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# Spatial attention and object-based attention: a comparison within a single task

David Soto, Manuel J. Blanco *

*Departamento de Psicología Social y Básica, Facultad de Psicología, University of Santiago de Compostela, Santiago de Compostela 15706, Spain*

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**Abstract**

There is now much experimental evidence supporting the idea that visual attention can be deployed in at least two ways: one space-based and other object-based. However, it is not clear whether space- and object-based attention work in an integrated way within the visual system. In this article, we present two experiments in which we compare both components of attention within a cueing paradigm. Participants had to discriminate the orientation of a line that appeared within one of four moving circles, differing in colour. A cue appearing close to one of the four circles indicated the location or circle where the target stimulus was likely to appear. Spatial and object cueing effects were observed: responses were faster when target appeared either at the precued location or within the precued object. In addition, the object-cueing effect occurred only when the cue was spatially invalid and not when it was spatially valid. These results suggest that object- and space-based attention interact, with selection by location being primary over object-based selection.


*Keywords:* Visual attention; Spatial attention; Object-based attention

## 1. Introduction

The visual system cannot process fully all the objects or stimuli that at any given time are projected at the retina. Because of this, attention mechanisms are needed to allow the organism to select for further processing information that is currently task-relevant, whilst ignoring other information that also appears as part of the visual scene but that is not relevant. One of the more basic and currently controversial issues related to visual attention is the type of representation on which selection is carried out. Does visual attention select from a spatial representation of the visual field or does it select perceptual objects? According to the space-based view, visual attention is directed to particular locations of the visual scene. Different analogies have been suggested to illustrate the functioning of spatial attention (see Cheal, Lyon, & Gottlob, 1994); for instance, a spotlight that enhances processing of stimuli within its beam (e.g. Posner, 1980), or a zoom lens (e.g. Eriksen & Yeh, 1985), which likens attention to the operation of a zoom lens of a camera. In contrast, the object-based view suggests that attention is directed to objects or perceptual groups of the visual scene previously segmented on the basis of gestalt principles (Kahneman & Henik, 1981; Neisser, 1967).

Evidence for spatial selection comes mostly from spatial cueing studies (e.g. Posner, 1980). In these studies, spatial attention is varied by precueing the location where the target stimulus is likely to appear. Two cueing conditions are usually compared: valid and invalid. In the valid condition, the target is preceded by a cue that indicates the spatial area where the stimulus will appear; in the invalid condition, the cue indicates a different location. The typical finding is that responses are faster, and also more accurate (e.g. Downing, 1988; Müller & Findlay, 1987), when stimuli are presented at cued relative to uncued locations. This finding is now very well established in the literature on attention. It has been observed with many different types of stimuli (both cues and targets), at different locations in the visual field, in different tasks (detection, discrimination, identification), when the target stimulus appears in an empty visual field and in a cluttered visual field, with different observers, etc.

* Corresponding author.
*E-mail address:* psmblanc@usc.es (M.J. Blanco).

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Evidence for object-based selection comes from a variety of different experimental studies (see Scholl, 2001; also Cave & Bichot, 1999, for reviews): "selective looking" (Neisser, 1967), divided attention to attributes from one or different objects (e.g. Duncan, 1984; see also Berhmann, Zemel, & Mozer, 1998), multiple object tracking (e.g. Pylyshyn & Storm, 1988), cued detection and cued discrimination tasks (e.g. Brawn & Snowden, 2000), dissociations in neurological patients (e.g. Egly, Driver, & Rafal, 1994; see also Rafal, 1997, for a review), response-competition (e.g. Kramer & Jacobson, 1991), inhibition of return (e.g. Tipper, Driver, & Weaver, 1991), negative priming (e.g. Tipper, Brehaut, & Driver, 1990), and experiments on certain visual illusions (e.g. Hikosaka, Miyauchi, & Shimojo, 1993). In general, these studies account for data difficult to explain from space-based theories. The main findings are that: (a) attention can be split among multiple moving objects which do not occupy a connected region of space, (b) object-based factors can modulate cueing effects, (c) grouping between targets and distractors can influence the magnitude of response-competition, and override the effects of the distance between stimuli under certain conditions.

Thus, there is now clear evidence supporting the idea that there is a space-based component or system of attention and another object-based component. However, it is not clear how both systems can work in an integrated way within the visual system. Several theories have been advanced, but no one account is sufficient for all experimental results. Some investigators have suggested that both systems could act in an independent way, with the type of task and the level of visual representation demanded by the task determining whether attention selects spatial locations or objects (Vecera & Farah, 1994). Other findings suggest that both systems could act in an interactive way, however. For instance, it seems that some clinical disorders (e.g. visual neglect) and experimental effects (e.g. inhibition of return) related to attention can be manifested in spatial or object-based frames of reference (e.g. Berhmann & Tipper, 1999; Tipper, Weaver, Jerraut, & Burak, 1994). Also, studies on the neural bases of both attentional systems suggest that they could act in an interactive way. Using PET measures of regional cerebral blood flow to index neural activity, Fink, Dolan, Halligan, Marshall, and Frith (1997) found that object-based and space-based attention share common neural mechanisms in the parietal lobes, in addition to task specific mechanisms in early visual processing areas of the temporal and occipital lobes (see also Arrington, Carr, Mayer, & Rao, 2000).

One of the reasons why this theoretical controversy on the inter-relations between object- and space-based attention has still not been resolved may be that few studies have compared attention to space and attention to objects within the same experimental paradigm. The first research designed to compare both attentional systems within the same paradigm was that of Egly et al. (1994). Egly et al. showed observers displays containing two rectangles. After a short time, one edge of one end of one rectangle was brightened briefly, providing a cue to attend to that location. Observers had then to detect a dark square that appeared within the same rectangle or within the uncued rectangle. There was one type of valid-cue trial and two different types of invalid-cue trials: on valid-cue trials, the target stimulus appeared at the cued end of the cued object. On invalid-cue trials, the target appeared at the other end of the cued rectangle (invalid-cue and same-object condition) or at one end of the uncued rectangle (invalid-cue and different-object condition). As usual in cueing experiments, responses were faster when the target appeared at the cued location than when it appeared elsewhere. For invalid-cue trials, responses were faster in the same-object condition than in the different-object condition, indicating an object-based component. Egly et al. (1994) proposed that these data demonstrate the existence of both components of attention, one space-based and other object-based (see also Chen, 1998; Moore, Yantis, & Vaughan, 1998). However, Egly et al.'s experiment has an important methodological limitation because at cued locations the target always appeared inside a cued object. Thus, it is not possible to verify the precise type of representation on which attention operated at the locus where the cue was displayed. For example, a truly object-based cost on performance due to a shift of attention between objects at the same spatial location cannot be assessed.

