design and procedure

The design and procedure for Experiments 8a and 8b were identical to Experiments 5a and 5b.

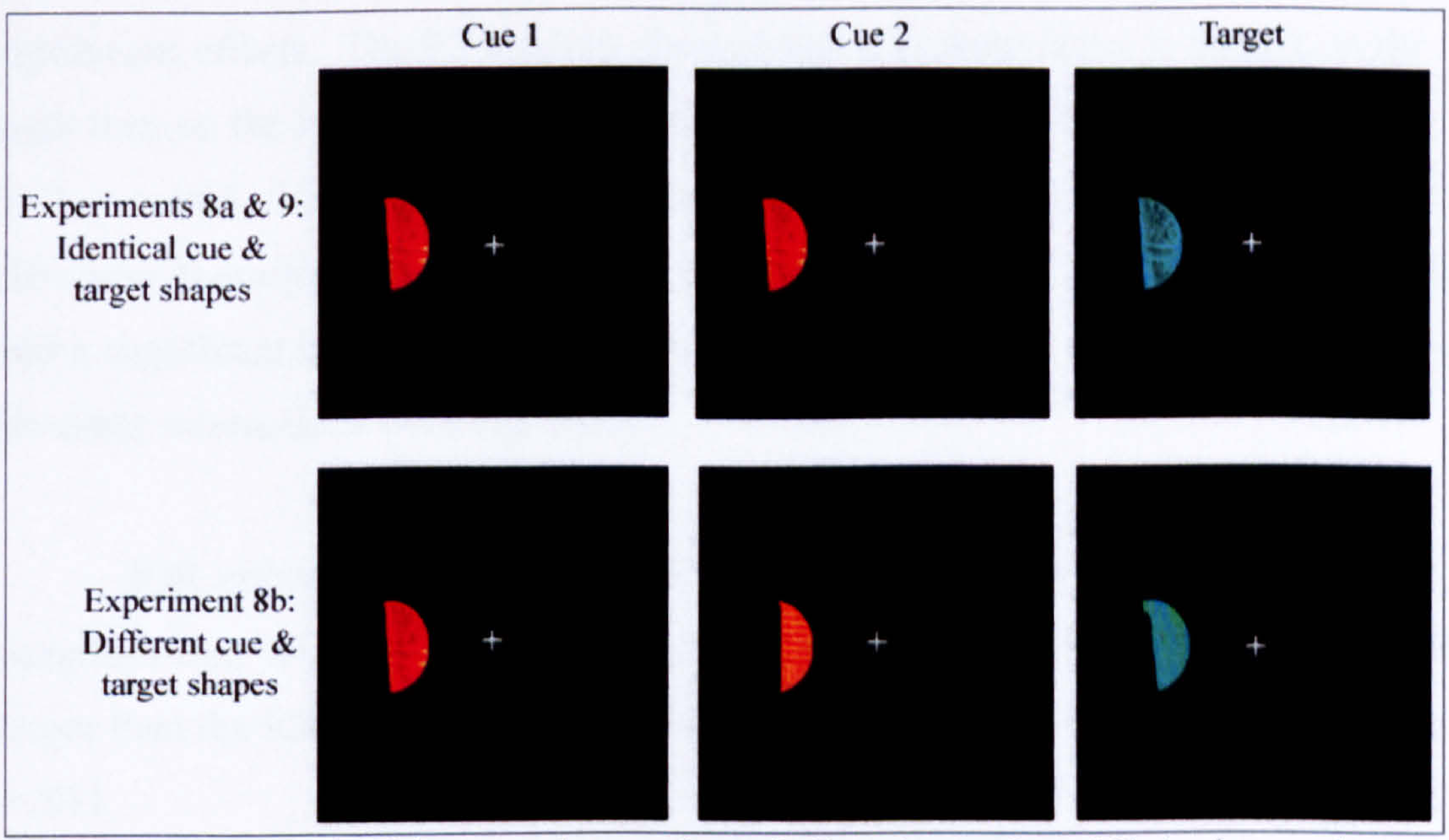

Figure 23: An example of the cue and target shapes in Experiments 8a and 8b (no intervening displays) and Experiment 9 (5 intervening displays).

Results and discussion

Table 11 shows the mean response time (RT), standard deviation, and percentage errors for each condition in Experiments 8a and 8b. As can be seen in Figure 24, IOR effects (cued RT minus uncued RT) were larger when the cue and target shapes were identical compared to when cue and target shapes varied. Catch trials were not analysed, and trials containing errors were excluded from the RT analysis.

Table 11: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiments 8a and 8b.

	Experiment 8a – Identical shapes				**Experiment 8b – Different shapes**			
	Cued		Uncued		Cued		Uncued	
	Left	Right	Left	Right	Left	Right	Left	Right
Mean RT (ms)	451.52	437.42	397.92	399.19	453.39	438.58	433.08	419.72
SD (ms)	85.39	67.70	63.67	56.71	138.17	127.76	138.88	136.95
% cue errors	0.83	0.42	0.42	0.83	0.42	0.28	0.42	0.42
% target errors	1.94	2.50	1.67	1.94	2.22	2.50	1.11	2.50

Median RTs and error rates were analysed using 2 x 2 x 2 ANOVAs with the factors *experiment*, *cueing*, and *target location*. The error analysis found no significant effects. The RT analysis showed that RTs were faster to targets on the right than on the left, and this main effect almost reached significance, $F(1, 34) = 3.63, p = .065$. There was no main effect of experiment, $F(1, 34) = 0.18$, ns. However, there was a significant main effect of cueing, $F(1, 34) = 45.20, p < .001$, and a significant interaction between cueing and experiment, $F(1, 34) = 7.29, p = .01$. No other interactions were significant.

IOR effects for the two experiments were compared using an independent-samples t-test. The IOR effect for identical shapes (Experiment 8a) was significantly larger than the IOR observed for different shapes (Experiment 8b), $t(34) = 2.70, p = .011$.

The cue and target shapes in the current experiments were the same as those used in Experiments 5a and 5b, and the only difference was that no objects were present in these experiments. The current experiments show the same pattern of results as Experiments 5a and 5b; that is, significantly larger IOR when cues and targets were identical compared to when cues and targets varied. This shows that IOR can be based entirely on the identity of the cues and targets, which suggests that realistic, meaningful objects may not be important for object-based IOR.

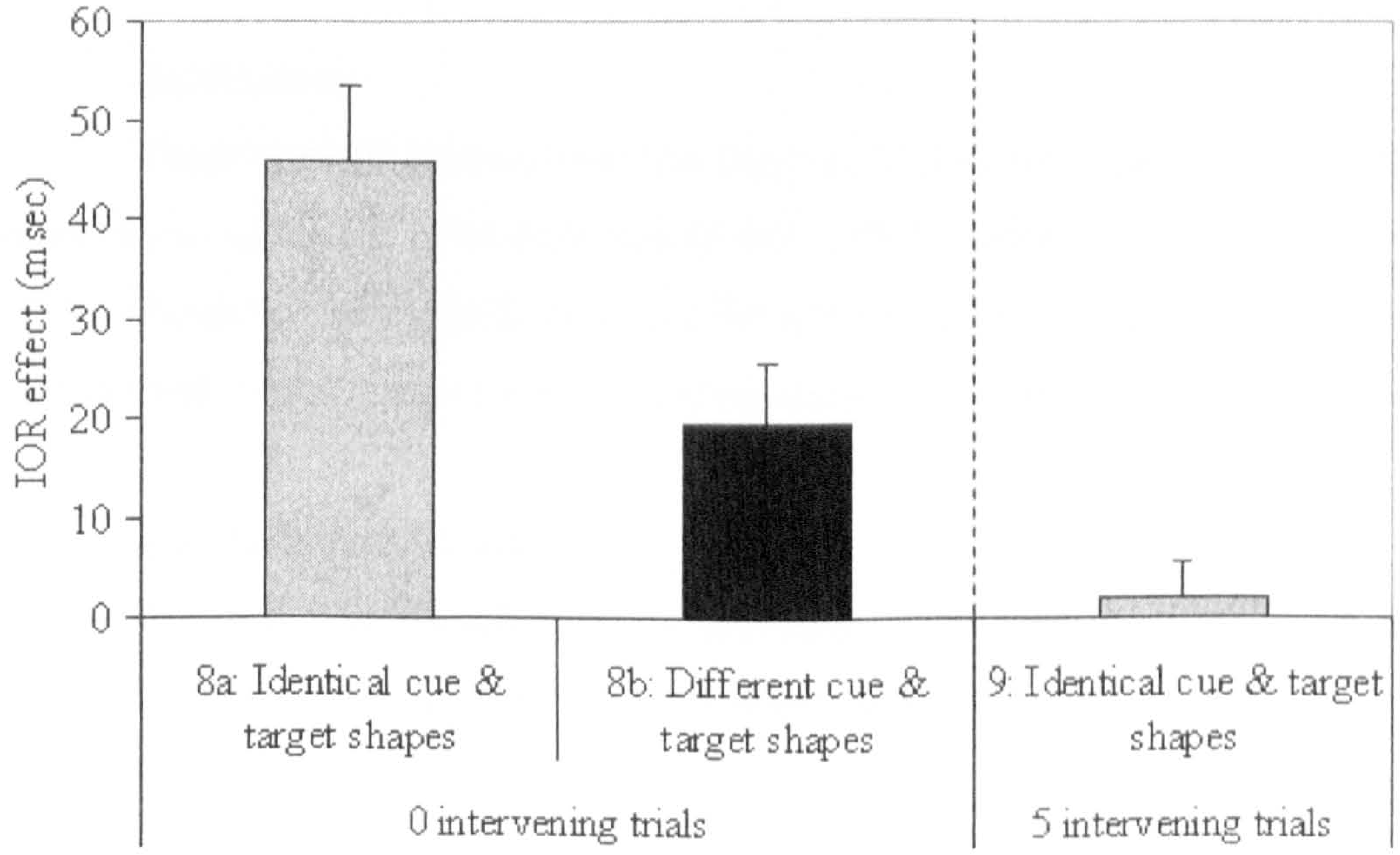

Figure 24: IOR effects (cued RT minus uncued RT) for Experiments 8a and 8b (no intervening displays) and Experiment 9 (5 intervening displays). Error bars indicate the standard error of the mean.

Experiment 9

The results of Experiments 8a and 8b show that IOR can operate on simple shapes. However, it seems unlikely that IOR based on briefly presented meaningless images could be encoded into and retrieved from memory. Therefore, it is possible that the long-term IOR effect observed in Experiment 6a was due to retrieval of inhibitory processes associated with the identity of the object, rather than with the cue. Experiment 9 examined whether realistic, meaningful objects are necessary for memory encoding and retrieval of inhibitory states. This experiment used the same stimuli as Experiment 8a (identical cue and target shapes), but the cue and target shapes were presented in sets of six, so that there were 5 intervening displays between each cue shape and its corresponding target shape (see Figure 25). If the long-term IOR effect observed in Experiment 6a was mediated by the identity of the cue, then this long-term IOR effect should also be present when the objects are removed from the display. Alternatively, if the long-term IOR observed in Experiment 6a was due to the identity of the objects, then this effect should be reduced or eliminated when objects are removed from the display.

Method

Participants

There were 18 participants (7 males and 11 females) aged between 18 and 35 years (mean age 24.8). The participants were either students at the University of Wales, Bangor or were residents of the Bangor area, and they were all right-handed with normal or corrected-to-normal colour vision. They received £5 for participating.

Apparatus and Stimuli

This experiment used the same apparatus as the previous experiments. The stimulus displays were identical to Experiment 8a (See Figure 23).

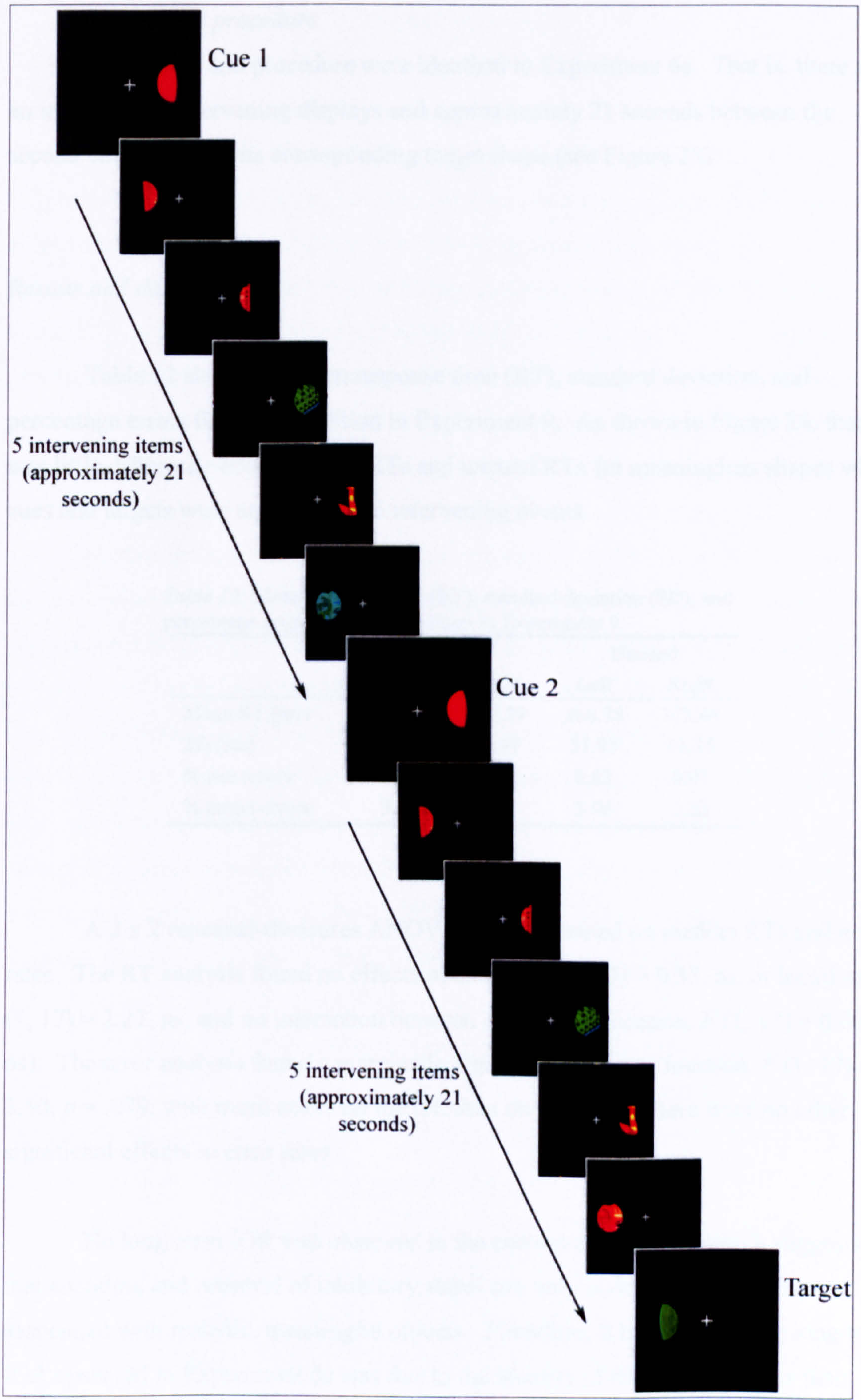

Figure 25: A typical trial sequence in Experiment 9. This example shows the *uncued left* condition.

