REAPPRAISING THE OBJECT EFFECT:

THE ROLE OF ATTENTIONAL SHIFT ACROSS A NON-UNIFORM REGION

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Abstract

Object-based attention refers to the facilitation in visual processing when stimuli belong to the same object compared with when they belong to different objects. In a typical experiment (e.g., Egly, Driver & Rafal, 1994), participants see two objects (e.g., two rectangles), then an informative spatial cue at one end of an object, followed by a target at either the same location or a different location. When the cue and the target appear at different locations, the target appears either at the other end of the same object (the same object condition) or in a different object (the different object condition). Importantly, the spatial separation between the cue and the target is identical in the same and different object conditions. The typical result is that the participants are faster and/or more accurate in the same object condition than in the different object condition. This object effect is taken as evidence for object-based guidance of attention.

In general, object effects are found more reliably in studies that use a spatial cuing paradigm, in which the target is preceded by an informative spatial cue as described above, as compared to studies that use a feature comparison paradigm, in which two stimuli are presented simultaneously and the task is to compare whether they are the same or different. In a recent study, Chen and Cave (in press) conducted a series of experiments using a feature comparison task. They found no object effects when the orientation of the target configuration was controlled. Their study raised the question about object-based allocation of attention in feature-comparison tasks.

The present study examined the cost of shifting attention across a uniform vs a non-uniform region as a function of the orientation of the target configuration, and the degree to which the object effect reported in previous research can be explained by the cost

incurred when shifting attention across a non-uniform region. In three experiments, participants saw letter targets presented on one or two objects, and the targets were aligned either horizontally or vertically. The task was to determine whether the targets were the same or different. In Experiment 1, targets were presented simultaneously within an object, and the shape of the object was manipulated. The goal was to examine the processing efficiency of the targets that were separated by a uniform region or a non-uniform region when no shifts of attention were required. Responses were faster and more accurate when the targets were horizontally configured than vertically configured, indicating a horizontal benefit. No difference was found between the uniform and the non-uniform conditions. In Experiment 2, targets were presented sequentially within the same object, and they were either across a uniform or a non-uniform region. A horizontal benefit was again found. In addition, performance was impaired in the non-uniform condition compared with the uniform condition. In Experiment 3, the targets were again presented sequentially. In some trials, two objects were presented in the target display, and the targets were either within the same object with a non-uniform region between them, or between two different objects. Once again, a horizontal benefit was found. Importantly, no difference in performance was found between the same and different object conditions. Taken together, these results suggest that the object effects in previous spatial cuing studies may be caused by shifting or spreading of attention across a non-uniform region rather than object-based guidance of attention. The results also provide converging evidence to the findings of previous research, which show that the horizontal benefit is a robust phenomenon, and that shifting or spreading attention across a non-uniform region incurs an additional cost compared to shifting or spreading attention across a uniform region.

1. Introduction

1.1 Overview

The world that surrounds us contains a vast amount of information. The human visual system has limitations in terms of processing capacity, because of which we are unable to process everything we see at any given moment, and are selective about what we perceive (Palmer, 1999; Townsend, 1974). Mechanisms exist to control and influence how we attend to stimuli around us, so that we may operate efficiently (Beck, 1966, 1972; Palmer, 1999). Until the early 1980s, research on visual attention focused primarily on the spatial properties of attention (see Chen, 2012, for a review). Multiple space-based models of attention were proposed, the main ones being the spotlight model (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972; Posner, Snyner, & Davidson, 1980), the zoom-lens model (Erisken & St. James, 1986; LaBerge, 1983), and the gradients model (Downing & Pinker, 1985). These models differ in their explanations of the flexibility of attention selection; however, all of them emphasize that attention is spatial in nature, i.e., we attend to stimuli within a selected region (see Cave & Bichot, 1999; and Lamy & Tsal, 2001, for reviews). Beginning from the early 1980s, object-based attention started to gain prominence in visual attention research. Object-based attention refers to the guidance of attention that respects object boundaries, as evidenced by the finding that attending to one part of an object facilitates the processing of other parts of the same object (Duncan, 1984; Kahneman & Chajczyk, 1983; Kahneman & Henik, 1981). A fundamental argument for object-based attention is that in natural scenes around us, objects can, and often do, overlap in space, yet we do not have trouble attending to a specific object (Chen, 2012). This suggests that at the very least, the spatial component of attention cannot be the only mechanism underlying visual attention, and that a mechanism based on features and objects must exist, in addition to mechanisms for spatial selection.

1.2 Main Paradigms in Object-Based Attention

Object-based attention studies have been carried out in a variety of paradigms including spatial cuing paradigms and feature comparison paradigms. In spatial cuing paradigms, a central or a peripheral cue is presented before the presentation of a target display. The target then occurs either at the cued location or at an uncued location. When the cue and the target occur at different locations, they are either within the same object or between two different objects. Importantly, the spatial distance between the cue and the target are the same in the two condition. The task in experiments that use such paradigms is to detect or identify the target (e.g., Chen, 1998; Egly, Driver, & Rafal, 1994; Moore, Yantis, & Vaughan, 1998). In feature comparison paradigms, the target display is typically not preceded by a spatial cue, and the task in such experiments is to determine whether two target stimuli, which appear either in the same object or in different objects, are the same or different (e.g., Chen & Cave, in press; Harrison & Feldman, 2009; Lamy & Egeth, 2002; Watson & Kramer, 1999).

Duncan (1984) was one of the very first to explore object-based attention. The study was designed to measure the number of objects that could be selected simultaneously without a cost. Observers were presented with displays that consisted of a bar running through a box at an angle. The bar was either dotted or made up of dashes, and tilted to the left or to the right. The box varied in size (small or large) and had a gap along its contour that was positioned either on the right or the left. The task was to report one feature on one object (i.e., either the bar or the box), two features on the same object, or two features on two different objects. The results revealed that observers showed a decrease in accuracy when making a second judgment on a different object, as compared to making a second judgment on the same object. This same object benefit, or object effect, was taken as evidence to demonstrate the limits of attention to two objects simultaneously.

Duncan's (1984) results could not be explained using spatial-based attention because the objects were overlapped in space. Egly et al. (1994) introduced a spatial cuing paradigm that allowed the investigation of both space and object-based attention. In their study, observers were presented with displays consisting of two rectangles, placed parallel to each other. An informative spatial cue then appeared at one end of one of the rectangles. Following this, a target appeared (except on catch trials) at the cued location (valid condition) or at one of two uncued locations, which was either the other end of the cued rectangle (the invalid same condition) or the near end of the other rectangle (the invalid different condition). Observers made a speeded response to the target. The rectangles were positioned such that the uncued end of the cued rectangle was the same distance from the cue as the near end of the uncued rectangle. The results of this study revealed that observers were faster to respond to the target appearing at the cued location than at uncued locations – indicating spaced-based attention. However, observers were also faster to respond to displays where the target appeared at an uncued location within the same rectangle as the cue than when it appeared at the uncued location on the other rectangle. This finding was taken as evidence for object-based attention, since the distance between the invalid same object condition and the invalid different object condition was the same, thereby removing the role of space-based attention. Since the publication of Egly et al.

(1994), the two-rectangle paradigm has become the most frequently used paradigm in research on object-based attention.

1.3 Absence of Object Effects and the Same-Object Cost

In general, object-based effects are more reliably found in studies that use a spatial cuing paradigm (e.g., Chen 1998; Egly et al., 1994; Moore et al., 1998), as compared to studies that use a feature comparison paradigm (e.g., Chen & Cave, in press; Harrison & Feldman, 2009; Lamy & Egeth, 2002). Lamy and Egeth (2002) used a feature comparison paradigm to study the factors that influence the manifestation of object effects. Participants saw displays that consisted of two rectangles. On each trial, two targets appeared either in the same rectangle or in different rectangles while holding constant the spatial separation between the two conditions. The targets were small or large filled squares, and the task was to judge whether the targets were the same or different in size. In Experiment 1, the targets were presented simultaneously, and no difference in performance was found between the same and different object conditions. This result indicates that no object-based effect was present.

