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Short article

Location- and object-based inhibition of return are affected by different kinds of working memory

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Castel, Pratt, and Craik (2003) have shown that inhibition of return (IOR, the delayed response to a recently cued item) is disrupted by a secondary task that involves spatial working memory (WM), and they suggest that IOR is mediated by spatial WM. However, they did not specify what kind of IOR was involved. We used a dual-task paradigm to examine whether the two kinds of IOR (location- and object-based IOR) are affected by two kinds of secondary task that involve spatial and nonspatial WM, respectively. The results show that location-based IOR was disrupted by a spatial secondary task while the object-based IOR was disrupted by a nonspatial secondary task. The present study further elaborates the conclusion of Castel et al. (2003) by differentiating the effect of the two kinds of WM (spatial vs. nonspatial) on the two kinds of IOR (location based vs. object based).

Keywords: Attention; Visual perception; Dual task.

When you search for a pen on your desktop, the best strategy is to remember where you have already looked and not search there again. Human behaviour observed in psychological experiments reveals a phenomenon similar to this strategy. Inhibition of return (IOR; Posner, Rafal, Choate, & Vaughan, 1985) refers to the increased reaction time (RT) when a target appears at a recently cued location. This phenomenon was first demonstrated by Posner and Cohen (1984). They used three outlined boxes with the central box as a fixation and

brightened the left or right box briefly as a noninformative peripheral cue. Compared to RT in detecting the target at the uncued box, they found a facilitatory effect (i.e., shorter RT) when the cue-to-target stimulus onset asynchrony (SOA) was shorter than 150 ms and an inhibitory effect (i.e., longer RT) when the SOA was longer than 300 ms. The initial RT benefit was explained by the summoning of attention to the cued location, replaced by a subsequent inhibition to the previously cued location after attention had returned to the central fixation.

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Although earlier studies (e.g., Posner & Cohen, 1984) emphasized that it was the cued *location* that was inhibited (but see Tipper, Weaver, Jerreat, & Burak, 1994), recent studies have shown that IOR can also be *object* based (e.g., Chou & Yeh, 2005; Gibson & Egeth, 1994; Jordan & Tipper, 1998; Tipper, Driver, & Weaver, 1991).

Tipper et al. (1991) first demonstrated object-based IOR in a dynamic display by using two objects rotated around an imaginary circle. The cued object rotated from its original location, and the inhibition associated with it was also shown to move. However, Schendel, Robertson, and Treisman (2001) note that the objects used in this experiment retained their relative locations topologically while rotating around the fixation point. Thus, the objects may simply help to set up a frame of reference in which attentional orienting operates on relative locations, but not on objects. Such a dynamic display has also been criticized as being confounded with the left-to-right attentive tracking strategy, and object-based IOR was found only under certain experimental conditions (Müller & von Muhlenen, 1996).

There are also studies that have shown object-based IOR in static displays. Jordan and Tipper (1998) found that the magnitude of IOR of an object was significantly larger than that of an empty location. They interpreted their results with the view that when objects are cued, both location- and object-based IOR can operate, while when only locations are cued only location-based IOR is involved. As they have admitted, these displays were unavoidably associated with space representation as well as object representation.

In our previous study (Chou & Yeh, 2005), we used overlapping objects to avoid interference from location-based effects (e.g., Duncan, 1984; Haimson & Behrmann, 2001) and successfully demonstrated that object-based IOR can occur for spatially overlapping objects. Using overlapping objects to probe object effect has an important advantage, in that location effects are undifferentiated or operate equally across objects. Additionally, using overlapping objects is justifiable on ecological grounds: The retinal images of many real-world objects are usually overlapped.

Notably, IOR can occur with SOA as long as three seconds (e.g., Samuel & Kat, 2003; Tipper, Grison, & Kessler, 2003): With such a long duration some memory process must be involved in maintaining the information. Indeed, Castel, Pratt, and Craik (2003) found that a secondary task disrupts IOR, but only when the secondary task involved spatial, as opposed to nonspatial, working memory (WM). Based on this they suggested that IOR is mediated by a spatial WM system.