Design and procedure

The design and procedure were identical to Experiment 6a. That is, there was an interval of 5 intervening displays and approximately 21 seconds between the second cue shape and its corresponding target shape (see Figure 25).

Results and discussion

Table 12 shows the mean response time (RT), standard deviation, and percentage errors for each condition in Experiment 9. As shown in Figure 24, there was little difference between cued RTs and uncued RTs for meaningless shapes when cues and targets were separated by 5 intervening events.

Table 12: Mean response time (RT), standard deviation (SD), and percentage errors for each condition in Experiment 9.

	Cued		Uncued	
	Left	Right	Left	Right
Mean RT (ms)	382.86	375.39	380.78	373.44
SD (ms)	50.48	41.69	51.95	41.35
% cue errors	0.69	0.69	0.83	0.97
% target errors	3.33	0.56	3.06	2.22

A 2 x 2 repeated-measures ANOVA was performed on median RTs and error rates. The RT analysis found no effects of cueing, F (1, 17) = 0.35, ns, or location, F (1, 17) = 2.27, ns, and no interaction between cueing and location, F (1, 17) = 0.00, ns). The error analysis found a marginally significant effect of location, F (1, 17) = 3.50, p = .079, with more errors on the left than on the right. There were no other significant effects in error rates.

No long-term IOR was observed in the current experiment, which suggests that encoding and retrieval of inhibitory states can only occur if the inhibition is associated with realistic, meaningful objects. Therefore, it is likely that the long-term IOR observed in Experiment 6a was due to the identity of the objects, rather than simply the identity of the cues and targets.

General Discussion

These experiments had two main aims. First, could they confirm previous work (Kessler & Tipper, 2004; Tipper et al., 2003) and the results of the previous chapters showing that IOR can be associated with an object's identity? The results in Experiments 5a and 5c do confirm that IOR is associated with an object's identity. That is, IOR was larger when cues and targets appeared on identical objects than when they appeared on different, unrelated objects. If IOR was a purely spatial mechanism that is blind to the nature of objects in the scene, then whether objects were repeated or not should have made no difference, as IOR would simply be based on the spatial location of the cues and targets (left and right of fixation).

Furthermore, Experiment 6a (long-term identical objects) confirmed that retrieval of prior inhibitory processes is mediated by object identity. That is, significant IOR was observed for identical objects when there were five intervening trials and an interval of approximately 21 seconds between the second cue and target display. Inhibition could not have been maintained over the intervening trials, as this would have interfered with ongoing behaviour. Therefore, the observation of IOR over such intervals can only be possible if inhibitory states associated with a particular object are encoded into memory, and then retrieved when the object is encountered again. This supports the findings of the previous chapters and the prior observations of Kessler and Tipper (2004) and Tipper et al. (2003).

The second aim of this chapter was to examine whether IOR could be associated with the category of an object. The results suggest that IOR cannot be associated with an object's category. That is, virtually identical IOR was observed in situations where objects within a category were cued (Experiment 5b) and when completely unrelated objects were cued (Experiment 5c). The results of Experiment 6b (long-term categories) provide further support for the notion that IOR cannot be associated with an object's category. When the second cue and the target were separated by an interval of 21 seconds and five intervening trials, no IOR was observed. It appears that encoding of an object in the target display does not automatically retrieve prior processing states of objects within the same basic-level category.

The results of Experiments 7a and 7b revealed that the use of semi-transparent cues and targets contributed to the effects observed in Experiments 5a and 5b, because the cues and targets varied slightly in the categories and different objects condition, whereas in the identical objects condition they were the same. That is, the larger IOR for identical objects in Experiment 5a was partly due to the identity of the cues and targets, and this effect decreased when the cues and targets were different (Experiment 7a). Conversely, the small IOR effect observed when categories were presented (Experiment 5b) increased when cues and targets were identical (Experiment 7b). These findings are consistent with the conclusion that IOR is mediated by the specific identity of objects, and not by more general object representations. Furthermore, these results suggest that IOR can be associated with the identity of meaningless shapes, as well as the identity of realistic objects.

This was confirmed by the results of Experiments 8a and 8b, in which IOR was greater for identical shapes than for different shapes in the absence of any realistic objects. This finding is interesting, as the different shapes in Experiment 8b were very similar, and the identity of the shapes was irrelevant to the low-level perceptual task of localising a green stimulus. Furthermore, these stimuli were presented very briefly (200 ms). Despite this, inhibitory mechanisms accessed information about the precise features of the cue shape. These results suggest that object-based IOR can be mediated by the identity of meaningless shapes.

These findings are consistent with research showing that inhibition can be associated with novel, meaningless shapes in a negative priming paradigm. DeSchepper & Treisman (1996) presented participants with a pair of overlapping red and green shapes adjacent to a white shape. Participants had to decide whether the green shape matched the white shape, while ignoring the red shape. Response times were slower when the green shape had been a distractor on the previous trial, relative to a control condition in which the green shape had not previously been seen. Interestingly, this negative priming effect for meaningless shapes was observed even when the cue and target were separated by 200 intervening displays, suggesting that inhibition associated with meaningless shapes can be encoded into and retrieved from memory.

In the context of these findings, it is perhaps surprising that Experiment 9 found that IOR associated with the identity of meaningless shapes could not be retrieved from memory. However, DeSchepper and Treisman (1996) used a shape judgement task, in which analysis of shape was central to the task goals. In contrast, the current experiments used a relatively simple colour detection task, in which shape was irrelevant to the task goals and was therefore ignored. Furthermore, the duration of stimulus presentation in the current experiments was very brief, and memory encoding decreases with shorter presentation times (Potter, 1976). So it is possible that presenting the shapes for longer durations would allow episodic encoding and retrieval of identity-based inhibition even for meaningless shapes. Alternatively, the presence of meaningful objects may be necessary for encoding and retrieval of inhibitory states in IOR. For example, meaningful objects may allow a deeper level of encoding, which has been shown to facilitate subsequent retrieval (Craik & Lockhart, 1972; Craik & Tulving, 1975; see Craik, 2002).

It appears that, in a task based on the standard IOR procedure, IOR is mediated by the identity of realistic objects and the identity of meaningless shapes. However, memory encoding and retrieval of inhibitory states can only occur if the inhibition is associated with the identity of realistic objects. This is consistent with research showing that IOR lasts for longer in working memory when objects are more salient and meaningful (Paul & Tipper, 2003; Samuel & Kat, 2003).

The finding that IOR is associated with identity-specific representations is also consistent with recent work by Reppa and Leek (2005), which used three-dimensional stimuli to investigate the nature of the object representations underlying object-based IOR. On each trial two objects were presented, each consisting of two volumetric components (geons). An exogenous cue appeared in one object, and the target could appear in either the cued or the uncued object. Cues and targets appearing on previously cued objects could appear either on the same surface of a volumetric component, on different surfaces of the same volumetric component, or on different volumetric components. The results showed that the relationship between cue and target on the planar surface of cued objects influenced the pattern of IOR effects. That is, IOR was larger when cues and targets were separated by an internal part boundary compared to when there was no intervening boundary (see also Reppa &

Leek, 2003). In contrast, the spatial configuration of volumetric parts had no impact on IOR.

According to Reppa and Leek (2005), these findings indicate that object-based selection occurs at a level of viewer-centred representation that encodes the internal structure of objects, such as surface structure and planar orientation, but does not encode the volumetric-part structure (e.g. He & Nakayama, 1992; Marr & Nishihara, 1978). These viewer-centred representations are identity-specific, because they are unique to a particular object. Therefore, these findings support the results of the current experiments, in which IOR was mediated by object identity. Reppa and Leek's (2005) finding that IOR was not influenced by volumetric part structure is also consistent with these experiments, because representations of an object's basic-level category would require information to be encoded in terms of the spatial configuration of volumetric parts (e.g. Biederman, 1987; Hummel, 2001; Marr & Nishihara, 1978), rather than internal structure. Therefore, these findings provide converging evidence for the idea that IOR operates on object identity and not basic-level category representations.

The finding that IOR cannot be associated with an object category is interesting, because it shows a clear contrast between IOR and negative priming. However, the lack of category-based IOR effects does not necessarily imply that IOR and negative priming are fundamentally different processes. The negative priming and IOR tasks are quite different, and such task differences might well be the cause for semantic inhibitory effects in some situations, and no effects in other situations. As suggested by Tipper et al. (1994a), behavioural goals can influence the forms of information that are inhibited, and semantic analysis (such as identifying objects in typical negative priming tasks) will activate semantic forms of inhibition.

Indeed, there is evidence that different forms of internal representation exist for different properties of objects. Research has shown that categorisation of objects and recognition of specific objects are different processes that depend on separate brain systems. For example, amnesic patients with severely impaired recognition memory can perform within the normal range on categorisation tasks (Knowlton & Squire, 1993; Kolodny, 1994; Reed, Squire, Patalano, Smith, & Jonides, 1999; Squire

& Knowlton, 1995). Also, brain imaging studies have revealed that the processes of object categorisation and recognition of specific objects have different temporal characteristics (e.g. Curran, Tanaka, & Weiskopf, 2002), and structural and semantic processes take place in different brain areas (e.g. Gerlach, Law, Gade, & Paulson, 2000).

So it is possible that the type of task may influence which properties of an object are associated with inhibition. Typical negative priming tasks require participants to respond to semantic properties of the target stimulus, such as the name or category of pictures or words. In this type of task the semantic properties of the distractor would interfere with behaviour and would need to be inhibited. In contrast, no semantic processing was required in the current series of experiments. Rather, to keep these experiments closely related to the standard IOR procedures, the task requirement was simply to localise a briefly flashed green target, and the object was irrelevant to the task. Therefore, inhibition of semantic forms of representation may not have been necessary in this task.

Furthermore, the IOR evoked by peripheral sudden onset cues *can* affect semantic processing in some circumstances. Fuentes, Vivas, and Humphreys (1999a, 1999b) and Vivas and Fuentes (2001) showed that the semantic processing of a stimulus presented at a previously cued location was inhibited (see also Chasteen & Pratt, 1999; Lupiáñez et al., 1997). Thus, in a series of studies they showed that the automatic semantic processing observed via priming and interference effects (e.g. Stroop, 1935) is curtailed when the prime/interfering distractor is presented in the cued location. Indeed, in some circumstances negative semantic priming effects were observed.

Therefore, the current results do not suggest that IOR can *never* influence semantic processes. In procedures that encourage semantic analysis of target stimuli, such category-based cueing effects may well be revealed. But what seems clear from the findings reported in this chapter is that, in a task closely related to the standard IOR procedure, where a target is detected or spatially localised, the inhibition evoked by the cue is not associated with basic-level object category representations.

In this context, the identity-based IOR effects observed in this chapter are particularly striking. As noted previously, the task required a relatively low-level perceptual task of localising a briefly flashed green stimulus. Nevertheless, the inhibition evoked by the to-be-ignored red cue was associated with the identity of realistic objects, as well as with the identity of the cue. Further experiments showed that IOR could be associated with the identity of briefly presented meaningless shapes. However, IOR could only be retrieved from memory when the cues and targets appeared on identical realistic objects. The finding that IOR can be associated with an object's specific identity, together with the finding that prior inhibitory processes can be retrieved from memory in the presence of the cued object provide converging evidence for the notion that IOR can operate on an object-based frame of reference.

Chapter 5 – Is IOR influenced by action-related properties of objects?

In the real world, perception of a target object in visual search is usually followed by an action towards that object. Therefore, highly efficient visuomotor processes are necessary to enable rapid responses in complex environments. As mentioned in Chapter 1, perception and action are closely linked and the conversion from vision to action often takes place independently of any conscious intention to act. For example, viewing an object can activate motor representations of the action associated with that object (e.g. Tucker & Ellis, 1998). The aim of this chapter was to determine whether IOR is influenced by the action affordances of irrelevant objects. Such an observation would provide further evidence for object-based IOR, as a purely space-based mechanism would not be affected by the action-related properties of an irrelevant object.

As noted previously, it is well established that the automatic activation of motor representations by a visual stimulus facilitates responses that are compatible with the evoked action, while incompatible responses are impaired (Ellis & Tucker, 2000; Grèzes et al., 2003; Tucker & Ellis, 1998, 2001, 2004). For example, Tucker and Ellis (1998) presented images of common objects, such as saucepans and kettles, and participants used a left- or right-hand key-press to indicate whether the object was upright or inverted. Responses were faster when the handle of the object appeared on the same side as the responding hand. For example, a cup with the handle oriented to the left would be responded to quicker with the left hand than with the right hand (see Figure 26). This automatic activation of compatible responses occurs even when the affording object is irrelevant to the task (Phillips & Ward, 2002).

