INHIBITION OF RETURN: A "DEPTH-BLIND" MECHANISM?

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ABSTRACT

When attention is oriented to a peripheral visual event, observers respond faster to stimuli presented at a cued location than at an uncued location. Following initial reaction time facilitation responses are slower to stimuli subsequently displayed at the cued location, an effect known as Inhibition Of Return (IOR). Both facilitatory and inhibitory effects have been extensively investigated in two-dimensional space. Facilitation has also been documented in three-dimensional space, however the presence of IOR in 3D space is unclear, possibly because IOR has not been evaluated in an empty 3D space. Determining if IOR is sensitive to the depth plane of stimuli or if only their bi-dimensional location is inhibited may clarify the nature of the IOR. To address this issue, we used an attentional cueing paradigm in three-dimensional (3D) space. Results were obtained from fourteen participants showed IOR components in 3D space when binocular disparity was used to induce depth. We conclude that attentional orienting in depth operates as efficiently as in the bi-dimensional space.

KEY WORDS: Inhibition Of Return (IOR), Location-based IOR, Object-based IOR, Three-dimensional environment

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INTRODUCTION

When attention is oriented to a peripheral visual event (e.g., an abrupt onset) an initial facilitation for the processing of nearby stimuli can be observed. This facilitating effect presumably represents reflexive orienting of attention toward the source of stimulation (e.g., Posner, 1980). The brief period of facilitation is followed by a long-lasting inhibitory effect, during which the response to stimuli presented at or near the subsequently cued location is delayed. This relative slowing of reaction times (RTs) has been termed 'Inhibition Of Return' (IOR), suggesting that subjects are inhibited in returning to a recently attended location (Posner & Cohen, 1984) thereby facilitating visual search (Klein, 2000).

In the last twenty years, IOR and facilitation effects have been largely studied in bi-dimensional (2D) horizontal and vertical planes (for a review, see: Klein, 2000; Lupiáñez et al., 2006). Many authors (Atchley & Kramer, 2001; Bourke et al., 2006; Couyoumdjian et al., 2003; Han et al., 2005; Miura et al., 2002; Moore et al., 2001; Robertson & Kim, 1999; Theeuwes et al., 1998; Theeuwes & Pratt, 2003; Tse, 2005) have evaluated the properties of spatial orienting in 3D space providing convincing evidence that attentional facilitation can occur at different depth planes. In contrast, how IOR behaves in the three-dimensional space has not been extensively investigated, with conflicting results coming from the only two studies into this field (Bourke et al., 2006; Theeuwes & Pratt, 2003).

To investigate whether IOR could be elicited in 3D space, Theeuwes & Pratt (2003) used a stereographic display in which four vertically oriented rectangles representing the number 8 were presented at different depth levels, two on each side of the screen, with the two rectangles in the back plane slightly displaced in order not to completely overlap with the rectangles in the front plane. The cue consisted of the brightening of one of the four rectangles and the target was presented after a variable inter-stimulus interval by removing some of the figure segments to obtain either an S or an H. Participants were asked to discriminate the target by pressing different keys on a keyboard. In line with previous findings, the results showed facilitation when crossing z-plane (i.e. RT's to targets in the same hemi-field and depth of the cue were faster than RT's to targets in the same hemi-field but at different depth) at brief cue-target intervals, whilst IOR was not observed in the z-plane (i.e., both the front and back location within the same hemi-field were equally inhibited). The conclusion reached by the authors was that IOR is insensitive to depth. In a subsequent study, Bourke, Partridge and Pollux (2006) questioned Theeuwes and Pratt's (2003) conclusions, suggesting that their results could be due to the use of overlapping stimuli as the rectangles presented in the back plane were partially occluded by those in the front plane thereby preventing the perception of stimuli as being separate in depth and potentially masking the occurrence of a three-dimensional IOR effect. As such, Bourke and co-workers (2006) added a critical experimental manipulation that consisted of increasing the horizontal separation between the two figures presented in each hemi-field in order to avoid overlap. Their results showed significantly different IOR in the two-depth planes that were attributed to the additive effect of the IOR attached to the figure and the IOR attached to its spatial location (object-based and location-based IOR effects, cf. Tipper & Weaver, 1998). According to the Authors, the fact that the cued object was more inhibited indicated that the object-based IOR operates within a three-dimensional representation. At the same time, since both depth planes were inhibited, albeit to a different extent, they concluded that the location-based IOR operates with a bi-dimensional representation. To support this interpretation, a second experiment was conducted in which the two corresponding front and back figures were joined at the corners to form two parallelepipeds, one at each side of the display, so that whenever cue and target were presented in the same hemi-field, regardless of depth space, they were always within the same object (the parallelepiped). Results showed that cueing one part of parallelepiped resulted in a similar inhibition effect to targets appearing in a different part of the same object. In this sense, authors conclude that object based IOR operates in a 3D space. It is worth noting that in Bourke et al.'s study cue and target were always presented within objects and so their results strongly support the conclusion of the object-based component operating with a 3D representation; at the same time, the conclusion that the location-based component was insensitive to depth does not seem supported as their experiments did not include a condition without objects.