In order to study adequately both attentional components, at least four experimental conditions should be compared within a single task. These four experimental conditions result from combining two spatial-attention conditions, cued vs. uncued location, and two object-attention conditions, cued vs. uncued object.

More recently, Lamy and Tsal (2000) included the relevant condition in which the target appeared within an uncued object at a cued location. Their task was similar to that used by Egly et al. (1994). Two objects differing in form (a rectangle and a hourglass figure) and colour were presented on each trial. The cue, an outline square presented at one of the corners of one of these objects, indicated the location of the target (Experiments 1 and 2) or the features of the object within which it would appear (Experiment 3). After cueing, the objects could remain at the same location (all experiments) or they could exchange their positions. They could exchange locations either abruptly (Experiments 1 and 3) or gradually, based on the sensation of apparent motion (Experiment 2). The task was to detect a luminance increment at one of the corners of the rectangles. The target could occur within an uncued object or within a cued object either at a cued or at an uncued location.

The results suggested that the cued object location (all the area subtended by the object) was attended whether or not the target was presented in that spatial area, whereas the cued object features (colour and form) were attended only when the target was presented within an object with identical features to those from the cued object. Lamy and Tsal (2000) concluded that attention would operate on object-based representations only when object features are relevant to the task and spatio-temporal continuity of the objects is maintained, whereas it would operate on spatial representations even when space is irrelevant to the task.

Lamy and Tsal's study deserves two methodological commentaries. First, a possible methodological problem could derive from the fact that they used dynamic and static displays in different experimental conditions, for cued objects and/or cued locations (Experiment 2). In the same-object and cued-location condition, they used static objects whereas in the different-object and cued-location condition they employed moving objects, with objects exchanging their positions. However, it is possible that attention operates in different ways with static objects than with moving objects. For instance, studies with the multiple object tracking paradigm (Pylyshyn & Storm, 1988; Scholl, Pylyshyn, & Feldman, 2001) show that attention can select multiple moving objects, whereas studies with static objects (Baylis & Driver, 1993; Duncan, 1984) suggest that attention can only select one object at a time. Second, the design used by Lamy and Tsal (2000) requires carrying out several comparisons between experiments and also between markedly different experimental conditions. It seems more parsimonious to use a single statistical test to decide the significance of main effects and interaction between factors.

In this paper, we present two experiments that compare object- and space-based attention within a cueing paradigm and with a single procedure. In both experiments, four moving objects differing in colour appeared on each trial. An exogenous cue at the location occupied by the object indicated the location and/or the object within which the target stimulus was likely to appear. The objects then either exchanged their positions or returned from the middle of their trajectories to the initial positions at the start of the trial. We had thus four experimental conditions, from combining two spatial-attention conditions (cued vs. uncued location), and two object-attention conditions (attended vs. unattended-object). In terms of an analysis of variance (ANOVA), main effects of location and object factors would be interpreted as evidence that there are space-based and object-based components or systems of attention. A significant statistical interaction between both factors would support the idea that both components of attention act in an interactive way (e.g. Humphreys & Riddoch, 1993). The lack of significant interaction would be interpreted as supporting the hypothesis that both components are independent.

Prior to Experiment 1, we conducted another experiment with static objects. In that study, four circles were initially displayed on each trial within a 500 ms frame similar to that used in the experiments reported here. Two of the four circles were of identical colour and the two remaining of different colours. A spatial cue composed of small dots around one of the circles signalled either the target's likely location or the colour of the circle within which the target was likely to appear. Observers had to identify the orientation of a line presented inside one of the circles 100 ms after the cue. There were four types of trials. In the cued object-feature condition, the target was presented within a circle of the same colour to that of the cued circle, whereas in the uncued object-feature condition, the target was presented within a circle of different colour to that of the cued circle. For one group of observers the target appeared at the cued location on 75% of the trials and at an uncued location on the remaining 25%. For another group of observers, the target appeared within an object with cued colour on 75% of the trials and on remaining 25% within an object with a colour different to the cued circle. The results showed the typical spatial-validity effect in both groups (RTs faster at cued than at uncued locations). The results did not show evidence for attentional selection by colour, however. If feature-based selection was occurring in this task, then, the cost of responding to targets presented at uncued locations should be reduced when the target appeared within an object that was the same colour as the cued object, relative to when it appeared within an object that differed in colour from the cued object. However, this pattern of results was not observed. There was little evidence for feature-based cueing of attention under the current conditions. In Experiment 1 then, we used objects that differed in colour from one another to enhance any object-based effects, knowing that feature-based effects were unlikely.

## 2. Experiment 1: effects of space- and object-based cueing

### 2.1. Method

#### 2.1.1. Participants

The participants were 14 volunteers (2 men and 12 women). They were psychology students and staff members of the University of Santiago de Compostela who were unaware of the purpose of the experiment. They were aged between 21 and 37 years of age. All participants had normal or corrected-to-normal vision.

#### 2.1.2. Apparatus

A Pentium III computer with a NVIDIA PRO TNT 32 MB graphics card controlled the stimulus displays and responses. The task was programmed and run on this computer using E-Prime V1.0 (Psychological Software Tools, 2002). The stimuli were displayed on a high-resolution colour monitor (IBM P275). Monitor resolution was 1024×768 pixels and its frame rate was fixed at 100 Hz, permitting display times to be varied in steps of 10 ms. The presentation of the stimuli was synchronized with the refresh rate of the monitor. All the displays were previously drawn off-screen and then copied for visualization. With our equipment, the required times to copy and erase were virtually zero (mean = 0.02 ms). The luminance and colour of the stimuli were measured with a CS-100A Minolta photometer. Responses were entered on a PST response box (see Schneider, 1995, for technical specifications). Electroculogram (EOG) recording was used to monitor vertical and horizontal eye movements. A Biopac MP100 system was used for these recordings. An adjustable chin rest helped to maintain head position.