Figure 26: An example of action affordances. Responses to the cup would be faster with the left hand than with the right hand, because the handle of the cup affords a left-hand response.

Recent research suggests that the degree to which these object affordances activate motor representations depends on the action state of the object. Tipper, Paul, and Hayes (in press) distinguished between "passive" and "active" action states. An object is said to be in a passive state if it evokes action, but does not appear as if it is being acted upon. For example, a cup with the handle oriented to the left (as in Figure 26) evokes a left hand response, but it does not imply that this action is being performed. An object is said to be in an active state if it appears that the evoked action is being carried out (see Figure 27). Previous studies of action affordances have always presented objects in passive states.

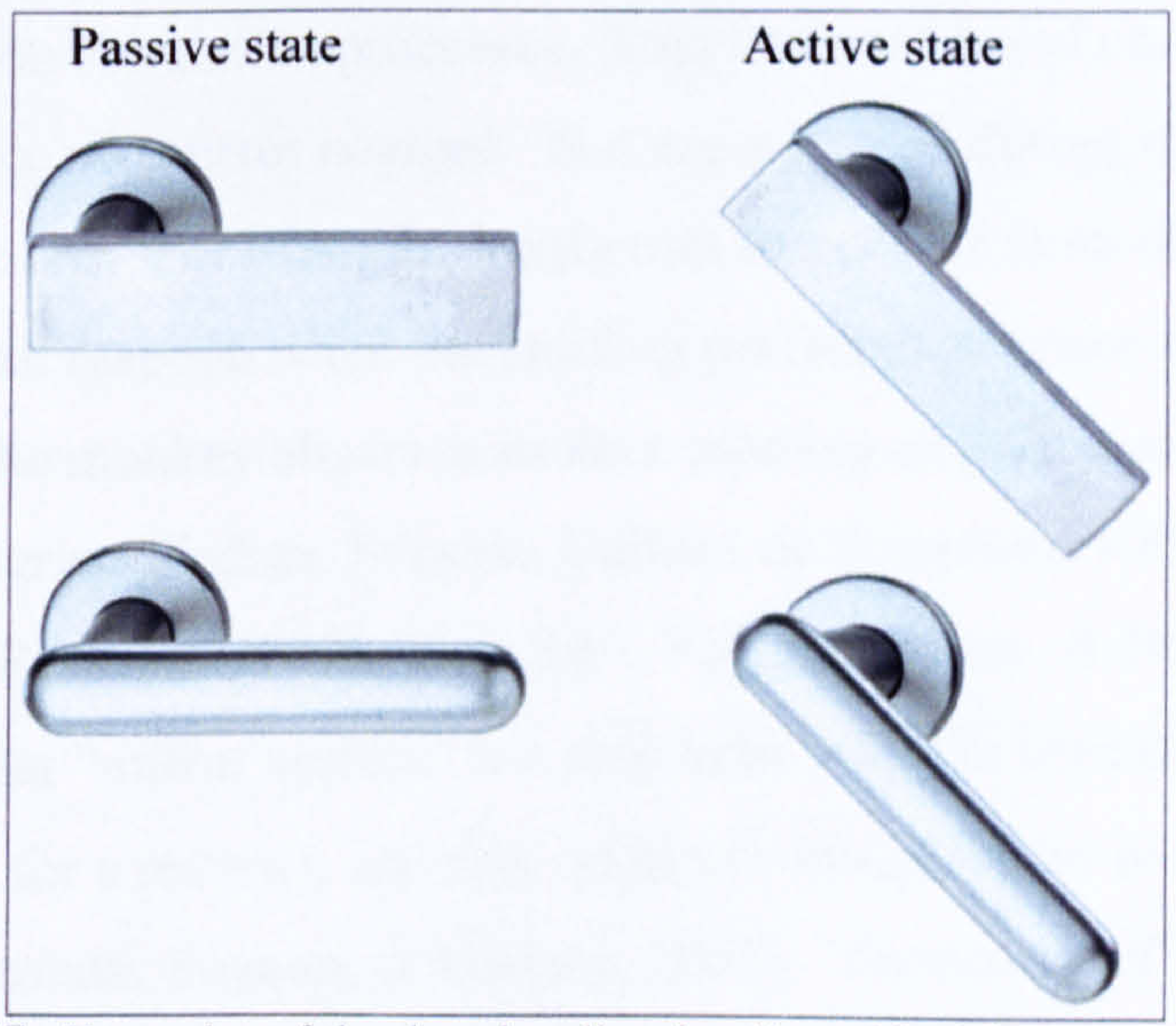

Figure 27: Examples of the door handle stimuli used by Tipper et al. (in press). The door handles on the right are said to be in an active state, because they imply that someone is acting upon them (i.e. they are being pressed down). The actions afforded by all the door handles in this example are compatible with a right-hand response, because the handle is oriented to the right.

Tipper et al. (in press) manipulated the action state of door handle stimuli that were oriented with the handle part on the left or on the right. In the passive condition these door handles were horizontal, as they would appear if no action was taking place. In the active condition the door handles were tilted downwards by 45 degrees, as if they were being pressed down to open a door. Examples of these stimuli are shown in Figure 27. To further increase the sense that door handles in the active condition were being acted upon, a short video clip showing a hand opening a door by pressing down the door handle was shown at the start of the experiment. Participants had to respond to the shape of the door handles by making a left-hand or right-hand key press to indicate whether the handle had round or square edges. Response times were faster when the action afforded by the door handle was compatible with the correct response compared to when it was incompatible, showing the standard action affordance effect. However, this action affordance effect was larger for door handles in the active condition than in the passive condition. This result could not be attributed to differences in the orientation of the stimulus, because a control condition, in which the stimuli were altered so they no longer resembled door handles, found no action affordance effects and no differences between the passive and active conditions.

According to Tipper et al. (in press), action affordances were larger for door handles in the active condition because they implied an action by another person, which activated action simulation processes. This idea was based on research showing the existence of "mirror neurons" that are activated during observation of another person's actions. For example, single unit recordings in monkeys have found premotor neurons that respond when the monkey performs an action and, most importantly, when the monkey observes another monkey or person make the same action (e.g. Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Evidence for a similar "mirror system" has also been found in humans (see Rizzolatti & Craighero, 2004, for a review), and this system is thought to be involved in action understanding (Rizzolatti, Fogassi, & Gallese, 2001). The results of Tipper et al.'s (in press) study suggest that viewing an object in an active state activates visuo-motor processes that are similar to the mirror system. In support of this idea, other work has shown that mirror systems can be activated when action is implied but not observed. For example, mirror neurons in monkeys respond when an action is occluded (Umilta et al., 2001), and when an action is heard but not seen (Kohler et al., 2002). Similarly, listening to action-related sentences has been shown to activate the same fronto-parietal areas that are activated during action execution and observation (Tettamanti et al., 2005).

The purpose of the following experiments was to determine whether IOR is influenced by the action affordances of objects. According to the Houghton and Tipper (1994) model described in Chapter 1, cues that are compatible with the action affordance of an object should produce greater initial activation and require greater inhibitory feedback than cues that are incompatible. For example, the left end of the door handle shown in Figure 28 automatically evokes grasp. Therefore, a cue that appears at the left end (the action-compatible end) of the door handle will evoke a greater level of activation, and will therefore require a greater level of reactive inhibition, compared to a cue that appears at the right end (the incompatible end).

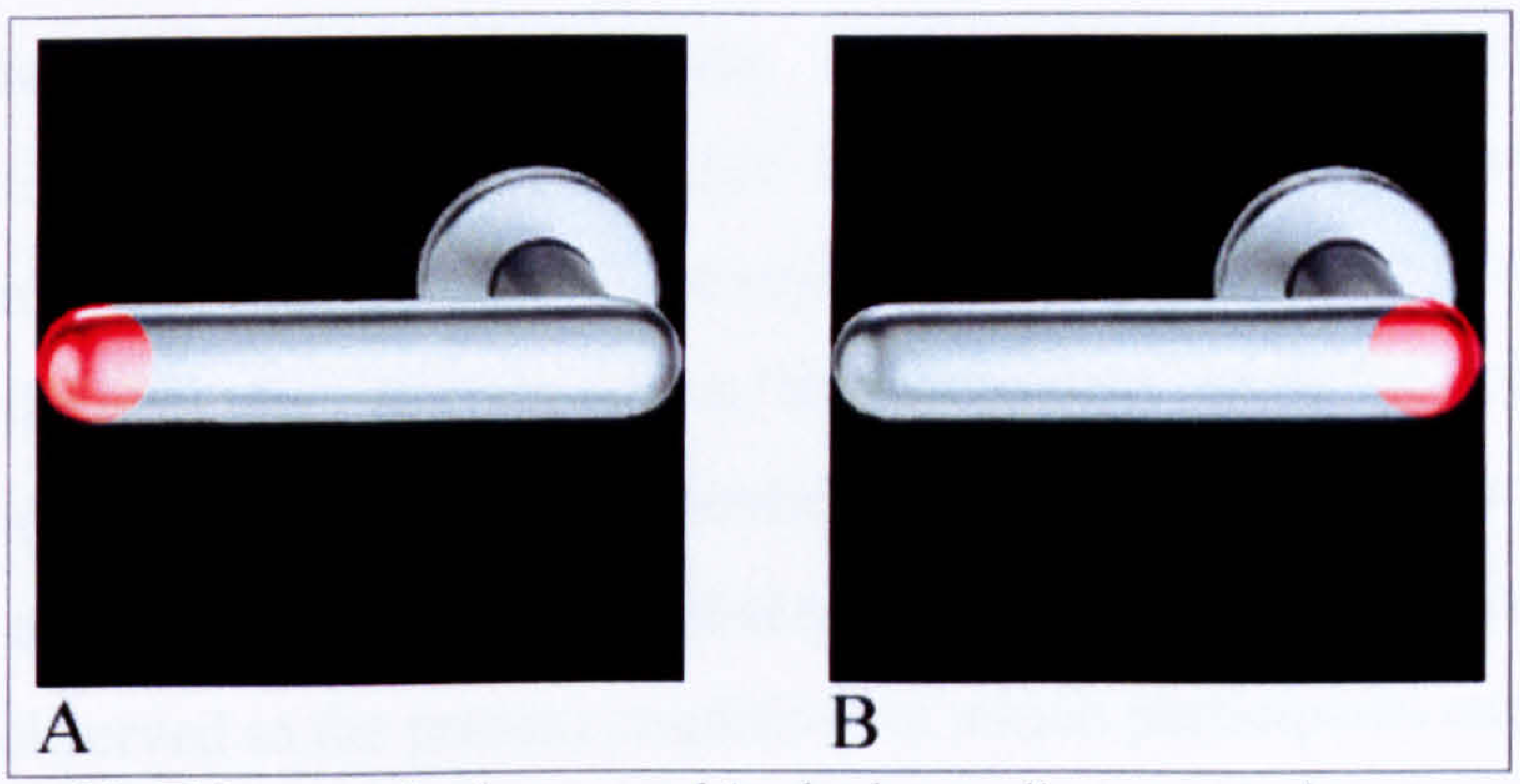

Figure 28: This example shows a red 'to-be-ignored' cue appearing at one end of a door handle. Greater levels of reactive inhibition should be necessary when the cue appears at the compatible end (A), than when it appears at the incompatible end (B).

It appears that action affordance effects are larger when viewing objects in an active state due to the activation of an action simulation system, as well as the activation of motor responses associated with the object. Therefore, based on Tipper et al.'s (in press) finding that action affordances are more robust when objects imply current action, objects were presented in both active and passive states. That is, door handles could be oriented horizontally (in the passive condition) or tilted downwards as if they had been pressed to open a door (in the active condition). In a further experiment, door handles in the active condition appeared horizontal during presentation of the cue, then move downwards before the target appeared. It was not clear what pattern of IOR would be observed for active door handles. However, unlike Tipper et al.'s (in press) study, the main purpose of the active stimuli in the current experiments was to increase action affordances by creating a context of implied action for all the door handles in the task.

This idea was based on recent work, which suggests that object-based IOR can be influenced by the context in which objects appear. Jefferies, Wright, and Di Lollo (in press) investigated the conditions under which IOR can be observed for occluded objects. Attention was oriented to the left or right by the sudden appearance of an object on one side of the display. This object remained stationary for a short time, then moved horizontally across the display and stopped behind an occluding object at the opposite side. Shortly afterwards a target appeared either at the end of the object's motion path (on the occluder), at the start of the motion path, or at a different location. These trials were mixed with "context" trials, in which the cued object was not occluded at the end of its motion sequence. The type of context trial was manipulated between participants. On "present context" trials the object remained visible after it had stopped moving; this established the expectation that the object would continue to exist behind the occluder. In contrast, on "absent context" trials the object disappeared as soon as it had stopped moving, creating the expectation that the object would cease to exist once it had moved behind the occluder. IOR for occluded objects was observed in the present condition, in which participants expected that the object behind the occluder continued to exist. However, no IOR occurred for occluded objects in the absent condition, in which participants expected that the object behind the occluder had disappeared.

Jefferies et al.'s (in press) findings suggest that observer expectation plays an important role in object-based IOR, and this expectation can be manipulated by the context in which objects appear. Therefore, the door handles in the passive condition were designed to reveal the influence of action affordances on IOR, and the main purpose of the active door handles was to establish a context of implied action. In addition, based on Tipper et al.'s (in press) methods, a video clip of a door being opened was also shown, in order to create a sense of current action.