Subsequent studies have not addressed whether this mechanism operates with 2D versus 3D representations and almost six years later the question is still unanswered. From a functional perspective it is unlikely that IOR, often described as a “foraging facilitator”, is not sensitive to depth as our visual environment is perceived in three-dimensions and so a “depth blind” search mechanism would be maladaptive. Furthermore, although the superior colliculus, a midbrain structure that codes the space in retinotopic (bi-dimensional) coordinates plays an important role in IOR (Klier, Wang, & Crawford, 2001), there is evidence suggesting that IOR operates via both retinotopic and spatiotopic coordinates (Maylor & Hockey, 1985; Posner & Cohen, 1984; Abrams & Pratt, 2000; Mathot & Theeuwes, 2010). Hence, establishing that IOR operates in three-dimensional space should confirm that IOR involves spatiotopic coordinates and is important in adaptive exploration of the environment. Put differently, if IOR is a general mechanism of attention that facilitates efficient exploration of surrounding space, then it is difficult to believe that IOR operates via both location and object-based coordinates in a bi-dimensional context (Lupiáñez, Klein, & Bartolomeo, 2006), yet uses only object-based coordinates in three-dimensional space (Bourke et al., 2006).

In order to directly assess the conditions in which IOR can be observed in three-dimensional space we developed an experiment examining IOR effects in an empty space (without objects). Three different visual backgrounds were separately administered and analysed: a 3D-stereoscopic background including also monocular cues (3D+), a 2D background with monocular cues (2D+) and 2D background. We used two 2D control conditions to evaluate whether the simulation of stereoscopic vision is necessary to observe IOR effects in depth or if the use of monocular depth-cues only (2D+) was sufficient. In all the conditions (3D+, 2D+, 2D) stimuli could be presented in four different locations: at right and left of the fixation point and far or near to the observer.

Three different SOAs (Stimulus Onset Asynchrony) were used; one short, one medium and one long, for two reasons: 1) the temporal uncertainty is one of the factors that maximize the possibility to observe IOR effects (Lupiáñez et al., 2001) preventing participants to give automated responses, 2) to assess if the time course of a depth-based IOR is the same as the one of IOR in bi-dimensional space.

Because of the functional role of IOR in facilitating visual search, we expected to observe depth-specific IOR effects in the 3D+ condition at the medium and long SOAs, with slower RTs in responding to target presented in the same hemi-field and at the same depth of the cue respect to RTs to target presented in the same hemi-field but at different depth. In addition, we were expecting to observe the well known attentional cueing effects in depth (e.g. Atchley & Kramer, 2001; Theeuwes & Pratt 2003) at the short SOA, with faster RTs in responding to target presented in the same hemi-field and depth of the cue respect to target presented in the same hemi-field but at different depth.

METHOD

Participants

Fourteen university students (mean age 24.5 ± 3.5) signed an informed consent before taking part as volunteers in the study. They were not paid and they did not receive any course credit. The study was approved by the local ethical committee.

Right handed participants were selected with a hand preference equal or greater than 85%, as assessed by means of a lateral preference questionnaire (Salmaso & Longoni, 1985). All participants had normal or corrected-to-normal vision and they were unaware of the purpose of the experiment.

In order to take part in the study the participants had to complete a screening test to determine whether they were able to perceive depth using binocular disparity. The stimuli consisted of two squares, presented in the centre of the screen, one in the front plane and the other in the back plane. Since all participants were able to see both the squares, all of them were admitted to the study.

Apparatus

The displays and the stimuli were presented on a high definition CRT 21-inch monitor with a Pentium-based computer system (running at 100 MHz) using a Nvidia Quadro FX 3500 (256 Mb) graphics card.