Note that Castel et al. (2003) used outline boxes as placeholders, and thus their participants may have viewed these boxes as locations, objects, or both (Tipper et al., 1994). In other words, location- and object-based IOR cannot be differentiated in such displays. A question that naturally follows is whether the two kinds of IOR are both mediated by spatial WM. Because location-based IOR relies on memory of spatial information, spatial WM is critical. In object-based IOR, which is revealed when spatial information is irrelevant (e.g., Chou & Yeh, 2005; Tipper et al., 1991), nonspatial WM is more likely to be involved.

Accordingly, we hypothesized that location-based IOR is mediated by spatial WM, and object-based IOR is mediated by nonspatial WM. We adopted a dual-task paradigm based on the assumption that if adding a secondary task interferes with performance on the primary task, they must be competing for a single resource. We used two kinds of secondary task, such that one (the *direction* task) involved spatial WM while the other (the *object* task) did not. To examine the role of WM type on location- and object-based IOR, we designed two conditions suitable for probing the effect of each, rendering a 2×2 design: two types of task versus two kinds of IOR. It was predicted that the direction task would disrupt location-based IOR only, and the object task would disrupt object-based IOR only.

EXPERIMENT 1

The display for probing object-based IOR consisted of two overlapping triangles (Figure 1A), while

Figure 1. Illustration of the displays used in this study. (A) Experiment 1, the triangles display. (B) Experiment 1, the dots display. (C) Experiment 2, the dots display. (D) Experiment 2, the triangles display. The dotted lines (not shown in the experiment) denote the luminance enhancement. These examples are brightened-target trials.

that for probing location-based IOR consisted of six dots (Figure 1B), removing the lines in the triangles display. The participants were told that there were two triangles or six marked locations, depending on the experiment, and postexperiment inquiry confirmed that they treated the triangles as individual objects and the dots as locations.

A *luminance change detection* task was used as the primary task throughout. In addition, two types of secondary task were used: a direction task, in which the participants reported the direction of the to-be-remembered item, and an object task, in which the participants were required to memorize its identity.

Method

Participants

A total of 160 undergraduates of National Taiwan University participated in eight experiments (1a–1h; $N = 20$ for each experiment) in exchange

for course credit. All reported normal or corrected-to-normal vision and were naïve as to the purpose of these experiments.

Stimulus materials

Stimulus presentations were controlled by an IBM 486 personal computer and were presented on a 14" ViewSonic monitor. The computer program DMDX (Forster & Forster, 2003) was used to present the stimuli and to collect the RT data. Participants sat at a viewing distance of 60 cm in a dimly lit chamber, with their heads supported by a chinrest.

The two kinds of display (triangles, dots) were crossed with the two kinds of secondary task (direction, object). Half the participants conducted one of the four dual-task experiments (Experiments 1a–1d), and the other half conducted one of the four single-task controls (Experiments 1e–1h). In the control experiments, only the main task, in which all stimuli were the same as those in their comparable dual-task experiments, was performed,

and the participants were told to ignore the direction/object symbols.

In the triangles condition, the fixation display contained a central white cross ($0.67^\circ \times 0.67^\circ$) and two overlapping outline (0.29° in width) triangles (9.46° /side), presented on a grey background. One of the triangles (randomly chosen) was green and the other red, and one was inverted and the other upright (also randomly chosen). On the corners of the triangles were three dots (0.95° in diameter), the same colour as the triangles. In the cue display, one of the triangles (and its end dots) was brightened; this was defined as the cued object. In the memory display, a rightward or a leftward arrow ($3^\circ \times 0.95^\circ$) was presented for the direction task, whereas a dumbbell or a two-way arrow was presented for the object task. In the target display, one of the six dots was either brightened or dimmed. In the dots condition, the displays were the same as those in the triangles condition except that the lines joining the individual dots were removed.