Experiments 10a, 10b, and 10c

These experiments used door handle stimuli, similar to those used by Tipper et al. (in press), to examine whether the action afforded by an object influences IOR. In Experiment 10a (control) the door handles to be used in subsequent experiments (10b and 10c) were replaced with a structurally identical image that was not recognised as a door handle (see Figure 29). This provided a baseline condition, in order to establish what effects could be attributed to the structural properties of the door handle. In Experiments 10b and 10c door handles were presented. The handle part could be on either the left (compatible with a left-hand response) or on the right (compatible with a right-hand response). A 'to be ignored' red cue appeared on one side of the door handle, then a green target requiring a rapid left- or right-handed localisation response appeared on either the cued or the uncued side. In addition, participants in Experiments 10b and 10c were shown a video clip of a door being opened. In Experiment 10b door handles in the passive condition were horizontal and door handles in the active condition were tilted 45 degrees downwards. In Experiment 10c the door handles were always horizontal when the cue appeared, but on half the trials the door handles moved downwards by 45 degrees before the target appeared (the active condition).

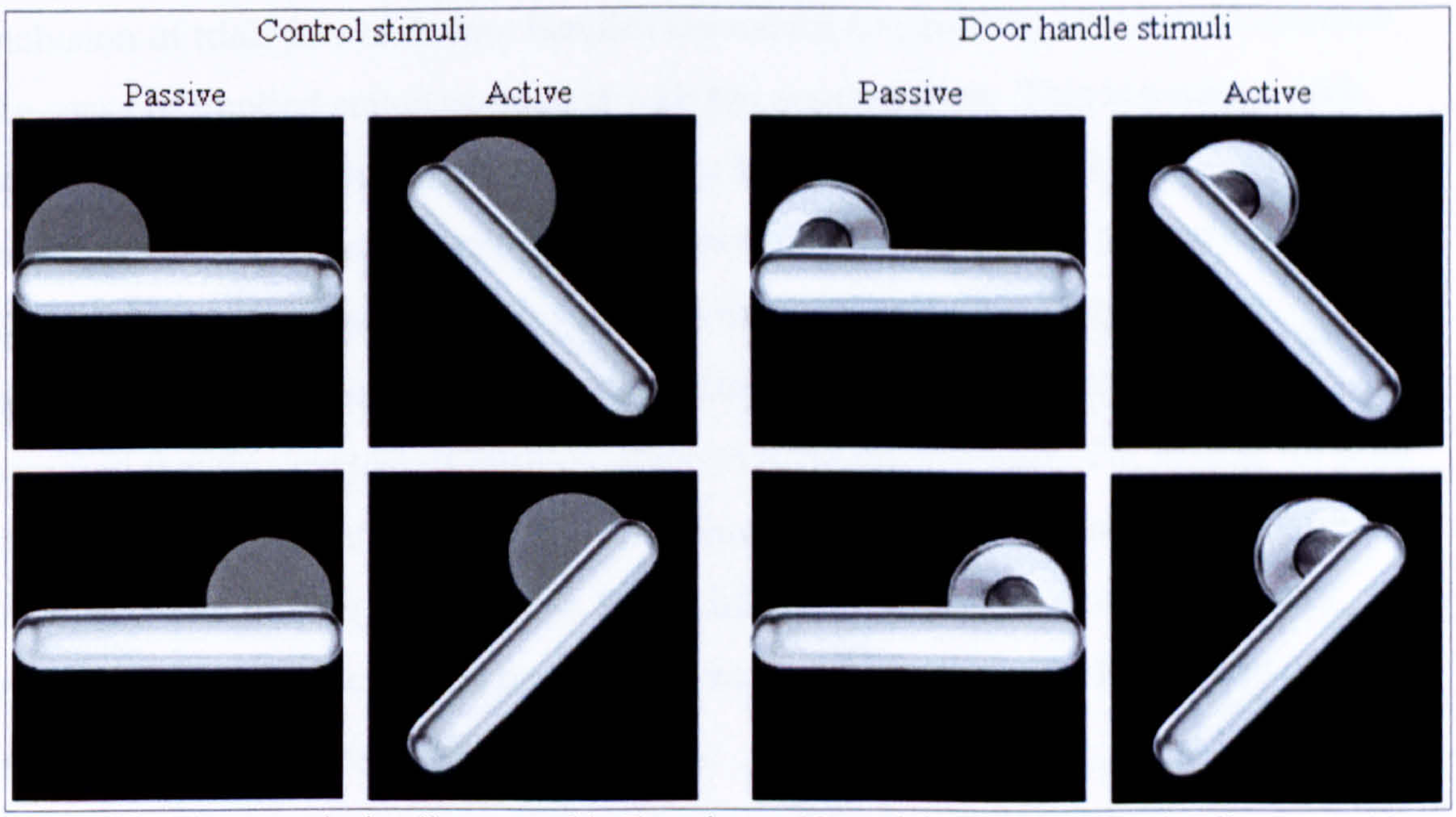

Figure 29: The control stimuli presented in Experiment 10a and the door handle stimuli presented in Experiments 10b and 10c. The door handles in the top row evoke a right-hand grasp, whereas the door handles in the bottom row evoke a left-hand grasp.

As already noted, the reason for presenting active stimuli in the current experiments was to create a sense of implied action for all the door handles in the task. It was unclear what pattern of IOR would be observed for active door handles in the current tasks, as there were many factors that could influence IOR and action affordances. For example, the compatible side of the stimulus was always lower in the visual field (and therefore closer to the responding hand) than the action-incompatible side, and this could result in greater action-compatibility effects. Furthermore, it was unclear whether the pattern of IOR for the active stimuli in Experiment 10c would be influenced by the potency of the action afforded by the moving door handle or by an attentional bias to track the moving (compatible) side of the door handle.

Therefore, the main comparisons made between the experiments involved the stimuli presented in the passive condition, as the procedures in this condition were identical for each experiment, and the stimuli in each experiment were structurally identical. Based on Houghton and Tipper's (1994) model of reactive inhibition, it was expected that IOR effects for door handles (Experiments 10b and 10c) would be larger, relative to the control condition (Experiment 10a), when the action afforded by the object was compatible with the response. Furthermore, it was expected that the inclusion of trials in which door handles moved (in Experiment 10c) would increase the sense of implied action associated with the door handles. This is because each trial in Experiment 10c started with the door handle in a horizontal position, and on half these trials (the active condition) the door handle then moved downwards. Therefore, this implied action may be associated with all door handles in the horizontal position, due to the expectation that they would move down. It was assumed that this context of implied action may produce greater IOR effects for door handles in Experiment 10c (moving door handles) than in Experiment 10b (static door handles). The finding that IOR can be modulated by action-related properties of objects would provide further evidence to support the idea that IOR operates on identity-based representations.

Method

Participants

There were 54 participants (12 males, 42 females) in Experiments 10a, 10b, and 10c (18 in each experiment). Participants were aged between 18 and 40 (mean age 21.1), and they took part in return for course credit or £5. The participants were students at the University of Wales, Bangor, and they were all right-handed with normal or corrected-to-normal colour vision.

Apparatus and stimuli

Stimulus presentation and recording of response times were performed by the *E-prime* program running on a PC. *Windows media player* was used to display the video clip (in Experiments 10b and 10c). The stimuli were presented on a 17 inch monitor, and a chinrest was used to keep participants at a distance of 57 cm from the monitor. A computer keyboard was located on a table within easy reach of the subjects. Keys 'A' and 'L' were used to register the responses, and the space bar was used to initiate trials.

The stimuli in Experiments 10b and 10c were photographs of door handles. The handle part of the stimulus was 500 pixels long and 93 pixels high, and the round disk at the incompatible end was 190 pixels in diameter. The cues and targets were semi-transparent red (cue) and green (target) circles (with a diameter of 90 pixels) that were superimposed over one end of the handle. The stimuli for Experiment 10a (control) were identical to the door handle stimuli, except that the round disk that appeared at the incompatible end of the door handle was filled in a uniform grey colour (see Figure 29). This made the control stimuli unrecognisable as door handles, even though the metal handle part, on which the cues and targets appeared, was identical to the door handle stimuli. None of the participants in this experiment recognised these stimuli as door handles.

In all three experiments the stimuli in the passive condition were oriented horizontally. In Experiments 10a and 10b the stimuli in the active condition were tilted downwards by 45 degrees. To give the impression of the door handle moving, the active stimuli for Experiment 10c were made by moving the handle part of the door handle downwards, while keeping the round disk in the same position. The impression of movement was achieved by three frames of animation, in which the door handle was oriented downwards by 15 degrees, then 30 degrees, and finally 45 degrees. This meant that in the action-compatible condition, previously cued targets appeared 6 degrees of visual angle away from the location of the cue.

The video clip shown in Experiments 10b and 10c was 17 seconds long and contained footage of a door being opened twice (once by a male hand and once by a female hand) using the right hand operating a rightward facing handle followed by footage showing the left hand operating a leftward facing handle twice (see Figure 30).

Stimuli were presented at the centre of a black screen, and a central white fixation cross (20 x 20 pixels) was presented before stimuli appeared.

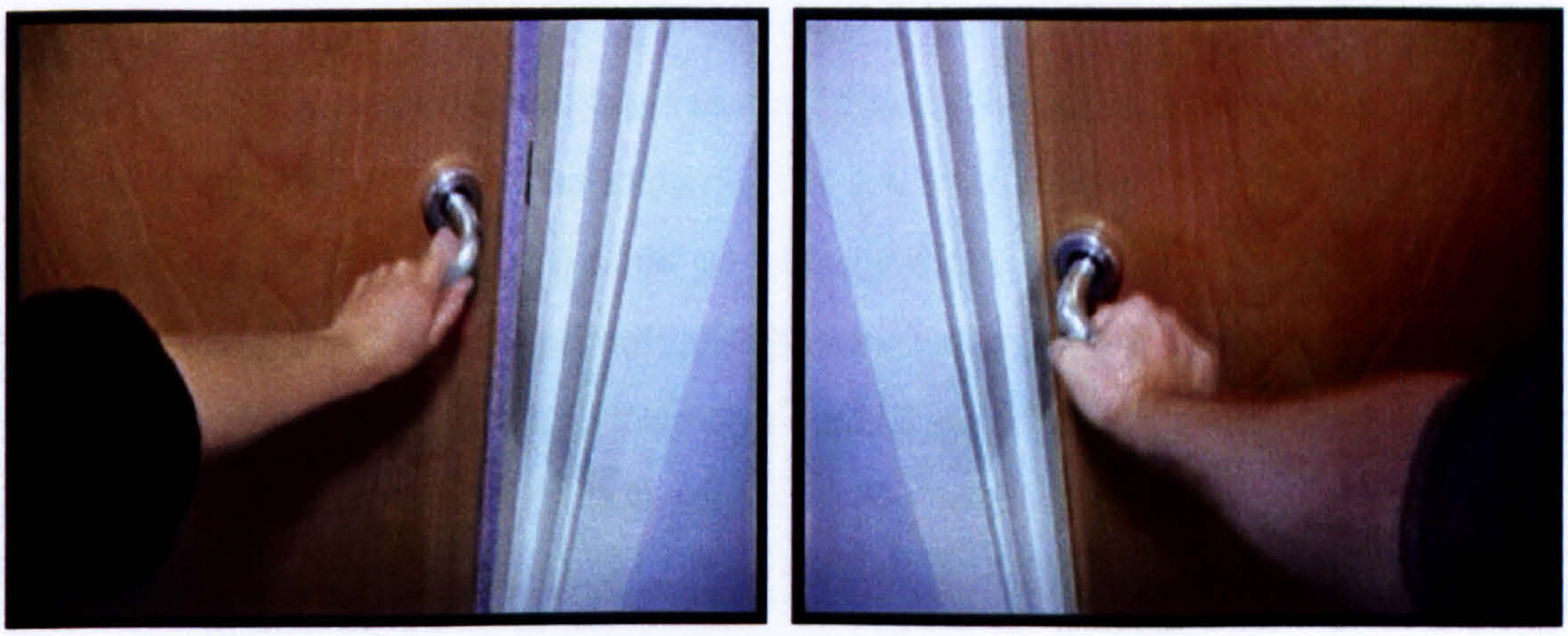

Figure 30: Frames taken from the video clip. The left panel shows a female hand opening a door with a left-hand reach. The right panel shows a male hand opening a door with a right-hand reach.

Design

Each experiment had a 2 x 2 x 2 repeated-measures design with the factors *action state* (passive or active), *cueing* (cued or uncued), and *action-compatibility* (incompatible or compatible with the afforded action). It is important to note that, although the control stimuli in Experiment 10a were not expected to evoke action affordances, the action state and action-compatibility factors were labelled to facilitate comparison with Experiments 10b and 10c. Each experiment contained 576 trials, divided into two blocks of 288 trials each. There was also a practice block containing 10 trials.

The order of conditions was randomised. In each block there were 192 IOR trials, in which participants had to ignore a red cue signal and then respond to a green target signal. The stimuli appeared in the passive state on half (96) of these trials and in the active state on the other half of the trials. For each action state there were 48 cued trials, in which the green target appeared at the same end of the handle as the red cue, and 48 uncued trials, in which the cue and target appeared on opposite ends.

Each action state also contained 48 compatible trials, in which the target appeared at the affording end of the handle, and 48 incompatible trials, in which the target appeared at the non-affording end of the handle; these trials were distributed evenly across the two levels of cueing. On half of the trials in each condition the target appeared on the left and on the other half the target appeared on the right.

To reduce the predictability of the 'no go – go' response sequence required for the IOR trials, the remaining 96 trials in each block were catch trials; 48 of these trials required a 'go – no go' response sequence, 24 trials required a 'go – go' response sequence, and 24 trials required a 'no go – no go' response sequence. Half of these catch trials contained passive stimuli and the other half contained active stimuli. The distribution of the two levels of action-compatibility was equal across the catch trials and targets appeared equally often on the left and right.