### 2.1.3. Task

The display was viewed binocularly from a distance of 70 cm. Each trial began with the presentation of a crosspiece (12.27°×12.27° of visual angle) that contained a fixation cross at its center (0.53°×0.53° of visual angle) and four circles 2.45° in diameter with contours of different colour. The crosspiece was black (luminance = 0 cd/m$^2$) and the fixation cross white (CIE coordinates: $x = 0.252$, $y = 0.269$; luminance = 1.50 cd/m$^2$). The contours of the circles were red, green, blue and yellow and their inner regions black. The luminance of the red circle ($x = 0.609$, $y = 0.361$) was 0.62 cd/m$^2$. The luminance of the other three contours was determined individually for each participant by the method of adjustment before running the task (see the procedure). Each participant adjusted the luminance of each circle to the luminance of the red circle, which constituted the reference stimulus. The mean of the adjusted luminance levels were 2.65 cd/m$^2$ for the green circle, 0.66 cd/m$^2$ for the blue one and 4.56 cd/m$^2$ for the yellow one. The background on which these images were displayed was grey ($x = 0.250$, $y = 0.270$; luminance = 0.30 cd/m$^2$).

The red, green, blue, and yellow circles were initially displayed at the upper leftwards, upper rightwards, lower leftwards and lower rightwards positions respectively (see Fig. 1). After 500 ms, a cue composed of four small dots (0.245°) around one of the circles was presented for 60 ms. The location of this cue was counterbalanced. The cue appeared in white ($x = 0.252$, $y = 0.269$) with a luminance of 8.81 cd/m$^2$. The cue disappeared and 20 ms later the circles also disappeared. 20 ms later the circles were displayed in the same horizontal plane partly occluded by the crosspiece for 20 ms. These partly occluded circles subtended 0.81°×2.2° of visual angle. This frame was followed by a time interval of 220 ms in which the circles were totally occluded by the crosspiece. Then, the circles reappeared partly occluded by the crosspiece during 20 ms either at their initial position or at the opposite side of the crosspiece. In the first case, they returned to their initial positions after a blank interval of 20 ms. In the second case, they

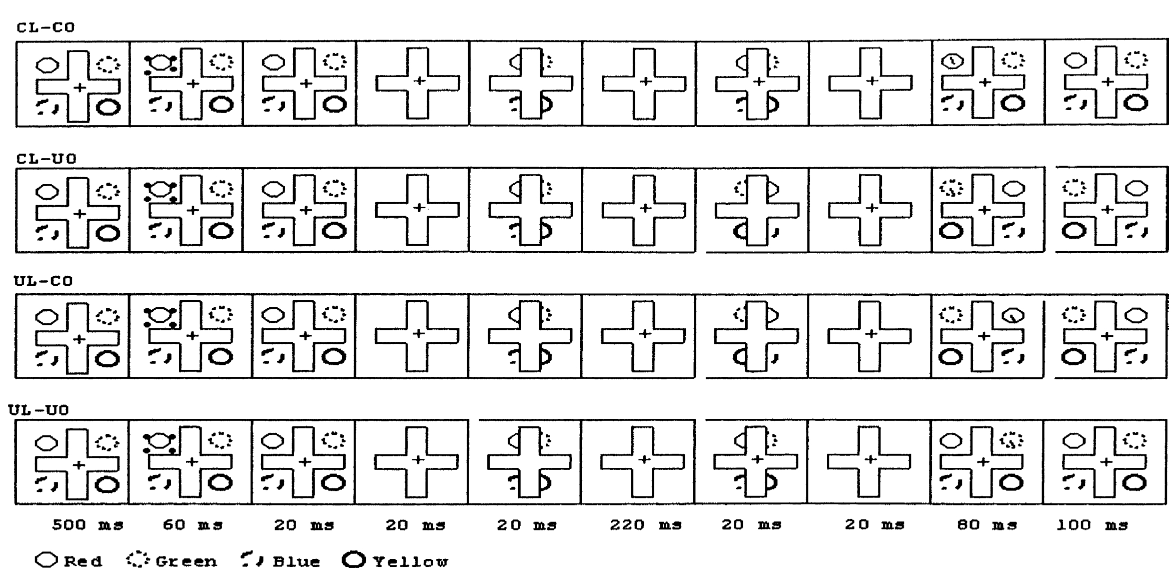


Fig. 1. Experimental conditions in Experiment 1. (CL–CO) cued location–cued object, (CL–UO) cued location–uncued object, (UL–CO) uncued location–cued object, and (UL–UO) uncued location–uncued object. Each trial in each one of these conditions began with a fixation display for 500 ms. Then, a cue, consisting of four small circles, was presented around one of the circles for 60 ms. After cue offset, a series of frames of 20 ms were presented. In these frames circles disappeared and reappeared partly occluded by the crosspiece. A frame in which the circles seem to be totally occluded by the crosspiece was presented for 220. Then, the circles reappeared again partly occluded by the crosspiece for 20 ms. Twenty ms later the target line was presented for 80 ms. After the target display frame, only circles and crosspiece were displayed for 100 ms.

reappeared at the position initially occupied by the adjacent circle after an identical blank interval (see Fig. 1). This sequence of events resulted in the sensation of motion. The circles seemed either to travel from one to another location passing behind the crosspiece, or to enter at the crosspiece and to return to their initial positions.

When the circles stopped moving, a target stimulus was presented inside one of the circles for 80 ms. The target stimulus was a line 0.9° in length tilted 6° right or left. The target line appeared in white ($x = 0.212$, $y = 0.233$) with a luminance of 0.39 cd/m$^2$. The observer was asked to identify target's orientation by pressing a button of the response box (a different button for each orientation). The observer was instructed to respond as fast and as accurately possible within a time window of 1500 ms.

#### 2.1.4. Procedure

The experiment was run in three phases. In the first phase, each participant adjusted the luminance of a circle to the luminance of a standard red circle. This procedure consisted of three upward trials, in which the luminance of the comparison circle increased, and three downward trials, in which that luminance decreased gradually. Each participant carried out this task for each of the three comparison circles. Luminance was controlled with the E-Prime sentence $canvas \cdot pencolor = ccolor(\text{“}R, G, B\text{”})$. This sentence specifies the luminance of the stimulus by a number for each of the three primary colours, from 0 to 255. The luminance was increased or decreased by adding or subtracting 1 to/from the last value.