In Experiment 2, the authors changed the paradigm from a feature-comparison one to a spatial cuing one. Participants saw a cue followed by a target with a varying cue-to-target interval, and the task was to judge whether the target was small or large. As in Egly et al. (1994), the target could appear at the cued location (the valid condition), at a different location within the same rectangle (the invalid same condition), or at a different location at the near end of the other rectangle (the invalid different condition). The results replicated both the space-based and the object-based effects that Egly et al. obtained. Reaction time

(RT) was faster in the valid than invalid conditions. It was also faster in the invalid same condition than in the invalid different condition.

To determine that the difference in results between Experiments 1 and 2 were not caused by the difference in task (a size comparison task in Experiment 1 vs a size identification task in Experiment 2), Lamy and Egeth (2002) conducted Experiment 3. In this experiment, the authors modified the paradigm used in Experiment 1 with one change – the two targets appeared sequentially with a cue-target stimulus onset asynchrony (SOA) of 100 ms, 200 ms, or 300 ms, rather than simultaneously. This change would result in participants shifting attention from one target to the other on each trial. The results showed a significant object effect when the SOA was 100 ms and 200 ms. Based on their findings, the authors concluded that the key factor in the manifestation of object effects is the requirement of shifts of attention within a task.

While Lamy and Egeth (2002) found no same-object benefit when the targets were presented simultaneously, a number of other studies reported a same-object cost under certain experimental conditions (e.g., Al-Janabi and Greenberg, 2016; Chen & Cave, in press; Davis, Welch, Holmes, & Shepherd, 2001; Harrison & Feldman, 2009; Hein, Blaschke, & Rolke, 2017; Pilz, Roggeveen, Creighton, Bennett, & Sekuler, 2012). Davis, Welch, Holmes, and Shepherd (2001) noted that in most studies on object-based attention, variation in the number of objects was confounded with the size of the attended object(s). To investigate this, they used concave and convex shaped objects, and manipulated the size and the number of objects across different experimental conditions. The targets were the "notches" on the objects. The task was to report whether the notches, which could be triangular or rectangular, were the same or different. The stimuli comprised either one large object, two small objects with notches in the same object, or two small objects with notches in different objects. The displays were presented with the objects always in the same orientation such that in the two small object trials the targets were always horizontally configured when they were within the same object and vertically configured when they were in different objects. In the one large object trials, the targets, which were always within the same object, were either horizontally or vertically aligned. In the two small object trials, the targets were either within the same object (the two-small same object condition) or in different objects (the two-small different object condition). In the two small object trials, the usual object effect was found. The result most relevant here is the response latencies in the one large object trials compared with the trials in the two-small different object condition. The participants took longer to respond in the one large object condition than in the two-small different object condition, indicating a same-object cost. It is worth noting that while the targets were equally likely to be horizontally or vertically aligned in the one large object condition, they were always vertically aligned in the two-small different object condition.

A same-object cost was also found in Al-Janabi and Greenberg (2016, Experiment 1), who investigated the effect of target-object integration (whether the target was “on” an object or “part” of an object) and object orientation (whether the objects were horizontal or vertical) on object-based attention. The objects were surfboard shaped ovals, each having two small circles (one at each end). The target display consisted of two ovals orientated horizontally or vertically. In one session (the “on” section), two numbers appeared ‘on’ two of the circles. The numbers could be odd or even and participants’ task was to report whether or not the numbers were of same or different parities. In the other session (the “part” session), two of the circles extended towards the centre of the surfboard shaped object. These extensions could either be narrow or wide, and participants’ task was to report whether the two extensions were the same or different in width. In both sessions, the targets were either in the same object or in different objects. The results showed that object effects were influenced by target-object integration. Specifically, when targets were ‘part of’ objects, an object-based effect was found, but when targets appeared ‘on’ objects, no such effect was seen. This latter result was consistent with Lamy and Egeth (2002, Experiment 1), who also found no object effect when the targets were presented simultaneously on objects. More importantly, Al-Janabi and Greenberg also reported an object effect by object orientation interaction. A same-object benefit was found when the objects were horizontal but this changed to a same-object cost when the objects were vertical. Al-Janabi and Greenberg explained their results in terms of object-based attention being more easily distributed across the vertical meridian than across the horizontal meridian. Similar pattern of data (i.e., object effects influenced by object orientation) has also been observed in several other studies (e.g., Chen and Cave, in press; Harrison & Feldman, 2009; Hein et al., 2017; Pilz et al., 2012).

1.4 The Horizontal Benefit and Object-Based Attention

As noted above, Al-Janabi and Greenberg (2016) found a same-object benefit on horizontal object trials and a same-object cost on vertical object trials, and they attribute these results to the difference in processing efficiency when object-based attention is allocated across the horizontal vs. the vertical meridian. This explanation was built on the meridian effect (Corbett & Carrasco, 2011; Sereno & Kosslyn, 1991), the phenomenon that horizontally aligned stimuli are more easily processed than those that are vertically aligned.

Many studies have reported the ‘horizontal benefit’ (Barnas & Greenberg, 2016; Chen & Cave, in press; Harrison & Feldman, 2009; Sereno & Kosslyn, 1991) Harrison and Feldman (2009) investigated the effect of “objecthood” on object-based attention. They manipulated the emergence of objects by varying the size of a disk that blocked part of the objects. Participants compared two features that belonged either to the same emerging object or different emerging objects. In one experiment, the target features were either horizontally or vertically aligned. The result showed no effect of objecthood. However, RT was faster when the targets were aligned horizontally than vertically, and a same-object benefit was found when objects were horizontal but not when they were vertical.

Barnas and Greenberg (2016) examined the effect of meridian crossing. They used a single ’L’ shaped object that permitted both vertical and horizontal shifts of attention. The target was preceded by a cue, and the task was target detection. The results showed faster RT when the cue-target shift of attention was horizontal rather than vertical. This horizontal benefit is consistent with the notion that crossing the vertical meridian is more efficient than crossing the horizontal meridian.

Chen and Cave (in press) further investigated the degree to which the interaction between object effects and object orientation in feature comparison tasks reflects the horizontal benefit. They noticed that in previous research, the results were organized by object orientation. This means that the orientation of the object is confounded with the orientation of the target alignment. In the horizontal object condition, the targets are horizontally aligned in the same object condition but vertically aligned in the different object condition. This is reversed in the vertical object condition, with the targets being vertically aligned in the same object condition but horizontally aligned in this different object condition. If processing stimuli across the vertical meridian (i.e., the target stimuli are horizontally aligned) is more efficient than processing stimuli across the horizontal meridian (i.e., the target stimuli are vertically aligned) as shown in previous studies (Barnas & Greenberg, 2016; Harrison & Feldman, 2009; Sereno & Kosslyn, 1999), this can explain the same-object benefit in the horizontal object condition and the same-object cost in the vertical object condition. If that is true, the object effect by object orientation interaction may have very little to do with object-based attention.

Chen and Cave (in press) conducted a series of experiments, and their results confirmed their hypotheses. In some of these experiments (Experiments 1 and 2), participants saw two target letters that were either in the same rectangle or in different rectangles, and the targets were equally likely to be aligned horizontally or vertically. When the results were arranged by rectangle orientation, the results replicated the findings of the previous research, i.e., a same-object benefit in the horizontal rectangle trials and a same-object cost in the vertical rectangle trials. However, when the results were arranged by target alignment, there was a horizontal benefit but no object-based effects. When Chen and Cave increased the proportion of the same-object trials in subsequent experiments (Experiments 3 and 4), in addition to a horizontal benefit, object effects emerged in vertical target alignment trials. However, further experiments (Experiments 4 through 6) showed that these effects were not really object effects, because the same pattern of data was observed even when the rectangles were replaced by a large, oriented bar. These experiments raised doubts on object-based guidance of attention in feature-comparison tasks. They raise the possibility that previously reported object effects in horizontal object trials may have little to do with object-based attention, but are caused by the horizontal benefit.