Design

A cueing paradigm was used for the primary task, and we compared the RT obtained between valid and invalid trials. IOR was indexed by longer RT in valid trials. In the triangles condition, the target appeared on one of the three dots of the cued triangle (a valid trial), or on one of the three uncued-triangle dots (an invalid trial). In the dots condition, similarly, the target appeared on one of the three cued dots (a valid trial), or on one of the three uncued dots (an invalid trial).

Each experiment contained 96 trials, divided into four blocks of 24, with an equal number of valid and invalid trials. An effort was made to balance the possible combinations of target locations within each block. A total of 24 practice trials preceded the formal trials, and the participants were allowed to take short self-paced breaks between blocks.

Procedure

The participants initiated each block by pressing the space bar. At the beginning of each trial, an auditory tone (100 ms) and a fixation display

(1,020 ms) were shown first, followed by the cue (255 ms), fixation (340 ms), memory (425 ms), fixation (340 ms), and target displays. The target display appeared at 1,360 ms SOA after the onset of the cue and stayed for 1,000 ms or until the participants responded, whichever happened first.

In Experiments 1a–1d (dual task), after the target display, the words “left or right?” or “dumbbell or two-way arrow?” were presented on the screen until a response was made. After the response, the entire display turned blank for an intertrial interval (ITI) of 1,000 ms, and then the next trial began. The participants’ primary task was to judge as quickly and accurately as possible whether the target was brightened or dimmed by pressing corresponding keys on the computer keyboard. They were informed that the cued object or location was not predictive of the subsequent target. In addition to the primary task, participants were asked to memorize the direction of the arrow (in the direction task), or the identity of the object (in the object task) and to press a corresponding key after responding to the primary task.

In Experiments 1e–1h (single task), the target display was followed by a blank for an ITI of 1,000 ms, and then the next trial began.

Results

RTs below 200 ms were excluded (less than 1%), and only trials with correct responses for both primary and secondary tasks were included in the analysis. Results are shown in Table 1. There was no speed–accuracy trade-off for the effects based on RT reported below, because there were no differences in error rates across conditions. As a baseline, all single-task experiments (1e–1h) showed longer RT in valid trials than in invalid trials—that is, IOR effects were obtained when no secondary task was performed, all $F_s(1, 19) > 4$, $p_s < .05$.

In the dots condition, IOR (presumably location based) was obtained when the secondary task was an object task—Experiment 1b, $F(1, 19) = 6.53$, $MSE = 167.96$, $p < .05$ —but not when it was a direction task—Experiment 1a, $F(1, 19) = 0.83$, $MSE = 289.01$, $p > .1$. In the

Table 1. Reaction time, percent error, IOR, and standard error of IOR in each experiment

Experiment	Task	Valid		Invalid		IOR	
		RT	PE	RT	PE	RT	SE
Experiment 1							
Dual task experiments							
1a	Dots/direction task	581	12	576	11	5	5
1b	Dots/object task	552	8	541	9	11	4
1c	Triangles/direction task	541	7	529	6	12	5
1d	Triangles/object task	529	7	532	6	−3	4
Single task experiments (control)							
1e	Dots/direction symbol	542	11	529	9	13	5
1f	Dots/object symbol	496	5	484	3	12	4
1 g	Triangles/direction symbol	521	7	510	5	11	5
1 h	Triangles/object symbol	502	5	492	4	10	5
Experiment 2							
2a	Dots/direction task	559	5	556	5	3	5
2a	Dots/object task	572	7	553	5	19	6
2b	Triangles/direction task	570	5	554	7	16	5
2b	Triangles/object task	554	5	555	5	−1	4

Note: RT = Reaction time (in ms); PE = percentage error; IOR = inhibition of return (in ms); SE = standard error.

triangles condition, IOR (presumably object based) was found when the secondary task was a direction task—Experiment 1c, $F(1, 19) = 5.19$, $MSE = 256.33$, $p < .05$ —but not when it was an object task—Experiment 1d, $F(1, 19) = 0.99$, $MSE = 119.05$, $p > .1$.