E-Prime software controlled the presentation of the stimuli, timing operations and data collection. Responses were gathered with a standard keyboard. The stimuli were created by using a commercial 3D rendering package (Cinema 4D). Stereopsis was obtained by using a set of liquid crystal shutter glasses (NuVision shutter glasses).

Stereopsis was achieved by creating stereo pairs of the visual scene images. One image corresponded to the right-eye view and the other image corresponded to the left-eye view. The stimuli in the scene were presented with a disparity of ± 0.50°. The glasses allowed each eye to receive the appropriate view, so that depth was perceived. Binocular fusion was guaranteed by synchronizing the alternated frame rate (50 Hz per eye) of the glasses to the monitor refresh rate (100Hz).

Stimuli

A different visual display was chosen for each trial block, according to the respective experimental condition (3D+, 2D+ and 2D).

3D+ Condition

The stimuli were presented on a complex background representing an empty room. The room consisted of a grey (RGB[158,158,158]) rectangle (18˚ x 9.8˚) representing a wall positioned in the centre of the visual field, and four chess board patterned surfaces (representing two side walls, the floor and the ceiling), defined by four lines departing from the corners of the grey rectangle and slanting up to the edges of the display. Walls and floor of the scene were generated using textured surfaces in order to render the scene more compelling and provide a rich set of monocular depth cues. A perspective camera was used in scene rendering. The room had an apparent height of 2.40 m, a width of 4.40 m and a depth of 7.70 m.

The software allowed the stimuli to be perceived as being located in two different z-planes. When the stimuli where presented at the larger eccentricity (and size) they gave the illusion of being located nearer to the observer as compared to when they were presented at the smaller eccentricity (and size), despite the fact that they were actually of different sizes and positioned at different eccentricities.

The cues and the target stimuli could appear in four possible positions: they were centred at 4.5˚ (degrees of visual angle) or 2˚ of eccentricity to the left or to the right with respect to the fixation point. The cue was a squared frame of 2° x 2° size when presented at 4.5˚ of eccentricity while it was of 1˚ x 1˚ size when presented at 2° of eccentricity. The target was a black sphere and occupied approximately a 2˚ x 2˚ area when presented at 4.5˚ of eccentricity, and a 1˚ x 1˚ area when presented at 2° of eccentricity. The fixation point was situated in the centre of the rectangle representing the grey wall, which corresponded to the centre of the visual field at an apparent distance of 3.85 m from the camera point of view. When perceived closer, the stimuli appeared at 2 m distance; when perceived further away, they appeared at 6 m distance, being 4.00 m distant from each other. The perceived horizontal distance between the left and right positions was 2.20 m (1.10 m from the fixation point).

2D+ Condition

The stimuli were the same as those of the 3D+ condition and they were presented on the same background and in the same locations as the 3D+ condition. The only difference was that a central view of the scene, rather than left and right eye's viewpoint, was used.

2D Condition

The stimuli were presented on a grey background (RGB [158,158,158]). Cue and target were identical and could appear in the same locations as the previous conditions. In the figure 1 an example of the 2D+ and 2D are reported.

[**Insert figure 1 about here**]

Procedure

The display was placed in a silent and dimly illuminated room at a distance of approximately 56 cm from the participant's eyes. A headrest was used to stabilize the observer's head.

For each block a trial began with a fixation period persisting 500 ms. This was followed by the cue for 100 ms. After the offset of the cue, a delay period of 60, 300 or 1000 ms occurred, depending on the SOA condition (160, 400 or 1100 ms SOAs). The target was then displayed for 100 ms in one of the four peripheral locations (right or left, near or far). If no response was detected within 1000 ms after the target onset, the next trial began. After the participant's response, the fixation display was presented indicating the beginning of a new trial.

We considered four cue levels: Valid (the target appeared in both the same x and z plane as the cue), Invalid in x (the target appeared in the same z-plane, but in a different x-plane compared to the cue position), Invalid in z (the target appeared in the same x-plane, but in a different z-plane compared to the cue position), Invalid in both x-z (the target appeared in both different x and z planes compared to the cue position).

The order of each experimental block within each experiment was randomized across subjects. Participants completed one 24-trial practice block and three experimental blocks (3D+, 2D+ and 2D visual backgrounds). Each experimental block consisted of 240 experimental trials: 57 trials for each condition (Valid, Invalid-z, Invalid-x, Invalid-x-z). In order to minimize the frequency of anticipatory responses, the experiment also included 5% of catch trials – 12 trials in which no target followed the cue. A trial sequence is shown in the Figure 2.