2. Experiments

2.1 Overview of the Present Experiments

Although object-based attention has not been reliably observed in feature comparison tasks, it is a robust finding in spatial cuing paradigm. The key difference between these two types of studies is the allocation of spatial attention prior to target onset. In feature comparison tasks, the targets are presented simultaneously. As the targets are equally likely to appear at all the locations, participants are likely to distribute attention broadly across both objects, and this is likely to reduce or eliminate object-based distribution of attention (Chen & Cave, in press). In contrast, in most spatial cuing experiments, the onset of the target is preceded by an informative cue that indicates the location of the target in most trials. This can facilitate attentional selection to the cued object, resulting in object-based distribution of attention.

So far, not many studies have investigated the degree to which the horizontal target benefit contributes to the object effect in spatial cuing experiments, and none have examined the joint effect of horizontal target benefit and shift of attention across non-uniform regions. The experiments reported in this thesis examined two questions: the cost of shifting attention across a uniform vs a non-uniform region as a function of target configuration, and the degree to which the object effect can be explained by the cost in shifting attention across a non-uniform region. In three experiments, participants saw letter targets presented on one or two objects modelled after those used by Davis and colleagues (Davis, Driver, Pavani, & Shepherd, 2000; Davis et al., 2001). The task was to determine whether the letter targets were the same or different. The targets were presented simultaneously in Experiment 1 but sequentially in Experiments 2 and 3. In all the experiments, the orientation of the target configuration was equally horizontal or vertical. In Experiment 1, the shape of the object (with concavity or convexity) was manipulated, and the targets always appeared within a single object. The goal was to examine the processing efficiency of the targets that were separated by a uniform region or a non-uniform region when no shifts of attention were required. Experiment 2 investigated the cost of shifting attention across a uniform vs a non-uniform region as a function of target configuration. The targets were displayed sequentially, and the region between the targets was either uniform or non-uniform. In Experiment 3, the targets, which were again presented sequentially, were equally likely to appear within the same object or between different objects. This last experiment was designed to test the hypothesis that the object effect in the spatial cuing paradigm could be explained to a large extent by the cost of attentional shift across a non-uniform region.

2.2 Experiment 1

Experiment 1 was designed to replicate the horizontal benefit that has been seen in the literature, with our stimuli. In addition to this, it was also to investigate the effects of object shape and type of region between the targets (uniform vs non-uniform) when a task does not require shifts of attention.

Previous literature has demonstrated the existence of a horizontal benefit when comparing target features across meridians, such that targets that are horizontally aligned to each other across the vertical meridian are compared faster than targets that are vertically aligned across the horizontal meridian (e.g., Harrison & Feldman, 2009; Chen & Cave, in press). In Experiment 1, participants saw two targets presented simultaneously within a single object, and the configuration of the target orientation was either horizontal or vertical. Based on previous research, it was hypothesized that the participants would show a horizontal benefit. The shape of the object (with concavity or convexity; see Figure 1) was also manipulated. Thus, in some trials the region between the targets was uniform, and in the other trials it was non-uniform. Because the targets were presented simultaneously and no shift of attention was needed, it was hypothesized that neither object shape nor the type of region between the targets would affect performance.

Method

Participants. Twenty-four participants at the University of Canterbury participated in the study for course credit. The mean age of participants was 21.54 years. The standard deviation was 8.64 years. Out of the 24 participants, 23 were female. All participants had normal, or corrected-to-normal-vision. The study was approved by the University of Canterbury Human Ethics Committee.

Stimuli and Apparatus. Participants were presented with a fixation cross measuring 0.29° in height and width in the centre of the screen at the beginning of every trial, following which an object was presented. The object was either a black convex or concave shape (see Figures 1a to 1d). It was made by using a square with a side measuring 11.42°, with either convex bulges on two sides being added, or concave sections cut out from two sides. For the convex object, the bulges stretched out 4.29° and began and ended 2.86° from the corners of the sides on which they stretched out. For the concave object, the process was reversed, and this resulted in the end of the concave section being 5.72° from the corners of the square. The targets were dark grey letters (Ts, Ls, or one T and one L).

Both target letters were 0.96° in height and width. They could be in two of four locations. If the first target was in position 1 (see the numbers on Figures 1a to 1d), the second would be in position 2 or 4; if the first was in position 2, the second would be in position 1 or 3; if the first was in position 3, the second would be in position 2 or 4, and so on. In other words, the configuration of the targets was such that they were either horizontally or vertically aligned to each other. Importantly, the distance between any two target letters was always 7.63°.

The monitors used had a screen resolution of 1680 x 1050 with a refresh rate of 60 Hz. E-prime 2.0 (Psychology Software Tools, Pittsburgh, PA) was used to present the stimuli and record responses. Participants were tested individually in two dimly lit rooms. They sat at a viewing distance of approximately 60 cm from the monitor.

Design. The experiment used a 2 x 2 within-subjects design. The principal manipulations were the shape of the object (convex vs concave) and the orientation of the target configuration (horizontal vs vertical). In half the trials, the object was convex and in the other half, it was concave. In both types, the orientation of the object was equally likely to be horizontal or vertical. The targets were presented simultaneously, and they were equally likely to be configured horizontally or vertically.

There were 4 blocks of trials, each consisting of 160 trials, for a total of 640 trials. Before the first block of experimental trials, participants were given 2 blocks of 12 practice trials. If necessary, they were required to complete 2 more blocks of practice trials.

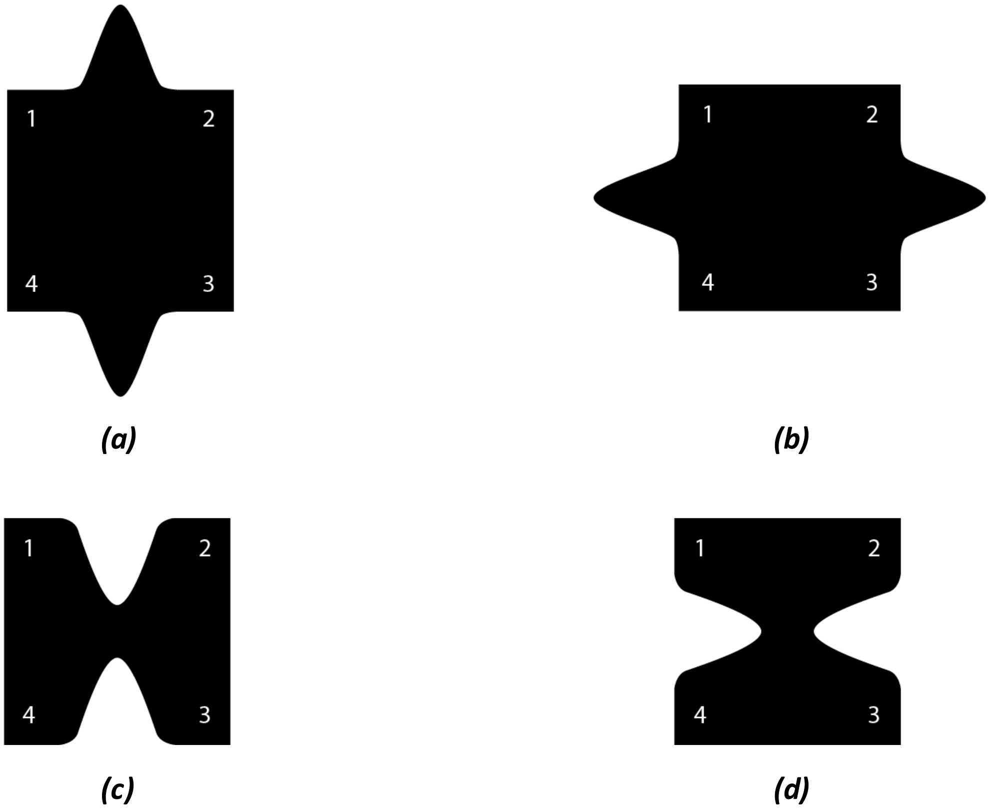


Figure 1. Stimuli used in Experiment 1. (a) Convex object orientated horizontally; (b) Convex object orientated vertically; (c) Concave object orientated horizontally; and (d) concave object orientated vertically. The numbers 1 to 4 indicate the possible positions where targets can appear. The targets appear one position apart, i.e., if one target is to appear at position 1, the other will appear at position 2 or position 4, and so on.