Procedure

Participants sat in a dimly lit room in front of the computer monitor. The keyboard was placed within easy reach, and the height of the chinrest was adjusted to a comfortable level. They were instructed to respond to green targets. They were also told to position their fingers on the response keys before each trial and to fixate on the fixation point at the start of each trial. They had to press the 'A' key with the left hand if the target appeared on the left and the 'L' key with the right hand if it appeared on the right. The participants then completed the practice block, followed by the first experimental block. They then had a short break, after which they completed the second block. In Experiments 10b and 10c participants were shown the video clip prior to starting the experiment and at the start of the second block.

In Experiments 10a (control) and 10b (static door handles) the sequence of events in a trial was as follows. Before every trial, a message appeared instructing participants to initiate the trial by pressing the spacebar (with the thumb). A central fixation cross appeared for 500 ms, then the stimulus appeared. After 500 ms one end of the stimulus was overlaid by the cue signal for 200 ms. This was followed by a 1000 ms interval, after which the target appeared for 200 ms. The stimulus remained on the screen for a further 300 ms, then a black screen was displayed for 500 ms. Participants had 1000 ms from the onset of the target signal to make a response.

The procedure for Experiment 10c (moving door handles) was identical, except for the movement in the active condition. The sequence of animation was as follows: The cue appeared on the horizontal door handle for 200 ms, and the door handle remained in the horizontal position for a further 250 ms. This was followed by the three frames of animation, each of which appeared for 250 ms. Then the target was presented for 200 ms on the third frame of animation (in which the door handle was tilted 45° downwards). The door handle remained on the screen for a further 300 ms, and was then replaced by a black screen for 500 ms.

Errors in responding to the cue or target produced auditory feedback that indicated an incorrect response. At the end of the trial, if participants had responded correctly to both the cue and target, they received auditory feedback indicating a correct response. The experiment lasted for approximately 40 minutes. The basic trial sequence is shown in Figure 31 and the trial sequence for the active condition in Experiment 10c is shown in Figure 32.

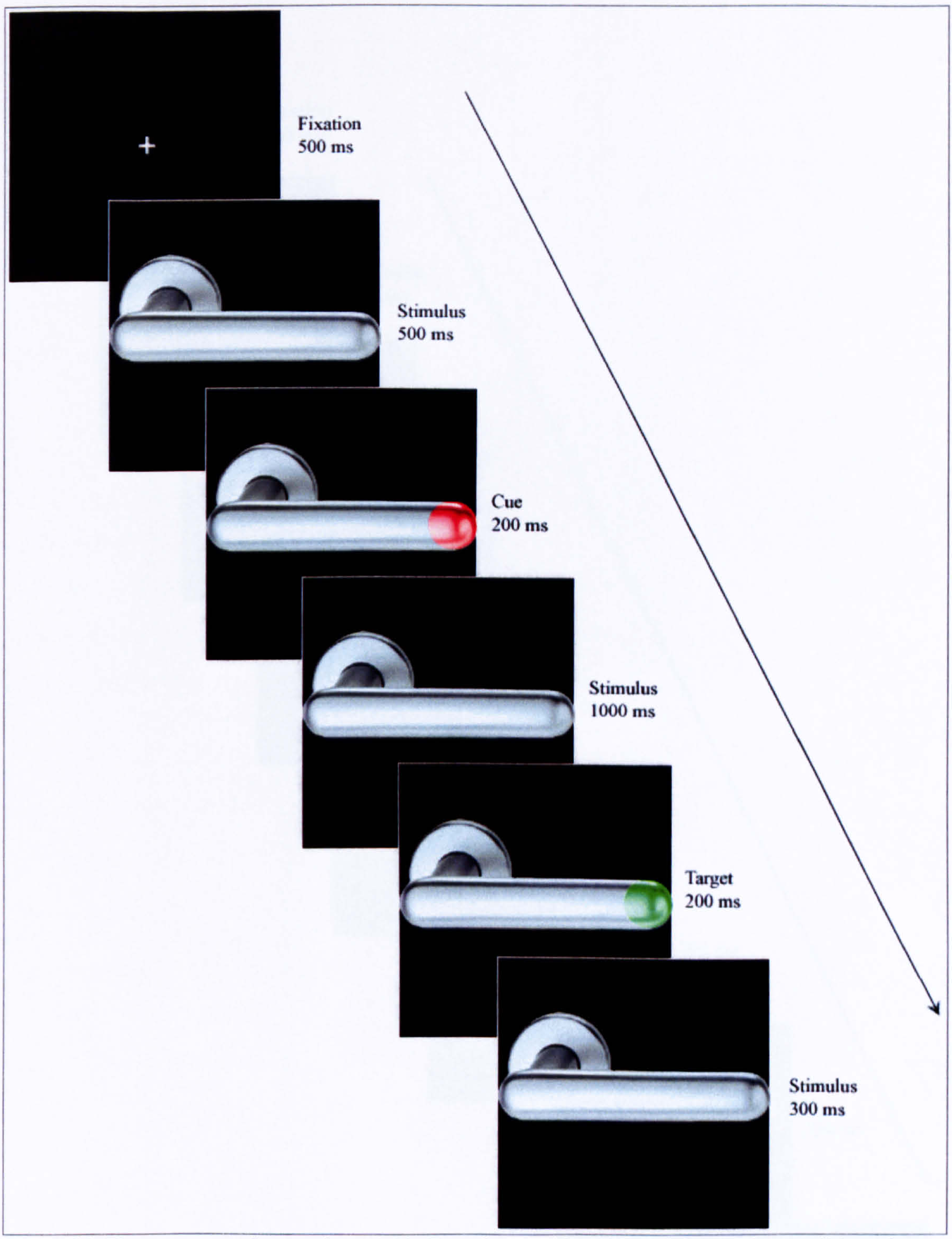

Figure 31: The sequence of events in a trial in Experiments 10a, 10b, and the passive condition of Experiment 10c. This example shows the *cued compatible* condition for passive door handles in Experiments 10b (static door handles) and 10c (moving door handles). The procedure for Experiment 10a (control) was identical.

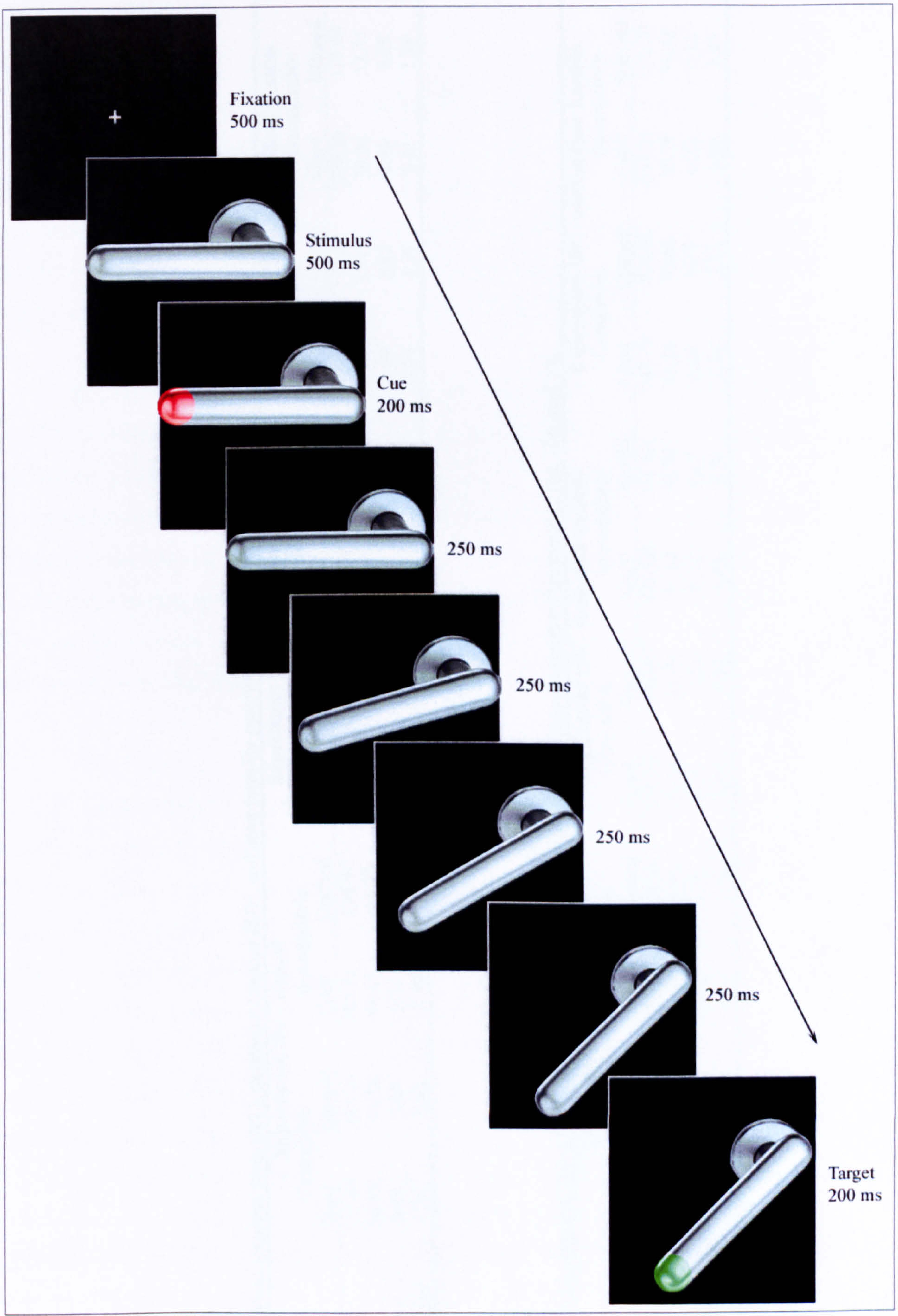

Figure 32: An example of the sequence of events in a trial in the active condition in Experiment 10c (moving door handles). This example shows the *cued compatible* condition, in which the locations of the cue and target were separated by a visual angle of 6 degrees.

Table 13: Mean response times (RT), standard deviations (SD), and error rates for passive stimuli in Experiments 10a, 10b, and 10c

	Experiment 10a – control				**Experiment 10b – static door handles**				**Experiment 10c – moving door handles**			
	Compatible		Incompatible		Compatible		Incompatible		Compatible		Incompatible	
	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
RT (ms)	373.86	328.21	383.31	330.97	387.14	339.09	392.00	349.85	367.53	310.61	370.20	317.09
SD (ms)	38.55	44.18	41.45	43.27	49.73	51.73	46.16	50.48	41.75	35.46	39.05	32.51
% cue errors	0.35	0.00	0.12	0.23	0.35	0.23	0.35	0.23	0.69	0.12	0.46	0.35
% target errors	1.39	0.93	1.50	1.51	1.85	1.51	1.51	1.62	1.04	1.39	0.81	1.39

Table 14: Mean response times (RT), standard deviations (SD), and error rates for active stimuli in Experiments 10a, 10b, and 10c

	Experiment 10a – control				**Experiment 10b – static door handles**				**Experiment 10c – moving door handles**			
	Compatible		Incompatible		Compatible		Incompatible		Compatible		Incompatible	
	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
RT (ms)	380.60	344.47	390.97	351.85	398.28	344.47	410.00	351.85	347.79	302.45	367.21	318.20
SD (ms)	40.53	58.84	37.98	58.70	59.21	58.84	55.64	58.70	41.83	30.68	40.78	34.58
% cue errors	0.35	0.35	0.12	0.23	0.23	0.12	0.12	0.23	0.23	0.12	0.23	0.35
% target errors	2.09	1.74	1.16	1.74	3.01	3.59	3.48	2.78	2.89	2.32	1.04	1.97

Results and discussion

Mean response times (RTs), standard deviations, and error rates for active and passive stimuli in each experiment are shown in Tables 13 and 14. Figure 33 shows mean RTs for each condition in each experiment. Cue errors were responding to the cue, and target errors were not responding, responding incorrectly, or responding too late (after 1000 ms) to the target. The data from the catch trials was not analysed, and trials containing cue or target errors were excluded from the RT analysis.

For each experiment, median RTs and error rates were submitted to 2 x 2 x 2 ANOVAs with the factors *action state* (passive or active), *cueing* (cued or uncued), and *action-compatibility* (compatible or incompatible). Then, because the main comparison between experiment involved the stimuli in the passive condition, median RTs and error rates for passive stimuli were analysed using 3 x 2 x 2 ANOVAs with the factors *experiment* (10a – control, 10b – static door handles, and 10c – moving door handles), *cueing*, and *action-compatibility.* A similar analysis was also performed on median RTs and error rates for active stimuli.

Experiment 10a – control

The RT analysis revealed a highly significant IOR effect, F (1, 17) = 117.71, p < .001, indicated by slower RTs to previously cued targets than to uncued targets. The main effect of action state was also significant, F (1, 17) = 12.95, p = .002, with faster RTs to passive stimuli than to active stimuli. Interestingly, there was a main effect of action-compatibility, F (1, 17) = 11.77, p = .003, with faster RTs to compatible targets compared to incompatible targets. There was also a significant interaction between cueing and action-compatibility, F (1, 17) = 9.71, p = .006. A paired t-test showed that IOR effects were significantly greater in the incompatible condition (55.1 ms) than in the compatible condition (46.5 ms), t (17) = 3.12, p = .006. This suggests that the main effect of action-compatibility was due to the effect of cueing. Indeed, follow-up analyses, using a 2 (action state) x 2 (action-compatibility) ANOVA showed no effect of action-compatibility in the uncued condition F (1, 17) = 0.58, ns. There were no other significant main effects or interactions in RTs. The error analysis found no significant effects.