[**Insert figure 2 about here**]

Task

Participants were instructed to fixate on the cross in the centre of the screen throughout the task and to respond as quickly as possible by clicking the space bar when they detected the target stimulus.

Data analysis

In each block, the experimental conditions were randomly presented: 4 types of *Cue* (Valid, Invalid-x, Invalid-z, Invalid-xz) x 3 types of *SOA* (160, 400, 1100 ms). For data analysis, only reaction times of correct responses, ranging between 200 ms and 800 ms, were considered. For the analysis of the effects, planned comparisons were used.

RESULTS

Mean RTs (± SD) and error rates (in percent) in each experimental condition are shown in Table 1.

3D+ condition

There was a main effect for the *Cue* (F(3,39)= 19.75, MSE= 397.57, p< .0000001; Figure 3). Planned comparison showed that RTs were slower for the valid condition compared to either Invalid-x (365 vs. 337 ms; F(1,13)= 33.32; MSE= 502.45, p< .0001), Invalid-z (365 vs. 357 ms; F(1,13)= 6.31, MSE= 239.72, p< .05) and Invalidxz (365 vs. 339 ms; F(1,13)= 38.33, MSE= 369.08, p< .0001). The SOA (F(2,26)<1) and the interaction (F(6,78)=1.46, MSE= 278.37, p= .20) were not significant.

2D+ condition

The ANOVA showed a main effect for the *Cue* (F(3,39)= 9.11, MSE= 353.81, p< .0001; see figure 3). Planned comparison showed that RTs were slower for the valid condition with respect to both the Invalid-x (341 vs. 326 ms; F(1,13)= 19.50, MSE= 254.13, p< .001) and the Invalid-xz (341 vs. 325 ms; F(1,13)= 10.11, MSE= 538.85, p< .01), but not with respect to the Invalid-z condition (341 vs. 340 ms; F(1,13)< 1). The SOA (F(2,26)= 1.8, MSE= 2428.22, p= .19) and the interaction (F(6,78)<1) were not significant.

2D condition

There were a main effect for the *SOA* (F(2,26)= 4.01, MSE= 1668.99, p< .05) and the *Cue* (F(3,39)= 10.84, MSE= 337.43, p< .0001; see figure 3). Additional planned comparisons showed slower RTs for the Valid condition with respect to both the Invalid-x (339 vs. 320 ms; F(1,13)= 15.17, MSE= 495.67, p<.005) and the Invalid-xz (339 vs. 322 ms; F(1,13)= 12.81, MSE= 427.92, p< .005), but not with respect to the Invalid-z condition (339 vs. 335 ms; F(1,13)= 1.41, MSE= 165.89, p= .26). The interaction was not significant (F(6,78)= 1.17, MSE= 338.99, p= .33).

[**Insert figure 3 and table 1 about here**]

Discussion

Our results showed a *location-based* IOR effect, specific to three-dimensional visual space (3D+ condition). This was present in a visual setting that did not contain objects and only when, in addition to a rich set of monocular depth cues in the visual background, binocular disparity was induced. The well-known IOR effect in the bi-dimensional plane was confirmed. For all the three conditions (3D+, 2D+ and 2D) slower RTs were found in the valid relative to the invalid-x trials.

The slower RTs in the 3D compared to both 2D and 2D+ conditions can be attributed to a greater difficulty of the 3D condition, most likely depending on the complexity of the visual display and the use of the goggles. It can be hypothesized that once 3D perception is induced both cue and target positions are coded using three-dimensional (rather than bi-dimensional) coordinates and hence responses are slower because of the addition of information regarding the depth of the stimulus. In turn, the IOR effect in the x-plane can be affected as a result of the cost of shifting attention in both the x and the z plane.

In line with this view, our IOR effects were greater in the 3D than in the other two conditions (see figure 3). This result can also be explained by the fact that the 3D condition provides a finer ecological visual setting and hence it appears more appropriate for eliciting IOR effects in both x- and z-planes. Furthermore, in agreement with this hypothesis, several studies support the view that IOR represents a foraging facilitator subserving visual search (Klein, 2000; Klein & MacInnes, 1999) and a mechanism operating in both environmental and retinotopic coordinates (Mathot & Theeuwes, 2010). This theoretical view is shared by the scientific community but it is important to note that the knowledge about attentional processes is, for the most part, based on studies that have been conducted within a two-dimensional world. Previous studies in 3D space were conflicting (Bourke et al., 2006; Theeuwes & Pratt, 2003) but the present study shows for the first time that the location-based IOR might function in a similar manner in both x- and z-planes, highlighting its importance as an adaptive attentional mechanism.