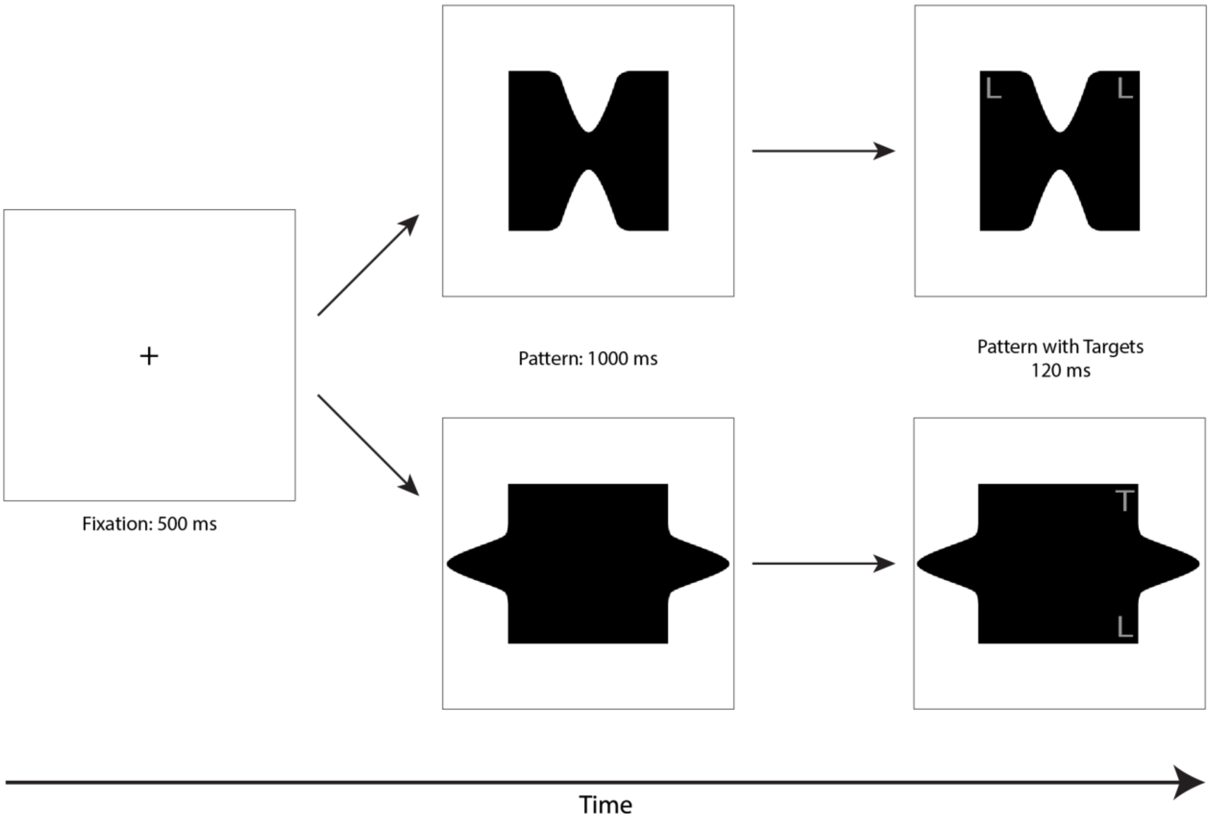


Figure. 2. Examples of the trial sequence in Experiment 1, with the concave object orientated horizontally and the convex object orientated vertically. On each trial, after the fixation cross, a blank screen (not shown above) was displayed for 500 ms, after which either a concave or a convex object was shown for 1000 ms. This was followed by a 120 ms display of two target letters that were horizontally or vertically aligned. A blank screen was then displayed until participants responded. In the sequence on the top, the region between the targets was non-uniform, whereas in the sequence on the bottom, the region between the targets was uniform. The contrast between the targets and the background was much less in the experiment than shown here.

Procedure. Before starting the experiment, each participant was instructed to maintain fixation on the black fixation cross displayed at the centre of the monitor at the beginning of each trial. The fixation cross was displayed for 500 ms, and it was followed by a blank screen for 500 ms., which was then followed by the presentation of a convex or concave object for 1000 ms. Finally, the targets were added to the object, and they were shown together for 120 ms. This was then followed by a blank screen until a response was given by the participant.

The task was to judge whether the target letters were the same or different. Participants pressed the 4 or 5 key on the number pad to make the “same” or “different” response, with 4 being labelled “same”, and 5 being labelled “different”. They were instructed to respond as quickly and as accurately as possible.

Results and Discussion

Response latencies were measured from the onset of the target stimuli. RTs for each participant that were more than 2 standard deviations on either side of the mean were discarded. This led to 3.3% of data being discarded. Analyses were based on the remaining trials with correct responses. The RT results are shown in Figures 3 and 4, and the error rates are shown in Tables 1 and 2. In all the figures below, the error bars represent the within-subjects standard error of the mean (Cousineau, 2005).

Two separate sets of analyses were conducted, with the 1st one analysing the effects of object shape and target configuration, and the 2nd one analysing the effects of region (uniform or non-uniform region) and target configuration. The first set of analyses was performed on trials with convex and concave trials as this allowed us to investigate the effect of object shape. The second analyses was performed on trials with only concave objects as the region between targets was uniform in all trials with convex objects. A 2 x 2 repeated-measures analysis of variance (ANOVA) with object type and target configuration as the two factors were performed on RTs. There was a main effect of target configuration, F (1, 23) = 30.92, p < .001, MSe = 215, η_p^2 = 0.57. Participants were faster when the target configuration was horizontal (631 ms) rather than vertical (647 ms), indicating a horizontal benefit. No effect on object shape was found, F (1, 23) < 1, *ns*. No significant interaction was found between object shape and target configuration, either, F (1, 23) < 1, *ns.*

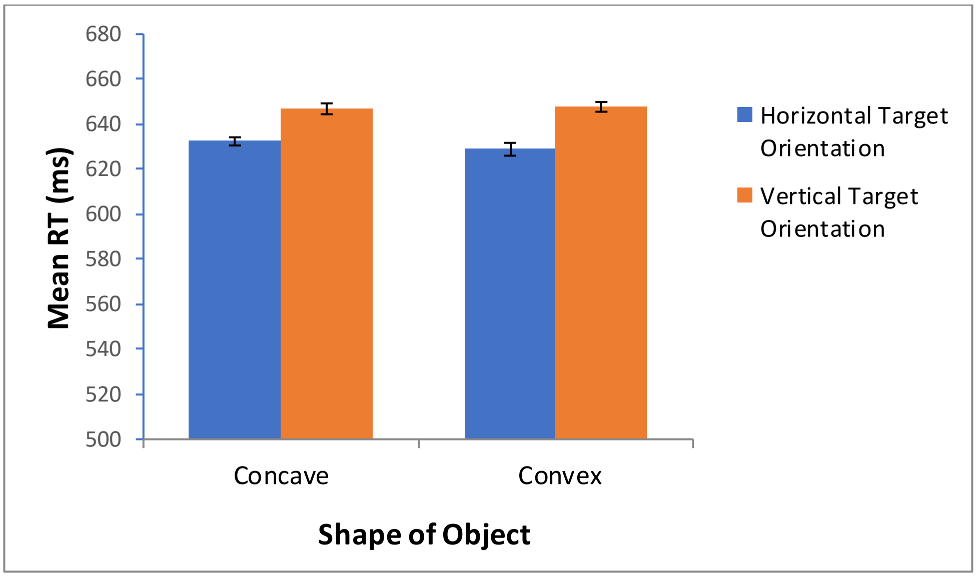


Figure. 3. Mean RT results from Experiment 1.

Table 1

Mean error rates (percent incorrect) as a function of object shape and target configuration in Experiment 1. Within-subject standard errors are in the parentheses.

Object Shape	**Concave**		**Convex**	
Target Configuration	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
	5.0 (0.4)	6.3 (0.3)	4.8 (0.3)	6.7 (0.4)

A 2 x 2 repeated-measures ANOVA on error rates showed a significant effect of target configuration, F (1, 23) = 12.10, p = .002, MSe = 5.1, η_p^2 = 0.35. No other effects reached significance. This was consistent with the RT results showing a horizontal benefit (4.9% error rate for trials with targets orientated horizontally versus 6.5% error rate for trials orientated vertically).