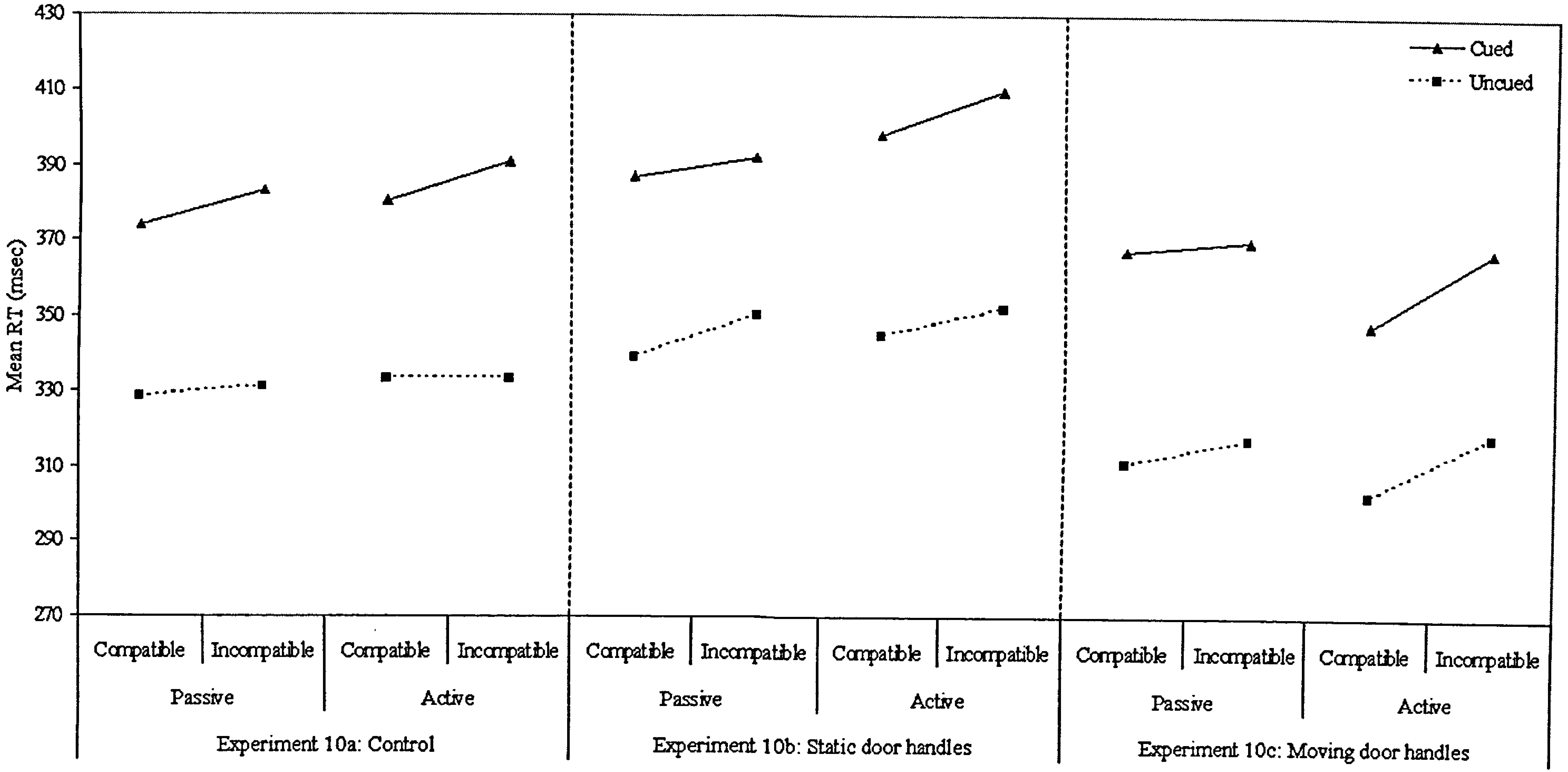

Figure 33: Mean RTs as a function of cueing and action-compatibility for passive and active control stimuli in Experiments 10a, 10b, and 10c.

Experiment 10b – static door handles

In the RT analysis the main effect of IOR was highly significant, F (1, 17) = 98.13, $p < .001$. There was also a main effect of action-compatibility, F (1, 17) = 6.35, $p = .022$, with faster RTs to compatible targets than to incompatible targets. A 2 x 2 ANOVA revealed that, unlike the control experiment, this action-compatibility effect was present in the uncued condition, F (1, 17) = 6.50, $p = .021$, and therefore cannot be explained by the effect of cueing. Indeed, there was no interaction between cueing and action-compatibility, F (1, 17) = 0.06, ns.

There was a main effect of action state, F (1, 17) = 8.99, $p = .008$, as RTs were slower when door handles appeared in the active state compared to the passive state. However, there was also a significant interaction between action state and cueing, F (1, 17) = 18.62, $p < .001$, suggesting that the slower RTs in the active condition were caused by larger IOR effects for active door handles. Indeed, a paired t-test showed that IOR effects were significantly larger for active door handles (56.0 ms) than for passive door handles (45.1 ms), t (17) = 4.31, $p < .001$. No other effects were significant. The error analysis found a significant main effect of action state, F (1, 17) = 8.33, $p = .01$, with more errors in the active condition than in the passive condition. There was a marginally significant interaction between action state, cueing, and action-compatibility, F (1, 17) = 3.40, $p = .083$, however follow-up analyses using paired t-tests found no significant effects. There were no other significant effects in the error data.

Experiment 10c – moving door handles

The RT analysis showed a highly significant IOR effect, F (1, 17) = 107.03, $p < .001$. There was a main effect of action state, F (1, 17) = 10.11, $p = .005$; participants were faster to respond to targets when the door handles moved downwards (the active condition) compared to when they remained horizontal (the passive condition). There was also a main effect of action-compatibility, F (1, 17) = 51.15, $p < .001$, with faster RTs to compatible targets than to incompatible targets. To confirm that this effect was not due to cueing, a 2 x 2 ANOVA using just the uncued RT data also found a main effect of action-compatibility, F (1, 17) = 32.72, $p < .001$. There was an interaction between action state and action-compatibility, F (1, 17) = 7.57, $p = .014$; separate 2 x 2 ANOVAs for each action state showed that the action-compatibility effect was greater in the active condition (17.58 ms), $F(1, 17) = 25.09, p < .001$, than in the passive condition (4.57 ms), $F(1, 17) = 5.71, p = .029$. There were no other significant effects in the RT analysis. The error analysis found a main effect of action state, $F(1, 17) = 9.70, p = .006$; participants made more errors to targets in the active condition than in the passive condition. There was also a marginally significant main effect of action-compatibility, $F(1, 17) = 3.64, p = .074$, with more errors to compatible targets compared to incompatible targets. No other effects were significant in the error analysis.

Passive stimuli in Experiments 10a, 10b, and 10c

The RT analysis found main effects of IOR, $F(1, 51) = 285.59, p < .001$, and action-compatibility, $F(1, 51) = 21.71, p < .001$. There was a significant interaction between cueing, action-compatibility, and experiment, $F(2, 51) = 3.44, p = .04$ (see Figure 34). Paired t-tests revealed that IOR effects were significantly larger in the incompatible condition than in the compatible condition in Experiment 10a (control), $t(17) = 2.57, p = .02$, whereas there were no significant differences in IOR for the compatible and incompatible conditions in Experiment 10b (static door handles), $t(17) = 1.44$, ns, and Experiment 10c (moving door handles), $t(17) = 0.95$, ns. However, it should be noted that these latter IOR effects in Experiments 10b and 10c show the predicted pattern, with a trend for greater IOR at the compatible end of the door handle. No other interactions were significant and there was no main effect of experiment, $F(2, 51) = 1.86$, ns. The error analysis found no significant effects.

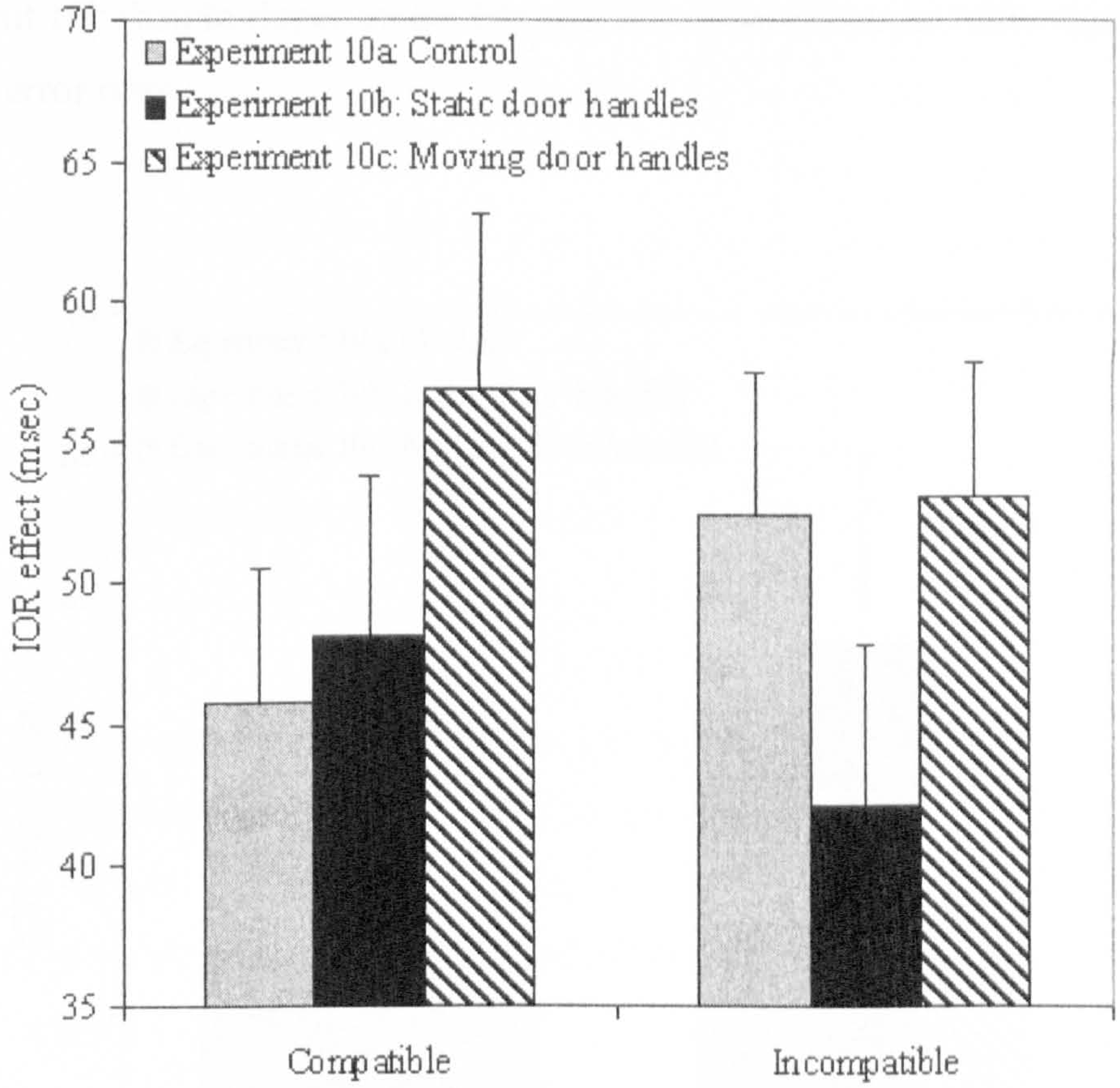

Figure 34: IOR effects (cued RT minus uncued RT) for passive stimuli in Experiments 10a, 10b, and 10c. A positive difference score indicates IOR. Error bars show the standard error of the mean.

Active stimuli in Experiments 10a, 10b, and 10c

The RT analysis found main effects of IOR, *F* (1, 51) = 288.47, *p* < .001, and action-compatibility, *F* (1, 51) = 21.06, *p* < .001. There was also a main effect of experiment, *F* (2, 51) = 4.45, *p* = .017. Follow-up independent t-tests (using bonferroni-corrected alpha values of .017 to allow for making multiple comparisons) revealed that RTs in Experiment 10c were marginally faster than RTs in Experiment 10a, *t* (34) = 2.31, *p* = .041, and significantly faster than RTs in Experiment 10b, *t* (34) = 2.86, *p* = .007. However, there was no difference in overall RTs in Experiments 10a and 10b, *t* (34) = 1.06, ns. There was a marginally significant interaction between cueing and action-compatibility, *F* (1, 51) = 3.99, *p* = .051, as IOR was greater in the incompatible condition (see Figure 35). No other interactions were significant. The error analysis found a marginally significant main effect of action-compatibility, *F* (1, 51) = 3.27, *p* = .077, with more errors in the compatible condition than in the incompatible condition. The main effect of experiment was also marginally significant, *F* (2, 51) = 2.65, *p* = .081; there were more errors in

Experiment 10b than in Experiments 10a and 10c. There were no other significant effects in error rates.