Discussion

We obtained typical IOR effects in single-task conditions, as shown in many other studies (e.g., Chou & Yeh, 2005; Gibson & Egeth, 1994; Jordan & Tipper, 1998, 1999; Posner et al., 1985; Tipper et al., 1991). Most importantly, in the dual-task experiments, IOR was disrupted by a spatial WM task in the dots condition and by a nonspatial WM task in the triangles condition. These results support our hypothesis: Location-based IOR and object-based IOR are mediated by spatial WM and nonspatial WM, respectively. The error rates between the direction-task and

object-task conditions were equal, suggesting no difference in difficulty or memory load between the two secondary tasks.

However, up to this point the support for our hypothesis is given only by cuing effects in independent experiments and not by direct comparisons.¹ To confirm the critical results directly, in Experiment 2 the secondary task type (direction or object) was varied within each participant.

EXPERIMENT 2

To compare the direction task condition with the object task condition within the same participant group, we designed the secondary task type as a within-subject factor, ensuring that any disparity between the two conditions would not be caused by individual differences. Also, we made some changes in the stimuli in order to further approximate typical location and object cueing paradigms.

¹ If Experiments 1a to 1d were combined in a 2 (display type: dots vs. triangles) $\times$ 2 (task type: direction vs. object) $\times$ 2 (trial type: valid vs. invalid) design, the three-way interaction was not significant, $F(1, 76) = 2.56$, $MSE = 215.89$, $p > .05$. Although this can be easily explained by low power due to the between-subject design, this result makes it clear that it is necessary to test our hypothesis more rigorously.

Method

Participants

Two groups of 30 undergraduates each, with the same characteristics as those described in Experiment 1, participated in Experiments 2a and 2b.

Stimuli, design, and procedure

The stimuli and procedure were the same as those in Experiment 1 except for the following. In Experiment 2a, six green dots were presented, and one of the dots was cued by presenting a white dot (0.6° in diameter, Figure 1C). In the target display, one dot was brightened or dimmed. In Experiment 2b, we used three white Vs (0.1° in width) and white dots (0.6° in diameter) on the corners of one triangle as the cue display (Figure 1D). One of the triangles (and its end dots) was brightened or dimmed as the target display. Each participant performed the direction and object tasks in different blocks, in a counterbalanced order. Experiment 2a contained 216 trials, in which one sixth were valid trials. Experiment 2b contained 144 trials, in which half were valid trials. Trials were divided into six blocks, with three blocks of the direction task and three of the object task.

Results

RTs below 200 ms were excluded (less than 1%). Again, there was no speed–accuracy trade-off, because there were no differences in error rates across conditions (Table 1).

A repeated measure analysis of variance (ANOVA) with the within-subject factors of trial type (valid, invalid) and task type (direction, object) was conducted for Experiments 2a and 2b separately. In both experiments the main effects of trial type and the interaction effects of trial type and task type were significant, all $F_s(1, 29) > 4$, $p_s < .05$. Simple main effects in Experiment 2a (dots display) showed that IOR (presumably location based) was obtained, $F(1, 58) = 13.7$, $MSE = 397$, $p < .001$, with an object task, but not with a direction task, $F(1, 58) = 0.30$,

$MSE = 397$, $p > .5$. In Experiment 2b (triangles display), IOR (presumably object based) was obtained, $F(1, 58) = 11.07$, $MSE = 324$, $p < .005$, with a direction task, but not with an object task, $F(1, 58) = 0.008$, $MSE = 324$, $p > .5$.