The next set of analyses was focussed on the effects of region (uniform vs non-uniform region) and target configuration (horizontal vs vertical). As the region between the targets was uniform in all the trials with convex objects, the analyses below were conducted on trials with concave objects only. A 2 x 2 repeated measures ANOVA was conducted on the mean RTs, with the factors being target configuration and type of region. The mean RT results are shown in Figure 4, and the error rates are shown in Table 2. There was a main effect of target configuration, F (1, 23) = 15.47, p < .001, MSe = 234, η_p^2 = 0.40, indicating that RT was faster when targets were orientated horizontally (633 ms) than vertically (645 ms). There was no significant effect of region, F (1, 23) < 1, *ns*, or its interaction with target configuration, either, F (1, 23) < 1, *ns.*

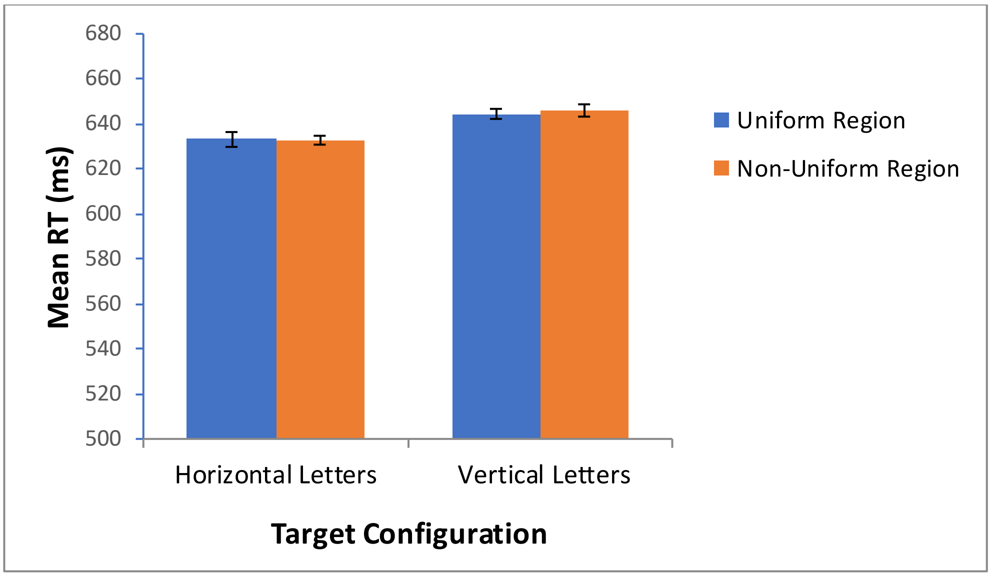


Figure. 4. Mean RT results of concave object trials from Experiment 1.

Table 2

Mean error rates (percent incorrect) as a function of target configuration and type of region between the targets in the concave object trials in Experiment 1. Within-subject standard errors are in the parentheses.

Target Configuration	**Horizontal**		**Vertical**	
Region	**Uniform**	**Non-Uniform**	**Uniform**	**Non-Uniform**
	4.8 (0.6)	5.2 (0.3)	5.7 (0.5)	6.7 (0.6)

A 2 x 2 ANOVA was also conducted on error rates, with no significant effects found for target configuration, $F = 3.02$, $p = 0.1$, or type of region, $F = 1.21$, $p = 0.3$. No interaction was present, either.

Experiment 1 tested two hypotheses. First, a horizontal target benefit would be found in the present experiment paradigm. Second, because the targets were presented simultaneously, there would be no difference in performance regardless of whether the region between the targets was uniform or non-uniform. Both hypotheses were confirmed.

Consistent with previous research (Barnas & Greenberg, 2016; Chen & Cave, in press; Corbett & Carrasco, 2011; Harrison & Feldman, 2009; Hein et al., 2017), a robust horizontal benefit was observed in both response latencies and accuracy. Participants were faster and more accurate when the targets were configured horizontally than vertically. Furthermore, this effect did not interact with object shape or the type of region between the targets. This finding provided converging evidence to Chen and Cave, who also reported a strong horizontal target benefit that did not interact with other factors.

The second main finding of the experiment was that performance did not differ regardless of whether the region between the targets was uniform or non-uniform. The result was not surprising, given that the targets were presented simultaneously. With simultaneous presentation, a good strategy to use was to distribute attention broadly so that all possible target locations were attended before the onset of the targets. In this way, no matter where targets appeared, there was no need to shift attention. As a result, whether the region between the targets was uniform or non-uniform did not influence the speed or accuracy of processing the targets. The finding of no difference between the concave and the convex object provided further support to the above statement.

2.3 Experiment 2

Experiment 2 investigated the cost in shifting attention across a uniform region compared with a non-uniform version. The targets were presented sequentially so that participants' attention would be drawn to the target shown first. When the 2nd target appeared, attention would need to shift or spread from the location of the 1st target to the location of the 2nd target. It was hypothesized that shifting or spreading of attention across a non-uniform region would have an additional cost compared with a uniform region. The SOA between the targets were also manipulated to determine the time required for the manifestation of the additional cost.

Method

Participants. Twenty-four new participants at the University of Canterbury participated in the study for course credit. The mean age of participants was 20.75 years. The standard deviation was 3.54 years. Twenty-one of the 24 participants were female. All participants had normal, or corrected-to-normal-vision.

Stimuli and Apparatus. The stimuli and apparatus were the same as those in Experiment 1 except that only the concave stimuli were used (Figs. 2c & 2d).

Design. The experiment used a 2 x 2 x 2 within-subjects design. The principal manipulations were the SOA between the targets (100 ms vs 200 ms), the target configuration (horizontal vs vertical) and the type of region between the targets (uniform vs non-uniform). These factors were all independently manipulated, with equal number of trials in each experimental condition. In half the trials, the concave shaped object was horizontally. As in Experiment 1, there were 640 trials divided into 4 blocks. There was a break after every block. Participants again completed 24 practice trials before starting the experiment.