It is also worth to noting that despite using a covert attention paradigm and peripheral non-informative cues, facilitation at the shortest SOA was not observed in all of the experimental conditions. These findings are in disagreement with early detection tasks results reported by Posner, usually indicating facilitation at short SOAs with a fast transition to IOR at longer SOAs (Samuel & Kat, 2003). Moreover, in many occasions IOR is observed without any hint of facilitation at shorter SOAs (Mele et al., 2008; Tassinari et al., 1994). In fact, when peripheral non-informative cues are used, specific conditions are needed in order to observe facilitation. Previous studies have shown that the occurrence of facilitation effects is closely linked to the duration of cue and target (e.g., Berlucchi et al., 1989; Maruff et al., 1999). Other factors might influence the facilitatory effect: cue-target spatio-temporal overlapping (McAuliffe & Pratt, 2005), practice (Lupiáñez et al., 2001; Weaver et al., 1998), temporal overlap between cue and target (e.g., Maruff et al., 1999; Maylor, 1985; Maylor & Hockey, 1987; Posner et al., 1985; Pratt & Abrams, 1995; Rafal et al., 1989; Rafal & Henik, 1994; Tassinari et al., 1994; Tassinari & Berlucchi, 1996), cue saliency (Mele et al., 2008), presence of catch trials (Okamoto-Barth & Kawai, 2006), physical characteristics of the cue (e.g., Pratt et al., 2001), when the cue remains visible until the target appears or when the target remains visible until the subject's response (e.g., Berlucchi et al., 1989; Tassinari et al., 1994; Tassinari & Berlucchi, 1996; Tassinari et al., 1989).

It has also been argued that facilitation is only observed with temporally overlapping cues, i.e., when the cue duration is longer than the cue-target SOA (Collie et al., 2000), and spatially non-overlapping cues (McAuliffe & Pratt, 2005). This might not be generally applied to all situations, as significant facilitation has been reported consistently without temporally overlapping cues (Lupiáñez et al., 1997), and no facilitation was observed in other paradigms, which used temporally overlapping cues (Tassinari et al., 1994).

Many of the abovementioned factors could have prevented early facilitation from being observed. Thus we can conclude that in the 3D plane, as well as in the 2D plane (e.g., Maruff et al., 1999; McAuliffe & Pratt, 2005; Pratt et al., 2001) a biphasic pattern – i.e. early facilitation and late inhibition – is not always observed in a peripheral cuing paradigm.

In conclusion, several explanations have been provided as to why IOR is observed on many occasions in a detection task without facilitation at shorter SOAs. Most explanations have focused on the speed with which attention is disengaged from the cued location, suggesting that attention may be disengaged from the cued location earlier in detection than in discrimination tasks (Klein, 2000; Lupiáñez et al., 2001), or that when catch trials are included (as in our experiment) participants are more motivated to disengage attention from the cued location (Okamoto-Barth & Kawai, 2006). In our task, it is possible that the brief duration of the cue (100ms) lead participants to maintain attention at the cued location for briefer time (until target appearance) and/or that with practice participants learn to disengage attention quicker and more efficiently, as our cueing task is long in duration (45 min).

As a final discussion point of this study, it must be noted that results from the different conditions (3D+, 2D+, 2D) seem to indicate that the exclusive use of monocular depth clues within the visual scene is unlikely to induce 3D perception. In fact, reaction times in the 2D+ and 2D conditions were virtually identical and no effects potentially attributable to depth were seen in the 2D+ condition. Taken together, these results suggest that both visual displays were acting as 2D conditions. In contrast, the use of binocular disparity in the 3D+ condition seems to have made the difference as it allowed us to observe depth-specific IOR effects. For these reasons we recommend that future studies interested in how attention behaves in three-dimensional space use a simulation of stereoscopic vision.

In sum, we believe that the findings of the present study elucidate one aspect of IOR that has been unclear for many years. In the three dimensional space a location-based IOR is observed and therefore it is not correct to conclude that only the object-based component of IOR is sensitive to depth. This finding emphasizes the general functions of IOR which seems to act similarly in both x and z coordinates of space.

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Footnotes

1. It is known (e.g., Maylor & Hockey, 1985; Bennett & Pratt, 2001) that the IOR effect decreases in magnitude when the distance between cues and targets increases.