During the second phase, the observer was familiarized with the task and performed a variable number of practice trials (between 50 and 150, approximately). In the third and last phase of the experiment, the observer performed three blocks of trials. The first and the second block were composed of 85 trials and the third was composed of 80 trials. There were two types of trials depending on the spatial validity of the cue. When the cue was spatially valid, the target appeared inside a circle displayed at the cued location. The target could appear either: (a) inside the cued circle, that is, within the same circle that had been displayed initially at the cued location; or (b) inside an uncued circle, that is, inside the circle that had been presented at the opposite side of the crosspiece with regard to the cued location. The target was thus displayed within the cued circle (on those trials in which the circles returned to their initial locations from the middle of their trajectories), or inside an uncued circle (on those trials in which the circles changed their locations). When the cue was spatially invalid, the target appeared inside a circle that was displayed at an uncued location. On these trials, the target could also appear either inside the cued circle or inside an uncued circle. It appeared within a cued circle on those trials in which circles exchanged their locations, and it appeared within an uncued circle on those trials in which circles returned to their initial positions. For these last trials, the target appeared in the same row or in the same column, but in both cases it was the same distance from the cued location. The four experimental conditions will be called here: cued location–cued object (CL–CO), cued location–uncued object (CL–UO), uncued location–cued object (UL–CO), and uncued location–uncued object (UL–UO).

Space- and object-cueing was manipulated between subjects by varying the probability of occurrence for the different types of trials. When space was task relevant, participants were instructed that the target stimulus would appear with a greater probability at the cued location than elsewhere. When object was relevant, they were instructed that the target would appear with greater probability inside the object where the cue had been presented than inside the other object. The participants were divided into two groups. For the first group, 80% of the trials were spatially valid (40% were CL–CO and 40% CL–UO). On the remaining trials, the target appeared inside an uncued location (10% were UL–CO trials and 10% UL–UO). For the other group, the target appeared within the cued object on the 80% of the trials (40% were CL–CO and 40% UL–CO) and within an uncued object on the remaining trials (10% CL–UO and 10% UL–UO). These groups are called high spatial-validity and high object-validity, respectively.

### 2.2. Results

Firstly, trials in which eye movements or blinks occurred were excluded from the analysis. On average, less than 2% of the each observer's total number of trials was rejected by this motive.

Table 1 shows the mean of median RTs of the correct responses and the standard deviations for each group as a function of spatial validity and object validity. These data were analysed using different analysis of variance (ANOVAs). In these analyses, all $p$ values for main or interaction effects involving the repeated measures factors were computed using the conservative Greenhouse–Geisser method with corrected degrees of freedom.

We carried out a three-factor ANOVA over median RTs with group (high probability of spatial validity vs. high probability of object validity), spatial validity and object validity as factors. The first factor was a between-subjects factor while the two last ones were within-subjects factors. This ANOVA gave main significant effects for spatial validity ($F(1,12) = 31.357$, $p < 0.0001$), and object validity ($F(1,12) = 15.740$, $p < 0.002$). RTs were shorter for targets at cued locations than for targets displayed at uncued locations, and also

Table 1
Data from Experiment 1

| Group | Spatial cue | | | |
|---|---|---|---|---|
| | Valid | | Invalid | |
| | Cued object | Uncued object | Cued object | Uncued object |
| High spatial validity | 547 (56) | 552 (62) | 606 (67) | 623 (72) |
| High object validity | 558 (98) | 576 (99) | 571 (91) | 613 (67) |

Mean of median RTs of the correct responses and its standard deviations (between brackets) for each group as a function of spatial validity and object validity.

for targets displayed within cued objects than for targets that appeared within uncued objects. The group factor only interacted with the spatial validity factor ($F(1,12) = 6.635$, $p < 0.027$). The spatial cueing effect was higher in the high probability spatial cueing group. There was no interaction between group and object validity. The main effect of the group factor was not significant ($F(1,12) = 0.004$ ns).

Spatial validity and object validity effects interacted significantly ($F(1,12) = 6.252$, $p < 0.028$). Fig. 2, which represents median RTs in each condition for each group, makes clear the interpretation of this interaction. The effect of object validity was greater when the cue was spatially invalid than when the cue was spatially valid. Separate ANOVAs confirmed the source of this interaction. First, we conducted 2×2 ANOVAs with group and object validity (cued object vs. uncued object) as factors separately for each spatial validity condition. The objective of these analyses was to assess whether the object cueing effect was modulated by spatial factors. These ANOVAs examined possible differences between performance (i) when the target was in a cued or uncued object, and it also fell at a cued location (CL–CO vs. CL–UO) and (ii) when the target was in a cued or uncued object and it fell at an uncued location (UL–CO vs. UL–UO). Only for the second analysis there was a significant effect of object validity ($F(1,12) = 20.453$, $p < 0.001$). These data indicate that the object cueing effect occurred only when the cue was spatially invalid, but not when the cue was spatially valid ($F(1,12) = 3.285$ ns). Second, we made similar 2×2 ANOVAs, with group and spatial validity (valid vs. invalid) as factors separately for each object validity condition. A first ANOVA examined effects of spatial cueing within a cued object (CL–CO vs. UL–CO). There was a significant effect of spatial validity ($F(1,12) = 24.886$, $p < 0.001$) and an interaction between this factor and the group factor ($F(1,12) = 10.499$, $p < 0.007$). The spatial cueing effect was higher for the high spatial validity group. Other ANOVA examined the effects of spatial cueing when targets fell in uncued objects (CL–UO vs. UL–UO). There was again a significant effects of spatial validity ($F(1,12) = 27.832$, $p < 0.0001$). These data clearly indicate that the spatial cueing effect was independent of object validity. Spatial cueing occurred both when the target appeared inside the cued object and when appeared inside an uncued object.