To compare Experiments 2a and 2b, the data were submitted to a three-way ANOVA with the factors of trial type (valid, invalid), task type (direction, object), and display type (dots, triangles). The first two factors were within subject while the last was between subject. The three-way interaction was significant, $F(1, 58) = 9.25$, $MSE = 419$, $p < .005$, confirming that the two types of task affected the two types of IOR differently.

Discussion

Experiment 2 replicated the results of Experiment 1. Since the task type was a within-subject factor in Experiments 2a and 2b, the result patterns in this study were not caused by individual differences. Again, error rates between direction task and object task conditions were equal. The two kinds of secondary task probed different kinds of WM but not degree of difficulty or memory load.

GENERAL DISCUSSION

We used a dual-task paradigm to examine whether different kinds of IOR (location based vs. object based) are mediated by different kinds of WM (spatial vs. nonspatial). Our answer is “yes”, based on the interaction of task type and display type that we found in this study. When participants needed to memorize the direction of an arrow, only location-based IOR was disrupted, while when participants needed to memorize the identity of an object, only object-based IOR was disrupted.

The disruption of location-based IOR by the direction task indicates that they compete for the same resource, possibly spatial WM. Castel et al. (2003) also showed that IOR was disrupted by a direction task, and they concluded that IOR was mediated by a spatial WM system. In addition to

replicating their results, we also differentiate the effects of two kinds of WM on object-based IOR. This is important because it constrains their conclusions. Our finding that object-based IOR was disrupted by a nonspatial secondary task further indicates that object-based IOR is mediated by a nonspatial WM system.

One could argue that the participants might treat the dots as objects (rather than locations) and that the number of objects is a critical factor in determining what kind of WM is involved. Thus, spatial WM would be involved when there are many objects in the display (the dots), and nonspatial WM would be involved when the display contains a relatively small number of objects (the triangles). Although not entirely impossible, there is no a priori reason to assume that displays with more objects involve spatial WM while those with fewer objects involve nonspatial WM. Furthermore, the participants were told that there were marked locations in the displays, and we confirmed with them after completion of the experiment that they indeed viewed the triangles as two objects, and the dots as six locations.

One may also argue that it is the degree of stimulus complexity, not object versus location, which determines which kind of WM is involved. In other words, when the display is more complex (such as the triangles display), nonspatial WM is critical for IOR, but not spatial WM, and when the display is relatively simple (such as the dots display), spatial WM becomes critical. This argument makes the assumption that viewing more complex displays involves object representation and that object WM is operating to maintain such information. Again, although not impossible, complexity is an ill-defined concept that does not provide a noncircular explanation, let alone prediction. For example, the opposite case might also be true: that more (rather than fewer) complex displays involve spatial WM.

Using different displays such as dots and overlapping objects to probe location- and object-based effect separately is the first step toward examining the role of different types of WM in location- and object-based IOR. It is worth trying other displays for follow-up studies, such

as the double-rectangle paradigm of Egly, Driver, and Rafal, (1994), which is useful to compare location and object effects in a single condition. Jordan and Tipper (1999) have used this paradigm by presenting two spatially separate rectangles with a peripheral cue appearing at one end of one rectangle. They found longer detection RT at the uncued end of the cued object than at that of the uncued object, demonstrating object-based IOR in static displays. Converging evidence may be sought by applying the two kinds of secondary task to the two kinds of IOR, as we have done in the current study.

To our knowledge, the present study is the first one to show a double dissociation pattern of location- and object-based IOR by manipulating different WM types, and it thus provides new insights into the mechanisms involved in each. It is possible that the inhibited location is held in spatial WM, such that intervening tasks using the same WM processes disrupt the trace of the inhibited location. In contrast, the inhibited object is held in a different form of WM, so that tasks involving nonspatial WM disrupt the trace of the inhibited object.

In conclusion, our findings further elaborate the results of Castel et al. (2003) by differentiating the effect of the two kinds of WM (spatial vs. nonspatial) on the two kinds of IOR (location based vs. object based) and suggest that the two kinds of IOR can operate differently within the WM system.

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