2. When using professional image editing software, the rendering tool allows the building of the image starting from a mathematical description of a three-dimensional scene. The perspective camera is used to imitate the functionality of the human eye, located at a certain distance from the point of interest. The software allows moving the camera in order to obtain different points of view.

Table

	Reaction times			Error rates	
SOA	160	400	1100	Anticipate response	Omissions
3D+ condition	Mean	Mean	Mean	2%	4%
Valid	355.7 (36.2)	366.1 (48.9)	373.3 (39.5)		
Invalid-x	337.8 (45.1)	336.7 (55.6)	335.8 (34.5)		
Invalid-z	359.5 (46.1)	349.8 (49.3)	360.2 (43.9)		
Invalid-xz	337.6 (51.3)	334.8 (43.9)	344.7 (38.5)		
2D+ condition				2%	2%
Valid	331.4 (23.9)	340.4 (25.5)	352.1 (37.1)		
Invalid-x	324.2 (27.9)	318.6 (38.3)	334.9 (52.3)		
Invalid-z	339.3 (31.9)	328.4 (26.8)	352.6 (46.7)		
Invalid-xz	319.1 (33.1)	322.7 (44.1)	333.7 (35.6)		
2D condition				1%	2%
Valid	324.6 (36.3)	334.6 (35.3)	356.4 (33.1)		
Invalid-x	317.2 (37.8)	310.7 (36.9)	330.8 (27.5)		
Invalid-z	325.1 (24.9)	333.9 (30.2)	346.6 (37.6)		
Invalid-xz	319.8 (39.9)	315.1 (30.1)	332.3 (32.7)		

Table 1. Mean values (± SD) and error rates (in percent) for each experimental condition.

Figure

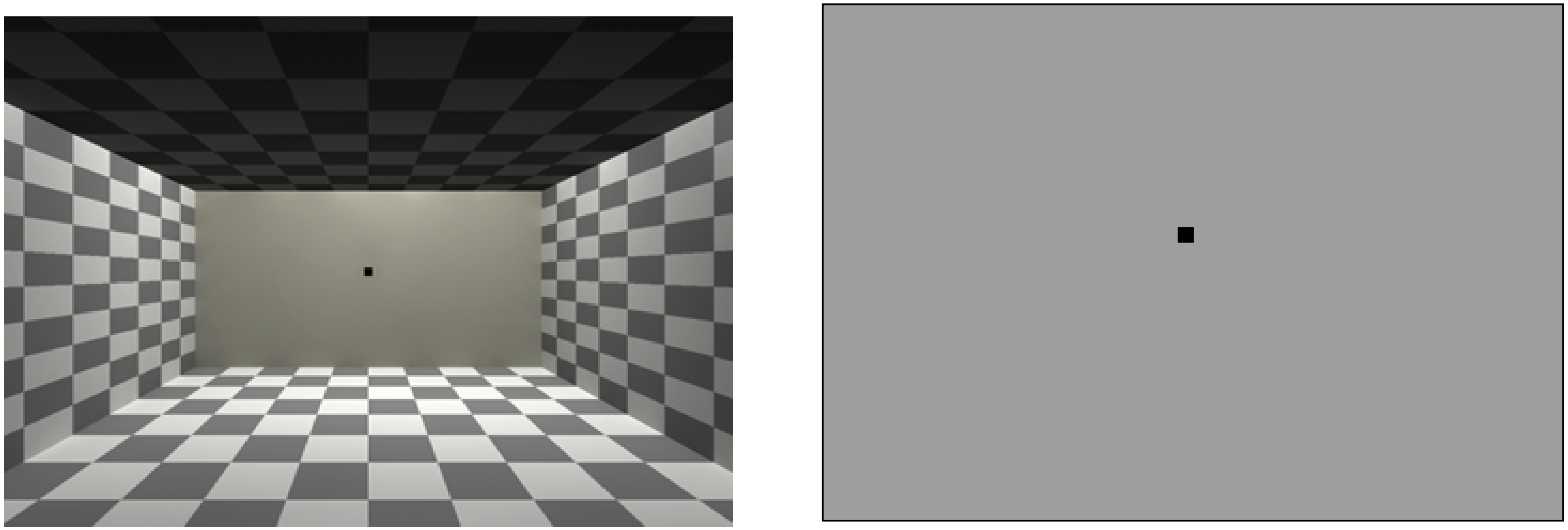


Figure 1. The figure shows an example of the three visual displays presented in each experimental block of the experiment. On the left the visual display for both 3D+ and 2D+ conditions are reported. On the right the 2D display is described.