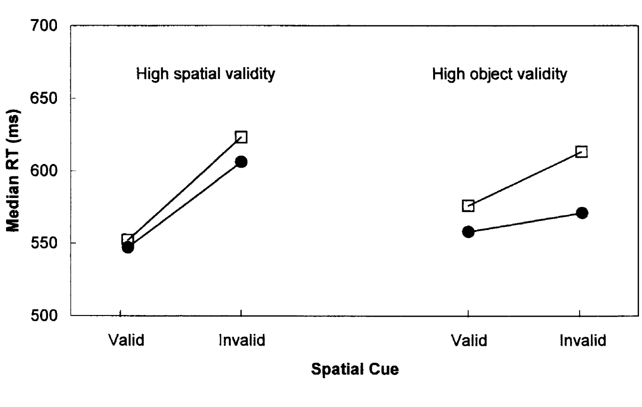


Fig. 2. Data from Experiment 1. Mean of median reaction times (RTs) of the correct responses for each group as a function of spatial validity and object validity.

On cued object trials, both the cued object and the target were always displayed in the same row as the cue. Therefore, there were more trials with targets on the row in which the cue was displayed than in the other row. Because of this, it might be that observers directed their attention to the complete row instead of attending to a specific location or object. Thus, on spatially invalid trials, attention may be directed endogenously to the location occupied by the cued object, even in the spatial group, because there was a higher probability that the target occurred in that row. If this were true, the object cueing effects observed in our study should be questioned because they could be explained by the orienting of spatial attention alone. In order to make sure that our findings were not confounded by this factor, we compared the sizes of the spatial cueing effect (RT spatially valid trials—RT spatially invalid trials) when spatial attention had to shift to an uncued object located in the same row as the cue and when it had to shift to an uncued object located in a different row. A 2(group)× 2(row) ANOVA was carried out over the spatial cueing effects. This analysis did not show any significant effect or interaction.

Lastly, the sizes of the location- and object-cueing effects were compared with a 2(group)×2(attention locus: location vs. object) ANOVA. This compared performance in conditions when either spatial cueing alone was valid (CL–UO) or when object cueing alone was valid (UL–CO). There was a significant effect of attention locus: RTs were shorter when targets appeared at a cued location inside an uncued object than when it appeared at an uncued location but inside the cued object ($F(1,12) = 6.379$, $p < 0.027$). Moreover, this effect was higher for the group where there was a high probability of valid spatial cues, than for the group where there was a high probability of valid object cues ($F(1,12) = 9.856$, $p < 0.009$).

The accuracy data (error mean = 10%) are not reported here, although they were analyzed in order to rule out a speed/accuracy tradeoff. These analyses were in the same direction as for RT. Therefore, a speed/accuracy tradeoff cannot explain the reported differences in RT.

### 2.3. Discussion

The main results can be summarized in four points:

(1) As expected, discrimination was quicker both for targets at cued locations and for targets within cued objects, relative to targets at uncued locations or uncued objects. These results confirm previous findings (e.g. Egly et al., 1994) and suggest that attention can operate on location-based representations and also on object-based representations. It has to be noted that because we used objects that only differed in colour, our results could be interpreted as showing selection by colour and not strictly an object-based selection. However, as we have noted, we have found little evidence for feature-based selection under similar conditions with static objects. We thus attribute our results to object-based cueing, under conditions of spatio-temporal continuity. Indeed, evidence from functional imaging indicates that attending to one attribute of an object enhances the neural representation not only of that attribute but also of the whole object (O'Craven, Downing, & Kanwisher, 1999).

(2) The spatial cueing effect was greater than the object cueing effect. This finding suggests that: selection by location is more effective and perhaps even more primary than object-based selection (Tsal & Lavie, 1988, 1993; though see point (3) below).

(3) The size of the spatial cueing effect varied depending on whether space or object cueing was task-relevant, being greater when the cue was likely to be spatially valid than when it was likely to cue the target object, whereas the size of the object cueing effect was independent of the probability of spatial and object cueing. This finding suggests that space-based attention can be modulated by strategic factors related to observer's expectancies and not by a strictly stimulus-driven process.

This pattern of results agrees well with recent experiments carried out by Atchley and Kramer (2001, Experiments 2–3). In this study, observers were required to identify the presence of one or two targets that could appear within the same or a different object. Spatial cues were presented near the location of one target and they were either unpredictive (Experiment 2) or predictive (Experiment 3) of the target's location. The results showed that performance was better when the two targets were present within the same object. Furthermore, this object-based effect appeared both when spatial cues were highly informative about the target's location and when they were noninformative, as was observed in our study. However, the pattern of results is unexpected if we take into account that the processing of spatial location is both faster and occurs earlier than feature or object processing, perhaps due to the different temporal courses of the dorsal and ventral pathways (Goodale & Milner, 1992; Maunsell, Nealey, & DePriest, 1990). It could be argued that the effects on performance, due to attention being directed in a top–down way by the cue, would be stronger for object-based attention, if, as the evidence suggests, object-based attention operates more slowly than spatial attention.

Our finding is not consistent with data from Lamy and Tsal (2000, Experiments 1 & 3). They showed that object features (e.g. colour) are selected only when they are relevant for the task. This divergence in the results could be explained by two factors. First, a key difference between our experiment and that of Lamy and Tsal is the type of task employed. They employed a detection task while we employed a identification task. There is evidence showing that object-based effects on attentional selection are stronger for identification, and also discrimination, tasks than for detection tasks (Brawn & Snowden, 2000; Vecera & Farah, 1994). It may be that identification relies more on object-based representations, whereas low-level array representations may suffice for carrying out detection tasks. Second, in our experiment, we cued locations and objects with identical procedures and displays. The only difference between our relevant and irrelevant conditions was that the target was more probable at either the cued location or inside the cued object. However, in Lamy and Tsal's experiment, there were important procedural differences between these two conditions. When space was relevant, subjects had to respond in all trials, whereas in the condition in which object features were task relevant, subjects were instructed to respond only if the cue appeared at the location of a specified object.

A possible explanation for the fact that object-based effects were not modulated by strategic factors or factors related to cueing probability in our study relates to the effect of preattentive segmentation processes on attentional selection (see Driver, Davis, Russell, Turatto, & Freeman, 2001, for a review). There is much work suggesting that the processes that parse the visual field into objects take place without attention (Driver, Baylis, & Rafal, 1992; Moore & Egeth, 1997). Our finding suggest that, under certain conditions, object-based attention could work at early stages of visual processing without being constrained by top–down factors.