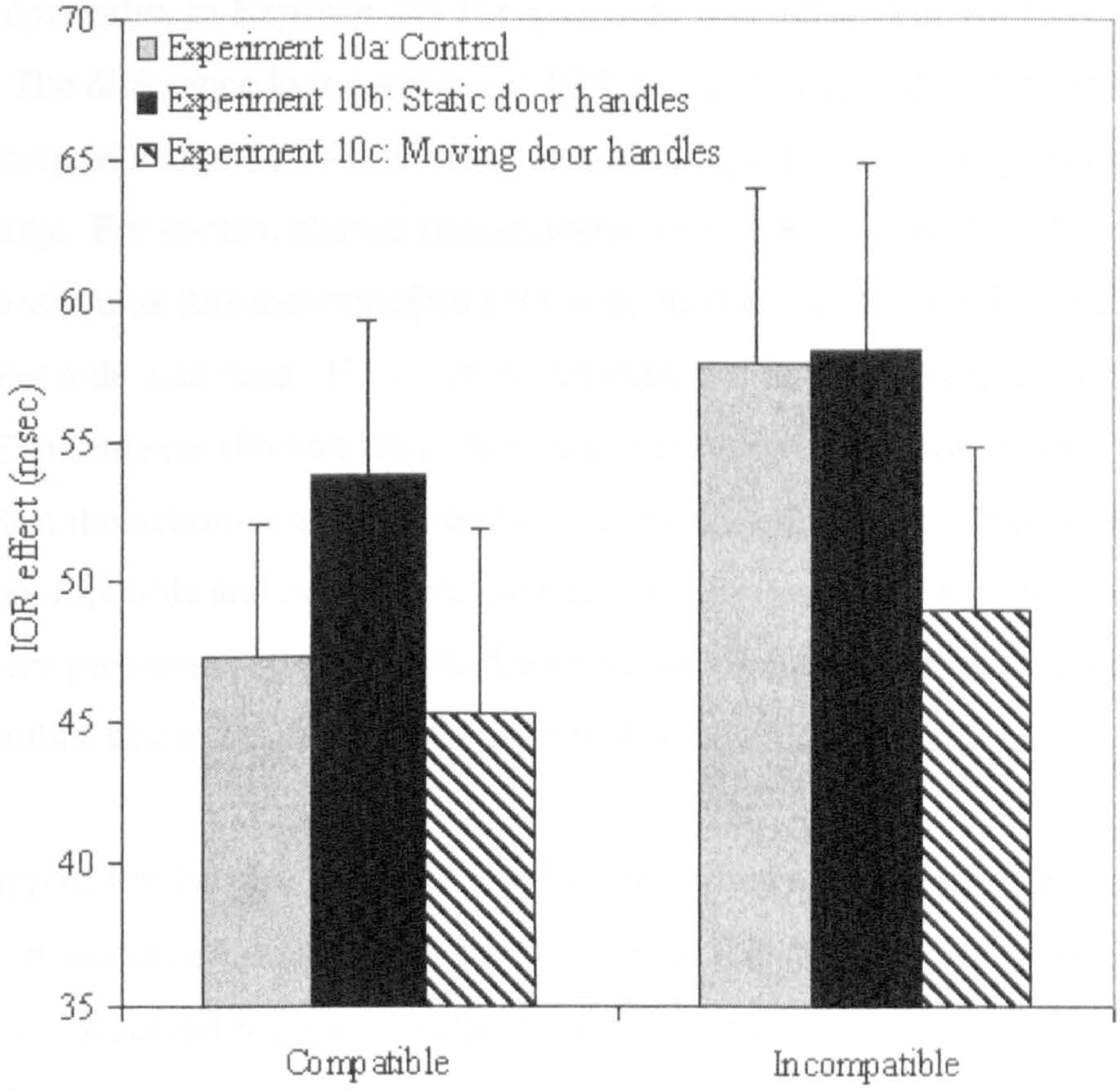

Figure 35: IOR effects (cued RT minus uncued RT) for active stimuli in Experiments 10a, 10b, and 10c. A positive difference score indicates IOR. Error bars show the standard error of the mean.

The results of Experiment 10a (control) show that the structural properties of door handle stimuli influence attention. That is, attention is biased towards the larger, incompatible end of the stimulus. This was revealed by the greater IOR for incompatible responses compared to compatible responses. Furthermore, although there was a main effect of action-compatibility in Experiment 10a, this was due to the effect of cueing, as no main effect of action-compatibility was found in the uncued data. IOR effects were greater in the incompatible condition, which may be because attention was biased towards the round disk at the incompatible location. Indeed, some participants commented that they found it difficult to ignore the round disk.

The goal of these experiments was to determine whether IOR is influenced by the action-affordances of objects. Indeed, when door handles were presented, instead of structurally identical control stimuli, the attentional bias towards the incompatible side of the stimulus was eliminated and there was no interaction between cueing and action-compatibility in Experiments 10b (static door handles) and 10c (moving door handles). The difference in the pattern of IOR for control stimuli and door handle stimuli produced a significant interaction between experiment, cueing, and action-compatibility. For control stimuli (Experiment 10a), IOR was greater when the larger side of the stimulus (the incompatible side) was cued compared to when the smaller (compatible) side was cued. However, when cues and targets appeared on door handles (Experiments 10b and 10c), there was a trend for the opposite pattern, with larger IOR at the action-compatible end of the door handle. IOR effects were equal for both incompatible and compatible conditions. This suggests that, when door handles were presented, attention was drawn away from the larger, incompatible side of the stimulus, due to the salience for action of the compatible side.

Support for the idea that door handle stimuli activated motor representations of the action associated with the object comes from the main effect of action-compatibility observed for door handle stimuli in Experiments 10b and 10c. That is, when the door handle was oriented to the right, targets appearing on the right (and therefore requiring a right hand response) were responded to faster than targets appearing on the left. Similarly, when the door handle was oriented to the left, targets on the left were responded to faster than targets on the right. Importantly, this action-compatibility effect was present in the uncued data in Experiments 10b and 10c, but not in Experiment 10a (control), which shows that this effect was not due to structural properties of the door handles.

Because the passive door handles in Experiment 10c were presented in the context of implied action (i.e. they were associated with the expectation that they could move), it was expected that IOR effects for passive door handles would be greater in Experiment 10c than in Experiment 10b. Indeed, Figure 34 shows that IOR effects were larger in Experiment 10c compared to Experiment 10b, even though the stimuli and procedure were identical. However, a comparison of the experiments using a 2 (experiment) x 2 (cueing) x 2 (action-compatibility) ANOVA revealed that the interaction between experiment and cueing did not reach statistical significance, *F* (1, 34) = 1.79, ns.

As mentioned previously, results for the stimuli in the active condition are difficult to interpret, as there are a number of factors that may have influenced IOR. However, it is interesting that cueing interacted with action state in Experiment 10b (static door handles) but not in Experiment 10a (control). That is, IOR was greater for active stimuli than for passive stimuli in Experiment 10b, but there was no difference in IOR for the active and passive conditions in Experiment 10a, even though the stimuli were structurally identical in both experiments. This suggests that the door handle was more salient when it appeared in an active state, rather than when it appeared in a passive state. Therefore, greater reactive inhibition was necessary when door handles appeared in the active condition compared to the passive condition. This is consistent with the idea that objects implying that an action is taking place activate action simulation processes.

The magnitude of the IOR effect for active (moving) door handles in Experiment 10c is also interesting. When door handles moved, the cue and target appeared on the same part of the object, but at different locations. Because the incompatible side of the door handle only moved a small distance, the locations of the cue and target overlapped. However, the locations of the cue and target in the compatible condition were relatively far apart. Although previous studies have found IOR when the object moves between presentation of the cue and presentation of the target (Gibson & Egeth, 1994; Tipper et al., 1991, 1999, 1994b), these effects are typically very small compared to the IOR observed for static objects. In contrast, the IOR observed for the active door handles in the compatible condition of Experiment 10c was very robust (45 ms), and there was no interaction between action state, cueing, and action-compatibility. Furthermore, as shown in Figure 35, the IOR in the active compatible condition was of a similar magnitude for moving door handles (Experiment 10c) and for control stimuli (Experiment 10a), even though the control stimuli did not move. This suggests that the action affordance associated with moving door handles in Experiment 10c may have increased the magnitude of the IOR effect in the compatible condition.

General discussion

The aim of this chapter was to determine whether IOR can be influenced by action-related properties of objects. Indeed, the results suggest that IOR can be influenced by the action affordance evoked by an object and also by the action state of the object. The attentional bias towards the larger, incompatible side of the control stimulus was eliminated when cues and targets appeared on door handles. In addition, IOR was larger when the door handles implied that an action was taking place (in Experiment 10b), compared to when the door handles appeared in a passive state.

Furthermore, IOR for moving door handles (Experiment 10c) was a similar magnitude in the compatible and incompatible conditions, even though the cues and targets appeared at overlapping locations in the incompatible condition and at different locations in the compatible condition. This meant that IOR in the incompatible condition could be both location- and object-based, as the cue and target appeared in overlapping locations, whereas IOR in the compatible condition could only be object-based as the cued part of the object moved away from its original location. The IOR effect in the compatible condition was 45 milliseconds, whereas previous studies of IOR for moving objects have reported IOR effects of around 20 milliseconds (Gibson & Egeth, 1994; Tipper et al, 1991, 1999, 1994b). The relatively large IOR effect observed for compatible responses in Experiment 10c suggests that the action afforded by the door handle may have increased the IOR effect. However, as the main purpose of these moving door handles was to create a context of implied action for the passive (non-moving) stimuli in Experiment 10c, it is difficult to draw conclusions from these results. Further studies, using a baseline condition in which cues and targets appear on structurally identical moving control stimuli, would be necessary to determine the cause of the large IOR for moving door handles observed in this experiment.

The results of the current experiments are consistent with Houghton and Tipper's (1994) model of inhibition, in which the initial activation level of an object determines the level of inhibition that is applied to the object. It appears that exogenous cues presented on the part of a stimulus that affords action (e.g. the handle part of a door handle) evoke greater activation, and require greater levels of inhibition, compared to cues which appear on the non-affording part of the stimulus. In addition, stimuli that imply current action require greater reactive inhibition than passive stimuli. These findings provide further support for the idea that IOR can operate on object-based representations, as a space-based mechanism would not be influenced by action-related properties of objects. These object-based representations must be identity-specific, as a different pattern of IOR was observed for door handle stimuli and structurally identical control stimuli.

Chapter 6 – General discussion

The experiments reported in this thesis examined the role of object-based representations in IOR. Previous work had suggested that object-based representations form the basis for efficient search over long intervals and intervening events (Kessler & Tipper, 2004; Tipper et al., 2003). However, these long-term IOR effects had only been observed for face stimuli, and it was possible that these effects could be due to memory retrieval of mismatching perceptual information, rather than inhibition.

Therefore, Chapter 2 aimed to confirm that inhibitory states associated with objects can be encoded into and retrieved from memory. Experiments 2a and 2b were successful in confirming previous findings of long-term IOR for faces, as response times were slower to a face that had been cued 4.8 minutes and 63 intervening displays previously, relative to an uncued face. In addition, these experiments also demonstrated, for the first time, long-term IOR for objects; there were more errors to cued than to uncued objects when the cue and target were separated by 4.8 minutes and 63 displays. Of most importance, these IOR effects for faces and objects remained even when the cue and target signals were the same colour, suggesting that long-term IOR is due to encoding and retrieval of object-based inhibitory states, rather than memory retrieval of mismatching perceptual information.

However, the long-term IOR effects in Chapter 2 were only observed for faces in the right visual field and for objects in the lower visual field. The visual field asymmetry for faces was the opposite to previous research in which long-term IOR had only occurred for faces on the left (Kessler & Tipper, 2004; Tipper et al., 2003). Therefore, Chapter 3 aimed to determine the reason for this reversal in visual field differences. Experiments 3a and 3b confirmed that, when faces alternate with objects, long-term IOR for faces on the left and right occurs only in the right visual field. Furthermore, marginally significant long-term IOR effects were observed for objects in the left VF, and there was a trend towards long-term IOR for faces in the upper VF. It was hypothesised that faces and objects were competing for processing resources in this task, and this competition caused face processing to be biased towards the right VF. This was confirmed in Experiments 4a and 4b, in which replacing the objects with either scenes or a blank screen caused a reversal in the pattern of IOR observed for faces in the previous experiments. The results of these experiments suggest that inhibitory states associated with object-based representations can be encoded into and retrieved from memory. In addition, it appears that the inhibitory mechanisms underlying long-term IOR are flexible and may operate differently depending on the nature of the task.

Chapter 4 examined the level of object representation that is inhibited in object-based IOR. The previous chapters showed evidence for identity-specific representations in IOR, as faces all belong to the same category. Based on research showing that inhibition can operate at a semantic level in negative priming tasks (e.g. Marí-Beffa et al., 2000; Tipper & Driver, 1988), Experiments 5 and 6 investigated whether IOR can also operate on basic-level category representations. To encourage inhibition to operate at a semantic level a new procedure was developed, in which each item was cued twice before target presentation. The two cues and the target could appear on identical objects, objects in the same basic-level category, or unrelated objects. When the interval between the second cue and the target was short (3 seconds and no intervening objects), IOR was significantly larger for identical objects (Experiment 5a) than for categories (Experiment 5b) and unrelated objects (Experiment 5c). When the cue-target interval was long (21 seconds and 5 intervening objects), long-term IOR was observed for identical objects (Experiment 6a), but not for categories (Experiment 6b). These results confirm the results of Chapters 2 and 3, showing that IOR can be associated with the identity of an object. In contrast, there was no evidence that IOR could be associated with an object's basic-level category.

This identity-specific IOR effect was examined in further experiments. Experiments 7a and 7b showed that the identity of the cue and target shapes contributed to the large identity-based IOR effect observed in Experiment 5a; the largest IOR effect occurred when identical cue and target shapes appeared on identical objects (Experiment 5a), IOR was smaller when different cue and target shapes appeared on identical objects (Experiment 7a) and when identical cue and target shapes appeared on different objects (Experiment 7b), and the smallest IOR effect occurred when different cue and target shapes appeared on different objects (Experiment 5b). Experiments 8a and 8b went on to show that IOR can be associated with the identity of cue and target shapes in the absence of any meaningful objects, as

IOR was significantly larger when the cue and target shapes were identical (Experiment 8a) than when they varied slightly (Experiment 8b). However, Experiment 9 did not find long-term IOR for meaningless shapes, suggesting that memory encoding and retrieval of inhibitory states can only occur if inhibition is associated with the identity of meaningful objects.