Figure

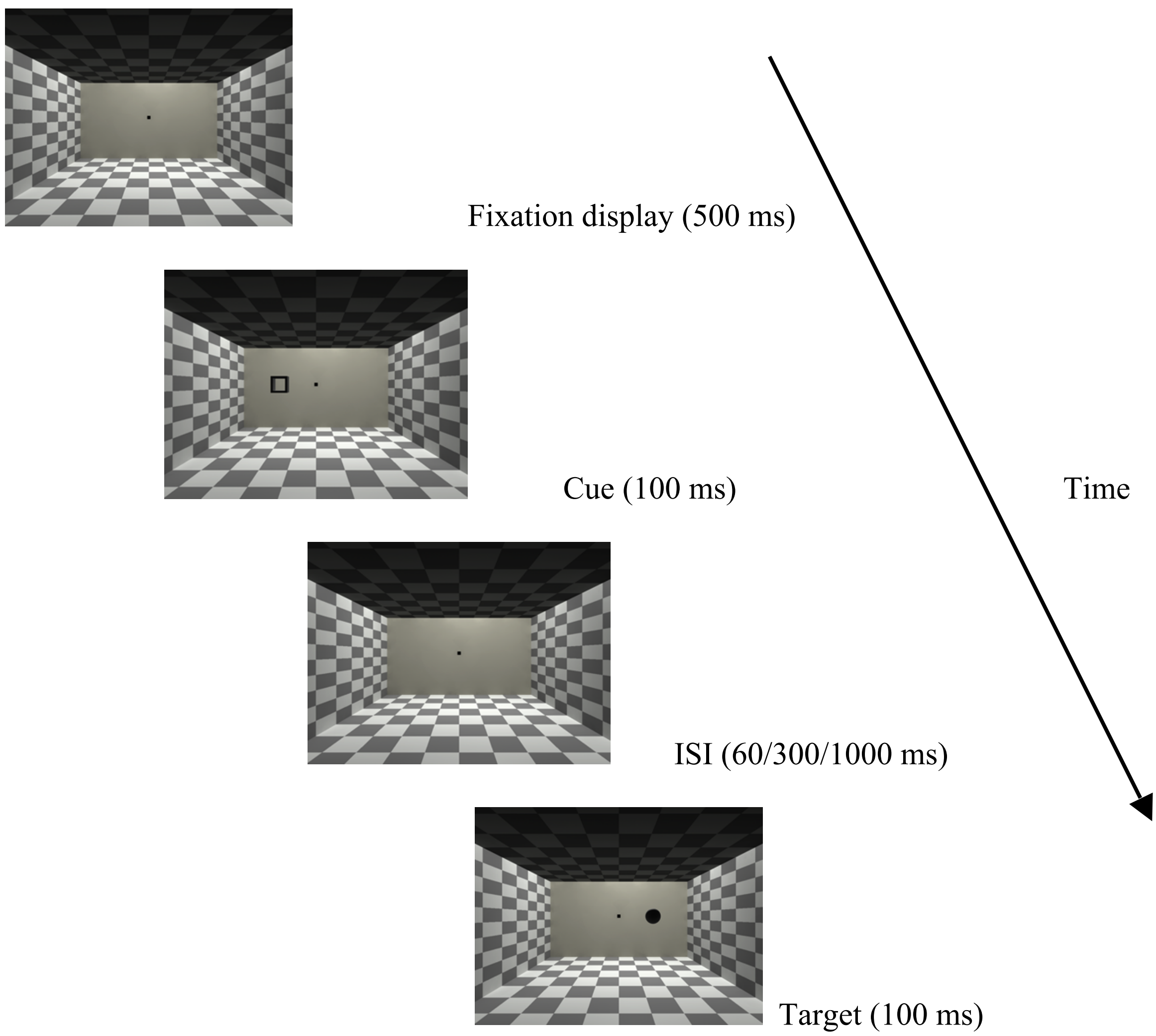
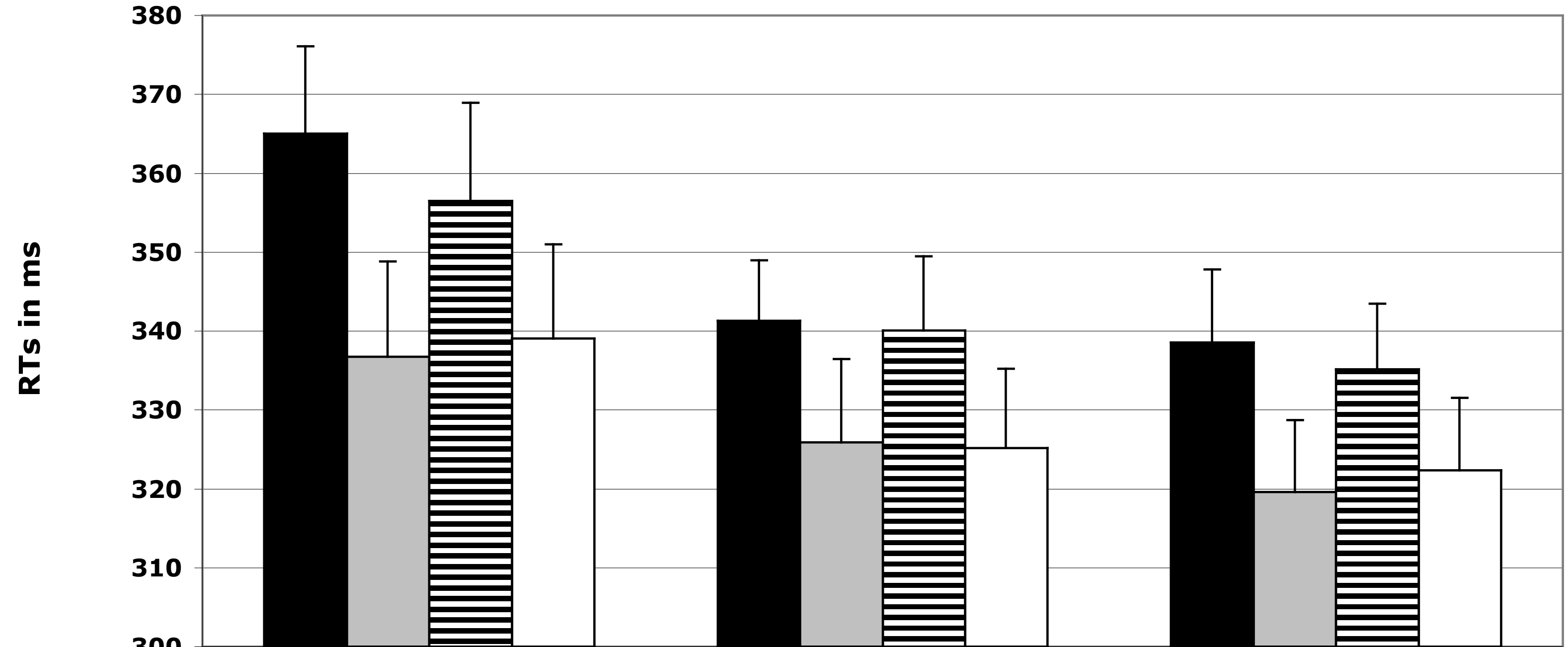