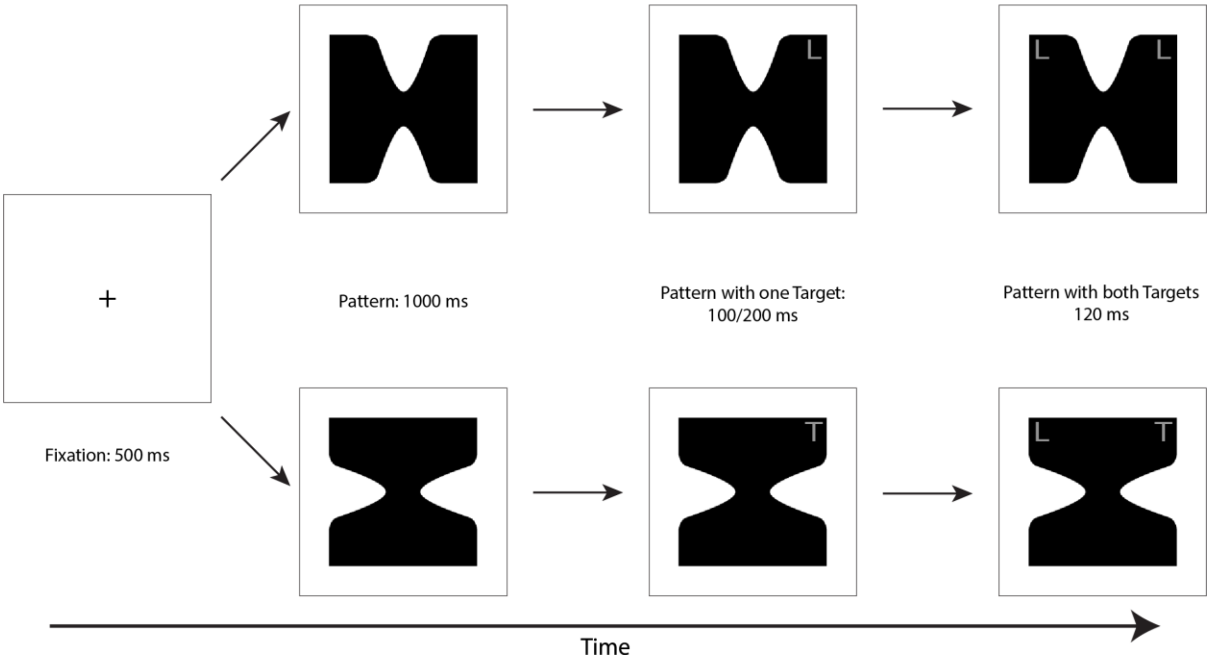


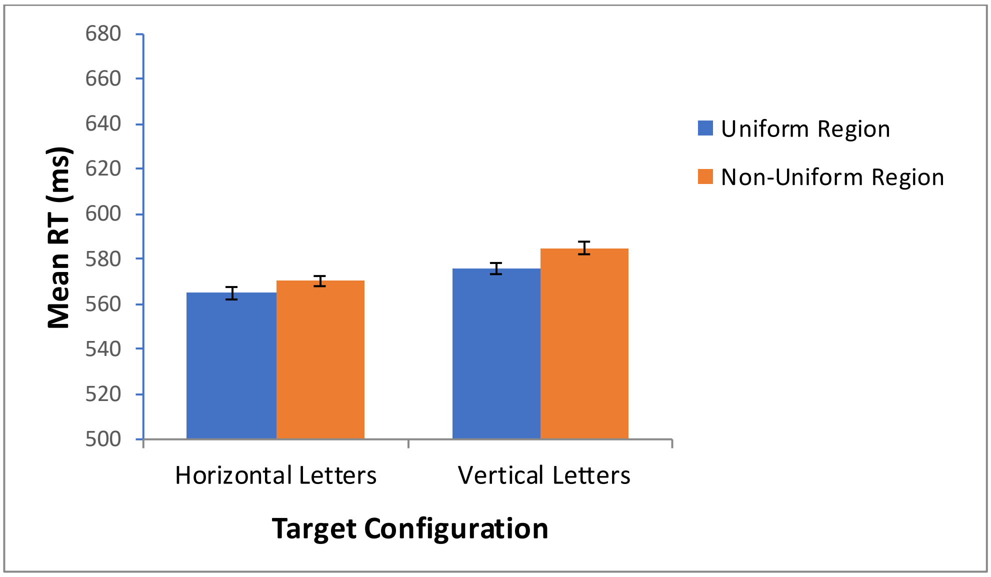
Figure. 5. Examples of trial sequences in Experiment 2, with the background object orientated horizontally (top) and vertically (bottom). On each trial, after the fixation cross, a blank screen was displayed for 500 ms, after which participants were presented with a concave object orientated horizontally or vertically, followed by a target letter. This was followed by a second target letter that was horizontally or vertically aligned to the first. On half the trials, the second target letter was presented 100 ms after the first, whereas on the other trials this difference was 200 ms. Following the presentation of the targets, a blank screen was displayed until participants responded. In the sequence on the top, the region between the targets was non-uniform, whereas in the sequence on the bottom, the region between the targets was uniform.

Procedure. The instructions given to participants were the same as in Experiment 1. The procedure was the same except the following change. After the display of the object for 1000 ms, only the first target was displayed, for 100 ms or 200 ms, followed by the second target, shown together for 120 ms.

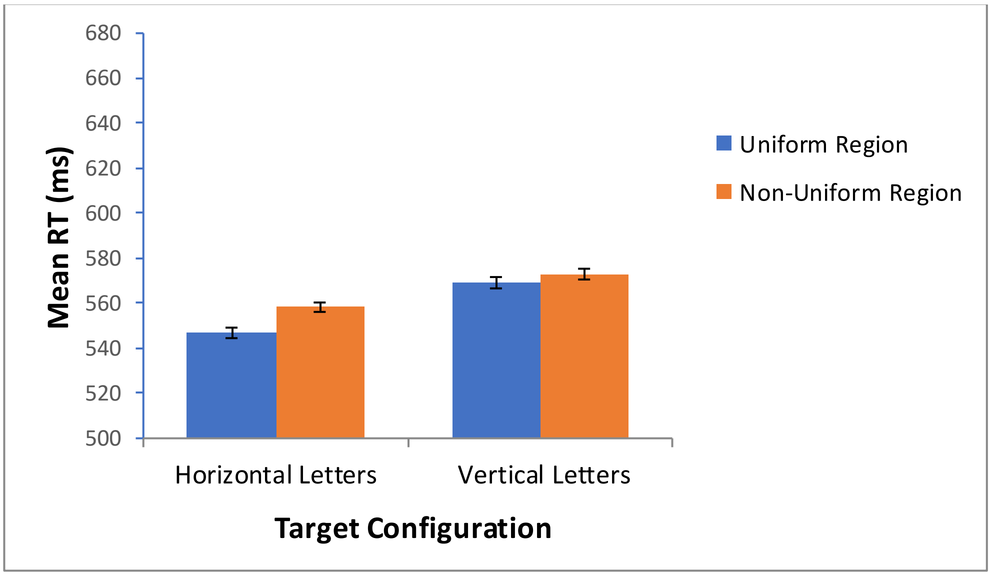
Results and Discussion

All RTs were measured from the presentation of the second target stimuli. RTs for each participant that were more than 2 standard deviations on either side of the mean were discarded. This resulted in 3.00% of data being excluded. The mean RT results are shown in Figures 6A and 6B, and the error rates are shown in Table 3. A 2 x 2 x 2 repeated measures ANOVA was conducted on the RTs with the factors being SOA, target configuration, and the type of region between the targets. A main effect of SOA was found, F (1, 23) = 30.01, p < .001, MSe = 239, η_p^2 = 0.57, indicating that the participants' RTs were slower in the 100 ms SOA condition (574 ms) than in the 200 ms SOA condition (562 ms). There was also a main effect of target configuration, F (1, 23) = 36.13, p < .001, MSe = 326, η_p^2 = 0.61. Participants were quicker when the target configuration was horizontal (560 ms) rather than vertical (576 ms). In addition, a main effect was found for type of region, F (1, 23) = 17.111, p < .001, MSe = 156, η_p^2 = 0.43, indicating that shifts of attention across a uniform region took less time than shifts of attention across a non-uniform regions (564 ms versus 572 ms in the uniform and non-uniform condition, respectively). No other effects reached significance. No interactions were present.

(A)



(B)



Figures 6A and 6B. Mean RT results from Experiment 2. (A) The SOA 100 ms condition. (B) The SOA 200 ms condition.

Table 3

Mean error rates (percent incorrect) as a function of stimulus onset asynchrony (SOA) between the targets, target configuration and type of region between the targets in Experiment 2. Within-subject standard errors are in the parentheses.

Target Configuration	**Horizontal**		**Vertical**	
Region	**Uniform**	**Non-Uniform**	**Uniform**	**Non-Uniform**
SOA 100 ms	4.0 (0.5)	4.7 (0.4)	5.6 (0.4)	5.3 (0.4)
SOA 200 ms	3.7 (0.4)	5.0 (0.4)	4.9 (0.6)	5.1 (0.4)

A 2 x 2 x 2 ANOVA on error rates were also performed. The results showed a significant effect of target configuration, F (1, 23) = 4.81, p = .04, MSe = 7.1, η_p^2 = 0.17, indicating lower error rate when the targets were configured horizontally (4.35%) than vertically (5.22%). No other effects reached significance. No interactions were present.

Experiment 2 had 3 main findings. First, RT was slower when the SOA was 100 ms than 200 ms. This effect was expected, as participants had less time to process the first target before the appearance of the second target when the SOA was shorter. Second, a horizontal benefit was found in both RT and accuracy. Participants responded faster and more accurately when the targets were horizontally configured compared with vertically configured. This result was consistent with the finding of Experiment 1, and it shows that the horizontal benefit is a robust phenomenon. Third, there was also a main effect for the type of region. Participants' responses were faster in the uniform condition than in the non-uniform condition even though the targets were in the same object in both conditions. This result is important, because it shows that shifting or spreading attention across a non-uniform region incurs an additional cost compared to shifting/spreading attention across a uniform region. As attention has to shift or spread across a non-uniform region in a typical different-object condition in the cuing paradigm (e.g., Egly et al., 1994), the additional cost observed in the non-uniform condition in Experiment 2 could potentially explain the object effects found spatial cuing experiments.