The final series of experiments, in Chapter 5, investigated whether IOR is influenced by action-related properties of objects. These experiments used door handle stimuli, and cues and targets could appear on the side of the stimulus that was either compatible with the afforded action (e.g. on the handle part) or incompatible with the afforded action. When cues and targets appeared on control stimuli (Experiment 10a) that were designed to be structurally identical to door handles, IOR was greater when the cue appeared on the larger 'incompatible' side of the control stimulus, relative to the compatible side. However, when cues and targets appeared on door handles (Experiment 10b), this attentional bias towards the incompatible side of the stimulus was eliminated, and IOR effects were equal for the incompatible and compatible conditions. Furthermore, IOR effects were larger when the door handle implied current action, compared to when it appeared in a passive state. When door handles could move between presentation of the cue and presentation of the target (Experiment 10c), the IOR effect for the compatible condition was of a similar magnitude to the IOR observed for the compatible condition for control stimuli, even though the cues and targets appeared at different locations when door handles moved. These findings suggest that IOR is influenced by the actions afforded by an object and by whether the object implies action.

There has been much debate about the locus of inhibition in IOR (see Klein, 2000; Taylor & Klein, 1998, for reviews). Accordingly, is not clear whether the IOR effects reported in this thesis reflect inhibition of attentional orienting (e.g. Handy et al., 1999; Reuter-Lorenz et al., 1996), motor responses (e.g. Klein, Schmidt, & Müller, 1998; Klein & Taylor, 1994; Posner et al., 1985), or a combination of both (e.g. Abrams & Dobkin, 1994b; Kingstone & Pratt, 1999; Taylor & Klein, 2000). However, this issue is not relevant to the main goal of this research, which was to determine the role of object-based representations in IOR. Future work could investigate the locus of these object-based IOR effects.

Implications of identity-based IOR

The experiments reported in this thesis have shown that IOR can operate on identity-based representations. These results cannot be accounted for by space-based models of attention (e.g. Robertson, 2004), as IOR for identical objects was observed after long intervals, during which cues and targets were presented to the same locations. These findings are consistent with other studies of attentional processes (e.g. Duncan, 1984; Egly et al., 1994), and provide further support for the idea that IOR can be object-based. The inhibitory mechanisms involved in long-term IOR were influenced by the type of stimuli in the task; faces and non-face objects seemed to compete for processing resources, and this competition varied the pattern of visual field differences in long-term IOR. The finding that IOR was influenced by competition between different types of objects demonstrates the importance of object-based representations in IOR.

Although the experiments described in this thesis have shown that IOR operates on identity-specific object representations, further work is necessary to determine the exact nature of these representations. An identical object can produce different retinal images when viewed from different angles, and research suggests that both viewpoint-dependent and viewpoint-invariant representations are important for object recognition (e.g. Farah, 1992; Foster & Gilson, 2002; Marsolek, 1999; Stankiewicz, 2002; Tarr & Pinker, 1990; see Hayward, 2003, for a review). However, it remains unclear which form of representation is inhibited in IOR. In the real world objects can be viewed from many different angles, therefore it seems logical that visual search processes may involve viewpoint-invariant object representations. However, as described in Chapter 4, recent work (Reppa & Leek, 2005) has shown that IOR is mediated by viewer-based object representations, which suggests that the representations underlying IOR are viewpoint-dependent. IOR was not found to operate on volumetric-part representations, which may allow viewpoint-invariant representations. These findings suggest that IOR is associated with viewpoint-dependent representations.

Future work could cue part of an object, then present the target on the same part of an identical object that is rotated in three-dimensional space. So the cue and target would appear on the same part of the object but at different locations. Viewpoint-invariant representations should produce IOR in this paradigm, whereas no IOR should occur if the representations underlying identity-based IOR are viewpoint-dependent. Alternatively, it is possible that both types of representation could mediate IOR; this could result in visual field differences in IOR effects, as research suggests that the right hemisphere is involved in viewpoint-dependent object recognition, whereas viewpoint-invariant recognition takes place in the left hemisphere (Burgund & Marsolek, 2000).

It is also possible that the identity-based inhibition in IOR can operate at different levels of representation. The finding that meaningful objects are necessary for long-term identity-based IOR suggests that IOR can operate on high-level identity-based representations. However, the finding that short-term IOR can be associated with the identity of meaningless shapes could reflect inhibition of very precise low-level object representations. Consistent with this idea, research has shown that priming effects (faster responses to previously seen stimuli) can be based on retinotopic object representations. McAuliffe and Knowlton (2000) found that priming effects were larger for identical objects than for left-right reflected objects. However, this increased priming effect for identical objects only occurred when the retinal positions of the prime and probe were the same; when the probe appeared in a different retinal position from the prime, the identical object advantage disappeared. Based on these findings it is possible that the IOR observed for meaningless shapes in Chapter 4 was based on low-level retinotopic representations. However, the representations formed for attended objects may be different from the representations that are formed for ignored objects, and further work is necessary to determine the exact level of object representation that is reached by meaningless shapes in an IOR paradigm.

Of most importance, the results of the current series of experiments clearly show that, in procedures that are similar to the standard IOR paradigm, IOR operates on very specific identity-based representations, and does not spread to categorically-related items or to items with similar features. However, as noted in Chapter 4, these findings do not rule out the possibility that different versions of the IOR paradigm may cause inhibition to be associated with different types of object representation.

It is very likely that the identity-based IOR observed in these experiments reflects cortical processing. This is because, as mentioned in Chapter 1, object-recognition computations take place in cortical areas (e.g. Kanwisher et al., 1997b; Malach et al., 1995), and the SC cannot process information about the identity of objects. The finding that IOR was influenced by competition between faces and objects provides further support for this idea, as these stimuli are processed in cortical areas (e.g. Garoff et al., 2005; Haxby et al., 2000; Kanwisher et al., 1997a; McCarthy et al., 1997). Therefore, the results of the current experiments are consistent with previous work suggesting that IOR does not require the SC (Sumner et al., 2004) and that object-based IOR relies on cortical processing (Tipper et al., 1994b).

Future work could use brain imaging methods to investigate the neural representations that are inhibited in long-term IOR for faces and objects. Research using event-related fMRI has shown that, when cues and targets appear in sparse stimulus displays, similar to those used by Posner and Cohen (1984), IOR is associated with activation in the supplementary and frontal eye fields, the supramarginal gyri, and parietal and dorsal premotor areas (Lepsien & Pollmann, 2002; Rosen et al., 1999). Similar brain imaging techniques could be applied to the long-term IOR procedure described in this thesis, in which naturalistic face and object stimuli were cued. It is possible that the identity-based IOR observed in this procedure may be accompanied by increased activation in areas of the ventral temporal cortex that are involved with object recognition. Alternatively, it is possible that attentional orienting to previously cued items would be impaired, but perceptual processing of the stimuli may not be influenced by IOR, and processing in the ventral temporal cortex would be unaffected. In either case, it is probable that IOR would be associated with processing in cortical areas, in the absence of any collicular activation. This finding would provide further support for the idea that identity-based IOR is mediated by cortical pathways.

Relationship between object-based IOR and memory

The results of these experiments show that object-based IOR facilitates efficient search over time and intervening events. These long-term IOR effects cannot be explained by on-line inhibitory mechanisms, as maintenance of inhibition over such long delays would interfere with ongoing behaviour. Furthermore, previous work has shown that inhibition can only be maintained online for up to 5 or 6 previously cued items (e.g. Birmingham & Pratt, 2005; Paul & Tipper, 2003; Snyder & Kingstone, 2000). Therefore, these findings are consistent with Grison et al.'s (2005) modification of Houghton & Tipper's (1994) model, in which transient inhibitory states associated with objects are encoded into an episodic memory sub-network that represents hippocampal processes. However, further work is necessary to determine the mechanisms that allow encoding and retrieval of inhibitory states.

There is some evidence to suggest that long-term IOR is mediated by implicit memory representations. Kessler and Tipper (2004) used similar methods to previous long-term IOR experiments (e.g. Tipper et al., 2003) to investigate the memory processes involved in long-term IOR. Pairs of faces were presented on the left and right, and the cue and target displays for each face pair were separated by 12.6 minutes and 192 intervening displays. In the cue display participants had to ignore red cues and localise green targets (that appeared on catch trials). However, in the target display, they had to recall where the red cue or green target had appeared. Explicit retrieval of prior cueing states would result in the cued face being correctly recalled. In contrast, the results revealed a significant bias to erroneously recall that the cue had appeared on the uncued face. According to Kessler and Tipper (2004), this result occurred because inhibition for the cued face was implicitly reinstated, which biased response towards the uncued face.

Further studies could use different methods to confirm that long-term IOR involves implicit retrieval of inhibition. This result has only been observed for faces which, unlike other objects, are often processed automatically and implicitly (e.g. Cauquil et al., 2000; Critchley et al., 2000; Lavie et al., 2003; Liu et al., 2000). Therefore it is important to determine whether long-term IOR for objects also depends on implicit memory retrieval. To examine this issue, Experiment 2a could be modified to include a recognition test. Instead of responding to green targets in the target display, participants would be presented with pairs of faces and objects consisting of one previously seen item and one new item, and they would have to select the old face or object. If retrieval of inhibition is implicit, as suggested by

Kessler and Tipper (2004), then participants should be more likely to incorrectly select a new item when the pair contains a previously cued item, but not when it contains an uncued item.

In addition, studies using electrophysiological recordings could provide more detailed information about encoding and retrieval processes in long-term IOR. Research has revealed that different event-related potential components are associated with different forms of memory. For example, a negative component occurring at around 250 ms (the N250r) is thought to indicate implicit retrieval (Joyce & Kutas, 2005; Paller, Hutson, Miller, & Boehm, 2003), whereas explicit memory may be revealed in a late negative component (the N400f; Joyce & Kutas, 2005) and a late centroparietal positive component (the LPC; Joyce & Kutas, 2005; Paller & Gross, 1998; Paller et al., 2003). Whereas behavioural response time measures only provide information about the response, ERP recordings can provide an online measure of the processes leading to response selection. Therefore, future experiments using ERP techniques are necessary to investigate memory encoding and retrieval of inhibitory processes.

Grison et al. (2005) suggested that the hippocampus mediates encoding and retrieval of inhibitory processing states in long-term IOR. However, there is evidence to suggest that episodic memory involves a widely distributed processing system that includes prefrontal and parietal areas, as well as the hippocampus (Cabeza, Dolcos, Graham, & Nyberg, 2002; Deweer, Pillon, Pochon, & Dubois, 2001; Rugg, Otten, & Henson, 2002). There is a substantial amount of evidence for the involvement of the hippocampus in explicit memory (Davachi, Mitchell, & Wagner, 2003; Henke, Weber, Kneifel, Wieser, & Buck, 1999; Mayes et al., 1998; Sperling et al., 2001). However, there is some uncertainty about the role of the hippocampus in implicit memory. While some studies have shown that many common tests of implicit memory, such as priming, do not require the hippocampus (see Cabeza & Nyberg, 2000; Schacter & Buckner, 1998, for reviews), other work suggests that the hippocampus may be involved in implicit associative learning (Degonda et al., 2005; Henke et al., 2003; Yang et al., 2003). Because the memory processes underlying long-term IOR are thought to be implicit (e.g. Kessler & Tipper, 2004), it is unclear whether these processes are mediated by the hippocampus, as suggested by Grison et al. (2005), or whether long-term IOR recruits other brain areas involved in memory. Therefore, to determine whether the hippocampus is necessary for long-term IOR, future work could investigate long-term IOR in patients with hippocampal lesions.

IOR and action affordances

The finding that IOR is influenced by action-related properties of objects reinforces the idea that IOR operates on object-based representations. This result is also consistent with previous work showing that perception of an object can automatically activate motor representations of actions (e.g. Ellis & Tucker, 2000; Grèzes et al., 2003; Phillips & Ward, 2002; Tucker & Ellis, 1998, 2001, 2004; Tipper et al., in press). In line with Houghton and Tipper's (1994) model of inhibitory mechanisms, it appears that greater reactive inhibition is necessary to suppress responses that are afforded by irrelevant stimuli.

Future work could investigate interactions between IOR and action affordances using more realistic techniques. The experiments reported here were conducted in highly artificial situations, in which participants responded to two-dimensional pictures of objects with keypress responses. However, in the real world visual search involves interacting with three-dimensional objects. Tasks which involve reaching and grasping for objects in a real-world environment would provide valuable information about the representations underlying IOR, as research has shown that inhibitory mechanisms of attention can access different representations depending on the behavioural goals of the task (Tipper et al., 1994a). Therefore, future work could use virtual reality techniques to investigate inhibitory mechanisms of visual search in ecologically valid environments. Furthermore, because virtual reality is interactive, this technique would allow the collection of data about reach trajectory, grip, and movement time, which would provide valuable information about the processes that lead to response selection.

The finding that IOR can also be influenced by the action state of an object is interesting, because it suggests that inhibitory search mechanisms can be influenced by simulation of other people's actions. Indeed, in order to allow coherent behaviour, inhibitory mechanisms must be necessary when mirror systems are activated. Future work could further investigate the link between inhibitory processes and mirror systems. For example, studies could investigate whether simulation of other people's inhibitory processes can influence behaviour.

Summary and conclusions

The experiments reported in this thesis used different approaches to show that IOR can be associated with identity-based representations. Previous findings of long-term IOR for faces were confirmed, and these experiments also demonstrated, for the first time, long-term IOR for non-face objects. These effects could not be explained by location-based theories of IOR, as each cue was separated from its corresponding target by many other cues and targets that were presented in the same locations. Furthermore, these effects were not due to memory retrieval of mismatching perceptual information, as IOR was observed when the cue and target were identical. These results are consistent with the idea that long-term IOR is due to the episodic retrieval of object-based inhibitory processes (Grison et al., 2005; Kessler & Tipper, 2004; Tipper et al., 2003). A further series of experiments showed that IOR is mediated by identity-based representations and not basic-level category representations. Furthermore, these experiments showed that, although IOR can operate on the identity of meaningless objects, meaningful objects are necessary for memory encoding and retrieval of inhibitory states. Finally, further evidence for the role of object-based representations in IOR was provided by the finding that IOR is influenced by action-related properties of objects. In conclusion, these experiments have shown that IOR can be associated with identity-based representations, and this identity-based IOR provides the basis for efficient search over time and intervening events.

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