(4) Lastly, an interaction between spatial validity and object validity was observed. The object-validity effect occurred only when the cue was spatially invalid and not when it was spatially valid. This finding agrees with the results of experiments showing that selection by feature cues has a greater effect on performance when spatial cues are invalid (Dunai, Castellio, & Rosseti, 2001; Hillyard & Munte, 1984; Lambert & Hockey, 1986). This agrees with the idea that selection by location is more primary than selection based on objects (Tsal & Lavie, 1988, 1993).

## 3. Experiment 2: varying target detectability

In Experiment 2 we attempted to generalize the findings from Experiment 1 by varying the salience of the target signal. Two levels of target detectability were compared: low and high. The target could be an onset line or a no-onset line tilted to the right or to the left. The first condition was a replica of Experiment 1. In a trial of this kind, a line tilted to the right or to the left appeared abruptly inside one of the four circles. In the no-onset condition, an "X" was displayed in each of the four circles immediately preceding the appearance of the target line. The target appeared by removing one of the line segments that formed the "X". Prior research has consistently shown that a stimulus appearing as an abrupt onset is more efficiently detected than the same stimulus revealed by removing other camouflaging stimuli (Jonides & Yantis, 1988; Yantis & Johnson, 1990). In this experiment, we did not want to explore the nature of the difference observed between onset and no-onset stimuli (see Gibson, 1996; Yantis & Jonides, 1996; and Folk, Remington, & Johnston, 1992, for different views on this issue). Simply, we wished to use this difference to investigate whether the validity effects observed in the previous experiment vary with the salience or the detectability level of targets.

### 3.1. Methods

#### 3.1.1. Participants

This experiment was run with a new group of naive subjects to eliminate the possibility that previous experience in a similar experiment could affect attentional strategies. Fourteen volunteers (7 men and 7 women) participated. They were staff members and students at the University of Santiago of Compostela and were unaware of the hypothesis and objectives of the experiment. They were aged between 23 and 28 years. All of them had normal or corrected-to-normal vision.

#### 3.1.2. Task

The task was identical to that of the previous experiment; however there were two target types: onset and no-onset targets.

In both conditions, each trial began with a 500 ms crosspiece containing a fixation cross at its center and four circles of the same colours to those used in Experiment 1. The luminance of these circles was determined for each subject before starting the task by a method of brightness adjustment. The red circle was the reference stimulus and its luminance and CIE coordinates were the same as those in Experiment 1. The mean of the adjusted luminance levels was 2.11 cd/m$^2$ for the green circle, 0.77 cd/m$^2$ for the blue one and 2.97 cd/m$^2$ for the yellow one.

In the no-onset condition, an "X" appeared inside each of the circles. In the onset condition, no stimulus appeared inside the objects in the fixation display. In both conditions, a cue composed of four dots positioned around one of the circles was displayed for 60 ms. The cue disappeared and 20 ms later the circles also disappeared. 20 ms later the circles reappeared in the same horizontal plane for 20 ms, partly occluded by the crosspiece. In the no-onset conditions, when the circles were partly occluded by the crosspiece, the crosses were also occluded. In the next frame, the circles were fully occluded by the crosspiece during 200 ms. Finally, the circles could be presented partly occluded by the crosspiece at their last position, before returning to their initial positions. Objects could be displayed at the opposite side of the crosspiece on those trials in which the circles exchanged their locations. After 20 ms, the partly occluded circles disappeared during 20 ms. Then, circles and "X" shapes were displayed for 20 ms in the no-onset condition. In the onset condition only circles were displayed in this frame. Lastly, once apparent motion of the circles ceased, the target stimulus was displayed for 60 ms in both onset and no-onset conditions. In the onset condition, a line tilted 20° to the right or 20° to the left appeared abruptly inside one of the four circles, as in the previous experiment. Thus, this condition was a replica of the Experiment 1. In the no-onset condition, a "X" formed by a line tilted 20° to the left and other line tilted 20° to the right was displayed in each of the four circles immediately preceding the appearance of the target line. The target appeared by removing one of the line segments in the "X" and the three remaining "X" shapes. Note that in both conditions, the temporal delay between cue and target was 380 ms, as in Experiment 1.

The size and luminance of the lines were identical to those of the previous experiment. The observers were asked to identify the orientation of the line by pressing a button of the response box. They were instructed to respond as fast and as accurately possible during a time window of 1500 ms.

### 3.1.3. Procedure

The apparatus, illumination, viewing conditions, and stimulus parameters were identical to those of Experiment 1. The luminance of the stimuli was determined by the procedure used in Experiment 1. Participants performed four blocks of 90 trials and they were again divided in two groups. For one group the cue had a high spatial validity (80% of valid trials) and for the other the cue had a high object validity (also, on 80% of valid trials).

## 3.2. Results

3.51% of the trials were excluded from the analysis because of ocular movements. Table 2 shows the mean of median RTs for the correct responses and its standard deviations for each subject group as a function of spatial validity, object validity, and target type. Errors were minimal (mean = 5%) and statistical analysis showed no indication of a speed-accuracy trade-off.

We conducted a four factor ANOVA over median RTs with group, target type, spatial validity and object validity as factors. Group was a between-subjects factor and the other three were within-subjects factors. The results showed a main effect of target type (($F1, 12) = 51.234$, $p < 0.0001$). Performance was better with onset targets than with no-onset targets. The effect of target type did not interact with another factor. The remaining results were identical to those obtained in Experiment 1. The effect of spatial validity was significant ($F(1,12) = 34.637$, $p < 0.0001$), as was the interaction between this factor and group ($F(1,12) = 13.436$, $p < 0.003$). RTs were faster for targets at cued than at uncued locations, and this cueing effect was greater when the cue was likely to be spatially valid than when it was likely to validly cue the object. The effect of object validity was also significant ($F(1,12) = 17.714$, $p < 0.001$). Performance was better when the target appeared within a cued object than when it appeared within an uncued object. Finally, spatial validity and object validity interacted ($F(1,12) = 16.932$, $p < 0.001$). Fig. 3 represents this pattern of results.