Figure 2. An example of an experimental trial sequence, from top left to bottom right. Specifically, the figure reported an Invalid-x trial, in one sequence employed in all the experiments make use of both 2D+ and 3D+ conditions.

Figure



	3D+	2D+	2D
■ VALID	365	341	339
■ INVALID-X	337	326	320
☰ INVVALID-Z	357	340	335
□ INVALID-XZ	339	325	322

Figure 3. The figure shows mean RTs and SE for every cue type (valid, invalid-x, invalid-z, invalid-xz trials). From left to right, data from the three visual displays (3D+, 2D+, 2D) are reported.

*Abstract

ABSTRACT

When attention is oriented to a peripheral visual event, observers respond faster to stimuli presented at a cued location than at an uncued location. Following initial reaction time facilitation responses are slower to stimuli subsequently displayed at the cued location, an effect known as Inhibition Of Return (IOR). Both facilitatory and inhibitory effects have been extensively investigated in two-dimensional space. Facilitation has also been documented in three-dimensional space, however the presence of IOR in 3D space is unclear, possibly because IOR has not been evaluated in an empty 3D space. Determining if IOR is sensitive to the depth plane of stimuli or if only their bi-dimensional location is inhibited may clarify the nature of the IOR. To address this issue, we used an attentional cueing paradigm in three-dimensional (3D) space. Results were obtained from fourteen participants showed IOR components in 3D space when binocular disparity was used to induce depth. We conclude that attentional orienting in depth operates as efficiently as in the bi-dimensional space.