2.4 Experiment 3

Experiment 3 investigates whether the object effect in spatial cuing studies can be explained by the larger cost in shifting/spreading attention across a non-uniform region than a uniform region. Two types of object were used in the experimental trials, 1Large object that consisted of a large concave object the same as that used in Experiment 2, and 2Small object that consisted of two small horizontal or vertical concave objects (see Figure 7). Importantly, for the 2Small object trials, the targets were either in two different objects (e.g., the targets were in positions 1 and 4 in the left object in Figure 7b or in positions 1 and 2 in the right object in Figure 7b; and this condition will be referred to as the 2Small different condition), or in the same object with a non-uniform region between the targets (e.g., the targets were in positions 1 and 2 in the left object in Figure 7a or in positions 1 and 4 in the right object in Figure 7b; and this condition will be referred to as the 2Small same condition). If performance in RT and/or accuracy did not differ between the 2Small different condition and the 2Small same condition, this would indicate that the object effect in previous spatial cuing studies can be explained, at least to a large extent, by the larger cost in shifting/spreading attention across a non-uniform region than a uniform region. If performance is better in the 2Small same condition than the 2Small different condition, this could support theories of object-based attention, which stresses the facilitation of attentional allocation within an object over across an object.

Method

Participants. Twenty-four new participants at the University of Canterbury participated in the study for course credit. The mean age of participants was 19.96 years. The standard deviation was 3.56 years. Eighteen of the participants were female. All participants had normal, or corrected-to-normal-vision.

Stimuli and Apparatus. In Experiment 3, there were two types of experimental trials in addition to filler trials. In half of the experimental trials, the stimuli were identical to those used in Experiment 2. These trials will be referred to as the 1Large object trials (see Figure 7a). In the other half of the experiment trials, the stimulus pattern consisted of two concave shaped object (Figure. 7b). These trials will be referred to as the 2Small object trials. The overall area of the two objects and the gap between them together was the same as the 1Large object. The gap between the objects measured 0.76°. The targets, which were at the same locations as those in the 1Large object trials, were equally likely to be in the same object or in two different object. The spatial separation between the targets was the same in both conditions.

In the filler trials, the stimulus pattern consisted of a single small concave shaped object. It was identical to one of the objects (equally likely to be the left one, the right one, the upper one, or the lower one) in the 2Small object trials. When the filler stimulus was presented, its location on the screen was also identical to its corresponding location in the

2Small object trials. The purpose of the filler trials was to induce the objects in the 2Small object condition to be perceived as two separate objects rather than one object with a white stripe running through it. Targets appeared in two locations on the filler trials (Fig. 7c). All the other aspects of stimuli and apparatus were the same as those in the two previous experiments.

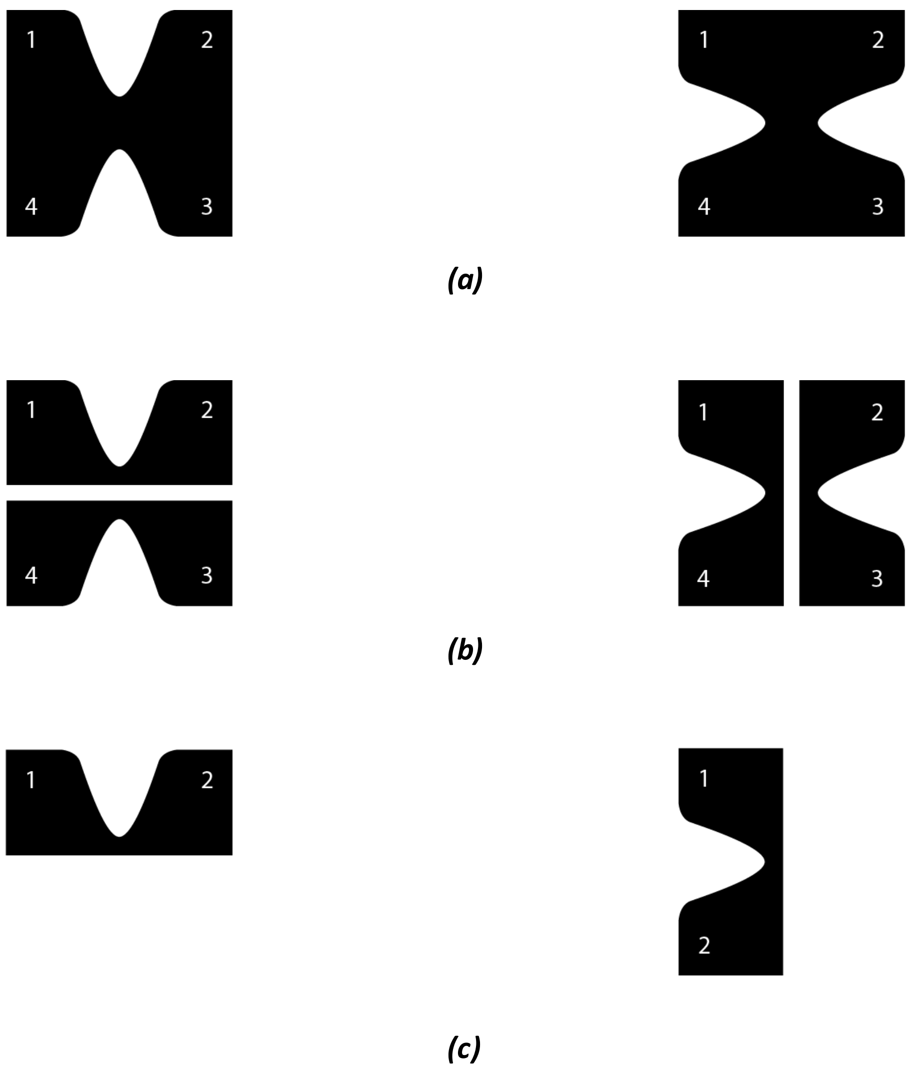


Figure 7: Stimuli used in Experiment 3. (a) 1 large concave objected orientated horizontally and vertically, (b) 2 small concave objects orientated horizontally and vertically, and (c) 1 small concave object used in filler trials in different orientations.