Several ANOVAs were conducted to assess the source of this last interaction. First, we tested whether the object-based effect was constrained by spatial factors. $2\times2$ ANOVAs with group and object validity (cued object vs. uncued object) were carried out separately for each spatial-validity condition and also for each target-type condition. These ANOVAs revealed a significant effect of object validity when the cue was spatially invalid ($F(1,12) = 8.151$, $p < 0.02$, and $F(1,12) = 15.609$, $p < 0.002$, in no-onset and onset conditions, respectively), but not when it was spatially valid ($F(1,12) = 1.743$ ns, and $F(1,12) = 1.296$ ns, in both conditions). Second, we conducted similar $2\times2$ ANOVAs, with group and spatial validity (cued location vs. uncued location) as factors separately for each object validity and target condition. A significant effect of spatial validity was observed in both target conditions for cued objects ($F(1,12) = 15.304$, $p < 0.002$ and $F(1,12) = 17.092$, $p < 0.0001$, for the no-onset and onset target conditions, respectively) and for uncued objects ($F(1,12) = 16.587$, $p < 0.002$ and $F(1,12) = 28.207$, $p < 0.0001$, for the no-onset and onset target conditions, respectively). Thus, the spatial cueing effect was present both when the target was displayed within a cued object and when it appeared within an uncued object. Also, in these four ANOVAs, a significant interaction between group and spatial-validity was observed ($p < 0.002$). This interaction indicates that the spatial cueing effect was greater when the cue had a high probability of being spatially valid, than when it had a high probability of cueing the target object.

We also compared location and object effect sizes with a 2(group)$\times$2 (attentional locus: location vs. object)$\times$2 (target type) ANOVA. Two conditions (CL–UO and UL–CO) where either spatial- or object-cueing alone was present were assessed. A significant effect of attentional locus was found ($F(1,12) = 10.121$, $p < 0.008$). Response latencies were faster for targets at cued locations than for targets within cued objects. This effect was modulated by the probability of spatial validity, as showed by the interaction between attention locus and

Table 2
Data from Experiment 2

| Group | Target type | Spatial cue | | | |
|---|---|---|---|---|---|
| | | Valid | | Invalid | |
| | | Cued object | Uncued object | Cued object | Uncued object |
| High spatial validity | Onset | 456 (36) | 474 (32) | 523 (53) | 545 (54) |
| High object validity | Onset | 490 (62) | 490 (48) | 491 (53) | 547 (52) |
| High spatial validity | No-onset | 499 (42) | 500 (39) | 582 (66) | 625 (72) |
| High object validity | No-onset | 538 (74) | 552 (72) | 533 (68) | 581 (41) |

Mean of median RTs of the correct responses and its standard deviations (between brackets) for each group as a function of spatial validity, object validity and target type (onset, no-onset).

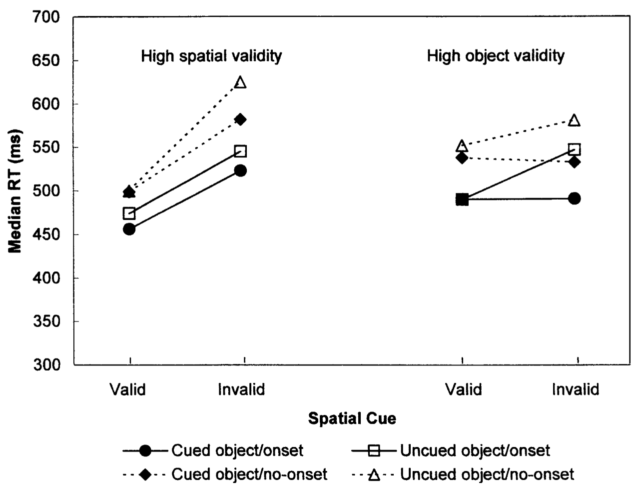


Fig. 3. Data from Experiment 2. Mean of median RTs of the correct responses for each group as a function of spatial validity, object validity and type of target (onset vs. no-onset).

group ($F(1,12) = 17.541$, $p < 0.001$). The main effect of target type was significant ($F(1,12) = 18.477$, $p < .001$). The interaction between the three factors was not significant ($F(1,12) = 4.507$ ns).

### 3.3. Discussion

The present results replicated all of those obtained in the previous experiment: (1) object- and spatial-cueing effects; (2) the finding that spatial cueing was greater than the object cueing effect; (3) that spatial-cueing was affected by the probability of spatial validity; and (4) that effect of object cueing was significant when the spatial cue was invalid. Also, as expected, a significant effect of target type was found: a target appearing abruptly was more efficiently identified than when the same stimulus was revealed by removing the camouflaging stimuli (Gibson, 1996, Yantis & Jonides, 1996). However, and more importantly, the cueing effects were independent of the salience or visibility of the target stimulus. This finding is not consistent with a previous study of Hawkins, Shafto, and Richardson (1988) who found that the spatial cueing effects in a luminance detection task interacted with target salience. In their experiments target salience was defined by luminance. They found that the cue validity effect was greater for less intense targets. However, this result may not be very robust. For example, it seems to depend on whether target luminance is treated as a between-blocks variable or a within-block variable, since the interaction between signal luminance and spatial-cue validity has been observed when luminance varies randomly within each trial block (Hawkins et al., 1988), but not when it is blocked (Blanco & Soto, 2002; Hawkins et al., 1990; Hawkins et al., 1988; Hughes, 1984). However, this last factor does not explain the discrepancy between our result and that from Hawkins et al. (1988), because we manipulated the salience of the signal randomly across trials. One possible explanation for this divergence in results could be that luminance was the relevant dimension in Hawkins et al's study while line orientation was the only relevant dimension in our study.

## 4. General discussion

Extensive prior research concerned with the type of representation on which attention operates suggests that there are at least two types of attentional mechanisms: a space-based mechanism and other object-based. Our findings clearly support this conclusion. We manipulated visual attention with a variation of the pre-cueing paradigm (Posner, 1980). In our procedure, attention was manipulated by precueing the location or object within which the target stimulus was likely to appear. The results confirmed the usual findings: the cue facilitated identification of the targets displayed either at the same location or within the same object, and it slowed identification responses when cues and targets were displayed within different locations or objects. These effects of visual cues seem highly robust. First, the two cueing effects (space and object) occurred under both low- and high-detectability conditions. Second, both validity effects appeared even when space or object-cueing was task irrelevant, although the spatial cueing effect was greater in magnitude when spatial cueing was task relevant. It does not seem easy to explain this pattern of results by assuming the existence of a single space-based attention mechanism. For example, Vecera and Farah (1994) suggested that many "object-based" effects might be explained without invoking a separate nonspatial selection process. Their idea is that spatial attention can conform to the object's shape by activating the spatial region in the visual field occupied by it. However, it seems difficult to accommodate our data within this model, because all the displayed objects had the same shape (all were circles) and they only differed in colour. Rather, our data support the idea that there is an object-based attention mechanism separated of other space-based mechanism.

The main goal of our study was to compare the two attention mechanisms within a single task, to assess whether they act in an independent or interactive manner. The results support this second possibility. We found effects of object cueing occurred only when spatial cues were invalid, but not when they were valid. How can the space- and object-based attention systems work in an integrated way in order to produce this effect? It is possible to explain the interaction between object validity and spatial validity in terms of differential amplification of the signal to targets provided by both components of attention. Both spatial attention and object-based attention may exert their influence on visual processing by enhancing sensitivity to the stimulus presented at attended or cued locations.

In order to explain the interaction between the two forms of cueing, we first assume that space-based component has a greater facilitatory effect than object-based component. When the target is presented at a cued location, an object-cueing effect may not be observed because there is sufficient activation to facilitate performance from space-based cueing alone. Alternatively, the interaction can be attributed to location cueing operating more rapidly than object cueing. When the target was presented at a valid location, spatial attention may facilitate a fast and accurate detection even before object features are processed sufficiently to facilitate the response.

These two theoretical interpretations suggest the idea of two attention mechanisms which have similar functions. A somewhat different view is that the two attention mechanisms have different functions but work in an integrated way (see Humphreys & Riddoch, 1993, for a similar view). Spatial attention may exert its influence on visual processing by enhancing sensitivity to the stimulus presented at the attended location. Space-based attention may be triggered by salient stimuli in the visual field (e.g. an onset of light, a great sensory change, appearance of a new object) (see Ruz & Lupiañez, 2002; Yantis, 2000, for recent theoretical and empirical reviews of the literature on attentional capture). Its function would be to enhance feature processing at the attended location. There is now much empirical evidence supporting the idea of spatial attention can modulate the 'responsivity' of the neural mechanisms or channels that are selectively sensitive to the features of a stimulus (e.g. orientation). Numerous physiological studies in animals have shown that the activity level of neurons in several areas of the visual cortex evoked by the target stimulus increases with spatial attention (see Maunsell, 1995, for a review; see also Desimone, 1998, for an alternative vision). In line with these physiological studies, psychophysical experiments in humans have demonstrated that spatial attention enhances visual processing. For instance, a number of psychophysical studies in humans have showed that the absolute threshold for detecting a luminance level is lower when the stimulus appears at cued than at uncued locations (e.g. Brawn & Snowden, 2000; Downing, 1988; Hawkins et al., 1990; Luck, Hillyard, Mouloua, & Hawkins, 1996; Luck et al., 1994; Müller & Humphreys, 1991; Smith, 1998). Also, and more related to our experiment, a number of relatively recent experiments have demonstrated that spatial cues affect the identification and discrimination of oriented lines (Blanco & Soto, 2002; Cheal & Gregory, 1997; Cheal, Lyon, & Hubbard, 1991; Downing, 1988) and other stimuli varying in orientation (Baldassi & Burr, 2000; Carrasco, Penpeci-Talgar, & Eckstein, 2000; Morgan, Ward, & Castet, 1998). In general, these findings are interpreted as supporting the notion that spatial attention exerts its influence on the visual processing by enhancing sensitivity to the stimulus presented at attended locations.

Perhaps following early spatial enhancement, the object-based attentional mechanism would select the cued object by an excitatory activation of the sensory pathways or structures that code the stimulus that appear at that location. [1] This activation pattern could be conceived as a process of forming an object file, as Kahneman and Treisman (1984) and Kahneman, Treisman, and Gibbs (1992) called it, and, as our results suggest, it can occur even when object's features (e.g. colour) are not relevant for the task (see also O'Craven et al., 1999). The activated representation would be updated as the object moves, even surviving to occlusion, as shown in our study (see also, Scholl & Pylyshyn, 1999). This idea is congruent with the biased competition hypothesis (Desimone, 1998; Desimone & Duncan, 1995).

According to this hypothesis, early sensory representations of different objects presented simultaneously within the visual field are mutually inhibitory, competing for access to higher-level processing. Object selection can be controlled by advance priming of units responsive to a particular target, so that the cued object representation competes more effectively with representations of other objects (cf. Chelazzi, Miller, Duncan, & Desimone, 1993).

In order to explain the fact that object-cueing only occurred when the spatial cue was invalid, we can suppose that an attended or selected object can guide spatial orienting. The motion of spatial attention would be faster when it is displaced towards the location occupied by a selected object and slower when it is displaced towards the location occupied by a nonselected object. According to this view, selective priming of an object representation elicited by the object-based mechanism would provide a top–down control of spatial attention (Desimone, 1998). Recent neuro-physiological studies have found neurons in the prefrontal cortex tuned either to object or spatial information or both and whose activity is modulated by attention (Rao, Rainer, & Miller, 1997). This prefrontal cortex could be a neural locus in which the interaction between spatial attention and object-based attention occurs.

Our account resembles the attentional priorizitation account outlined by Shomstein and Yantis (2002). These authors term attentional priorizitation "a later process that affects the order in which different regions of the

[1] Another possibility would be that the attention mechanism produces inhibition of the sensory pathways that code inputs from the uncued locations or objects (Desimone, 1998; Duncan, 1998), but this is not relevant for what follows.

scene are visually investigated when multiple attentional glimpses are required" (p. 42). According to our view, space-based attention orients to relevant locations enhancing processing of stimulus properties, whereas object-based attention guides spatial attention biasing its distribution over the objects displayed in the visual field. In this sense, spatial attention could be considered a slave process to object-based attention. However, because the spatial cue guided object-selection in our task, both attentional systems can be considered to be coupled (Humphreys & Riddoch, 1993). Either spatial attention or object-based attention could thus guide the other.

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