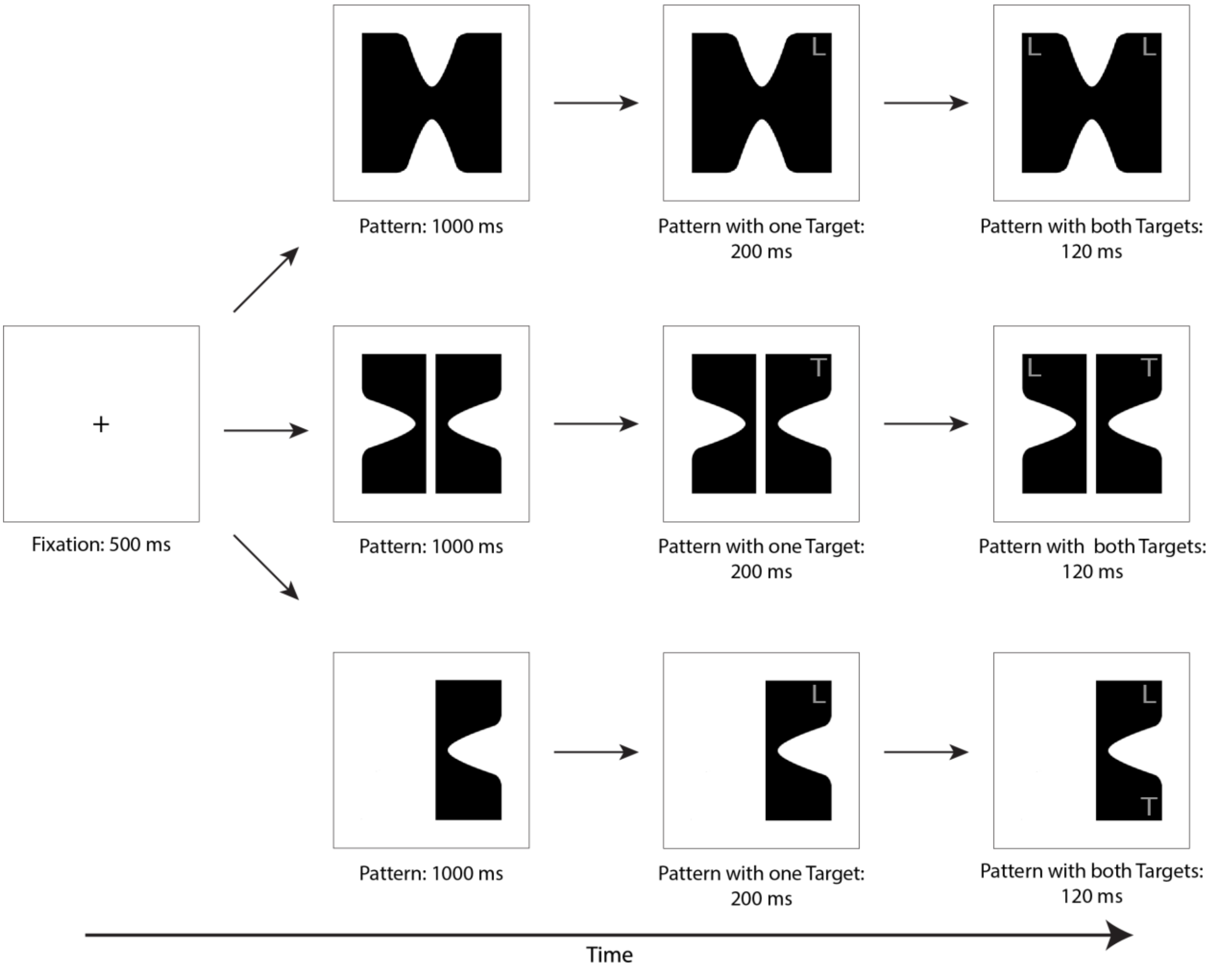


Figure 8. Examples of trial sequences in Experiment 3. The sequence on the top shows 1 large object (the 1Large condition) orientated horizontally with horizontal target configuration and non-uniform region between the targets. The sequence in the middle shows 2 small objects (the 2Small condition) orientated vertically with the targets configured horizontally and in two different objects. The sequence at the bottom shows a filler trial. On each trial, after the fixation cross, a blank screen was displayed for 500 ms, after which the object was displayed, followed by the presentation of a target letter. This was then followed by a second target letter. Upon the offset of the targets, a blank screen was displayed until participants responded.

Design and Procedure. The experiment used a 2 x 2 x 2 within-subjects design. The first two variables refer to the type of object (1Large vs 2Small), and the target configuration (horizontal vs vertical). The 3rd variable refers to the type of region between the targets (uniform vs non-uniform) for 1Large object trials, but the number of object(s) on which the targets were present for 2Small object trials (the same object vs two different objects). It is important to note that in the 2Small same condition, the region between the targets was always non-uniform.

There were 4 blocks of trials, each containing 160 trials, for a total of 640 trials. There was a break between every block of trials. 40% (256) of trials consisted of 1 large object, while 40% (256) of trials consisted of 2 small objects, with the remaining 20% (128) being filler trials. As before, there were as many horizontal target configuration as vertical target configuration trials. Half of all objects in the 1Large object condition were orientated horizontally (128), while the other half were orientated vertically (128). This was true for the 2Small object condition as well. In all the trials, the SOA between the two targets was 200 ms. All the other aspects of the design and the procedure were the same as those in Experiment 2.

Results and Discussion

All RTs were measured from presentation of the second target stimuli. One participant’s data were excluded from analyses due to high error rates (over 30% in one condition). RTs for each participant that were more than 2 standard deviations on either side of the mean were discarded, which led to 2.80% of data being discarded. The filler trials were not included in any of the analyses. For the results in the 1Large condition, Figure 9 and Table 4 show the RT and error rates, respectively. For the results in the 2Small condition, Figure 10 and Table 5 show the RT and error rates respectively.

Two sets of analyses were performed, one on the data in the 1Large object condition, and the other on the data in the 2Small object condition.[1] For the data in the 1Large object condition, a 2 x 2 repeated measures ANOVA with target configuration (horizontal, vertical), and the type of region between the targets (uniform vs non-uniform) was conducted. A main effect was found for target configuration, $F\ (1, 22) = 10.80$, $p < .01$, $MSe = 268$, $\eta_p^2 = 0.33$. Participants' RTs were quicker when the target configuration was horizontal (562 ms) rather than vertical (573 ms). Type of region also had a main effect, $F\ (1, 22) = 10.93$, $p < .01$, $MSe = 340$, $\eta_p^2 = 0.33$, with faster responses in the uniform condition (561 ms) than in the non-uniform condition (574 ms). No interactions were present.

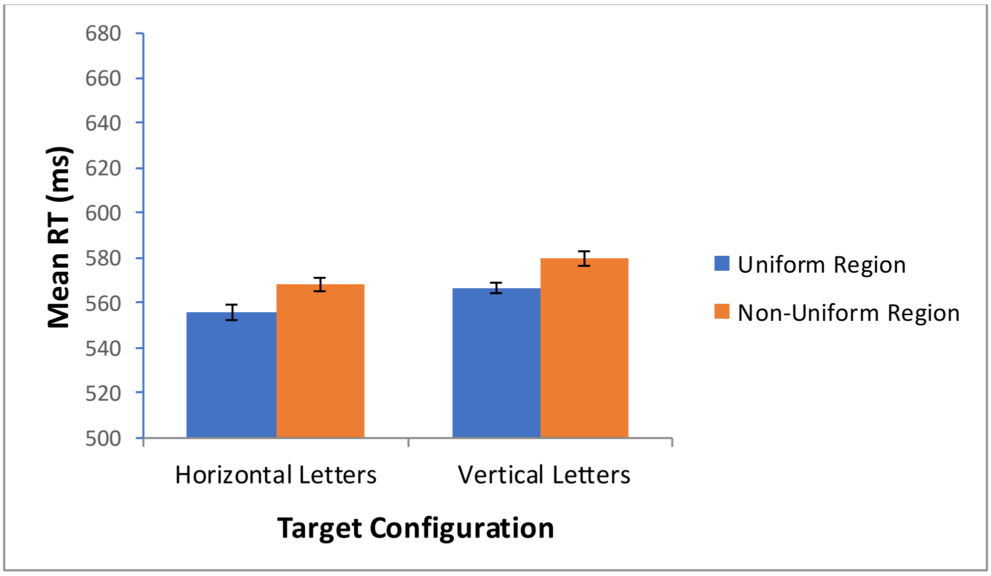


Figure. 9: Mean RT results from the 1Lage object condition in Experiment 3.

Table 4

Mean error rates (percent incorrect) as a function of target configuration and type of region between the targets in the 1Large object condition in Experiment 3. Within-subject standard errors are in the parentheses.

Target Configuration	**Horizontal**		**Vertical**	
Region	**Uniform**	**Non-Uniform**	**Uniform**	**Non-Uniform**
	4.6 (0.6)	6.6 (0.6)	7.4 (0.6)	7.2 (0.6)

A 2 x 2 ANOVA on the error rates showed a significant effect of target configuration, F (1, 22) = 4.77, $p < 0.1$, MSe = 13, $\eta_p^2 = 0.18$. No other effects reached significance, and no interactions were present.

For the data in the 2Small object condition, a 2 x 2 repeated measures ANOVA, with the two factors being target configuration and the number of objects in which the targets were presented, was conducted on the RT data. The results showed a main effect for target configuration, F (1, 22) = 13.63, $p < .01$, MSe = 224, $\eta_p^2 = 0.38$, indicating faster RTs when the target configuration was horizontal (559 ms) rather than vertical (571 ms). Importantly, there was no main effect for the number of objects, F (1, 22) = 1.29, $p > 0.1$, MSe = 332, $\eta_p^2 = 0.05$. This results indicated that RTs did not differ between the 2Small same condition and the 2Small different condition. No interactions were found.

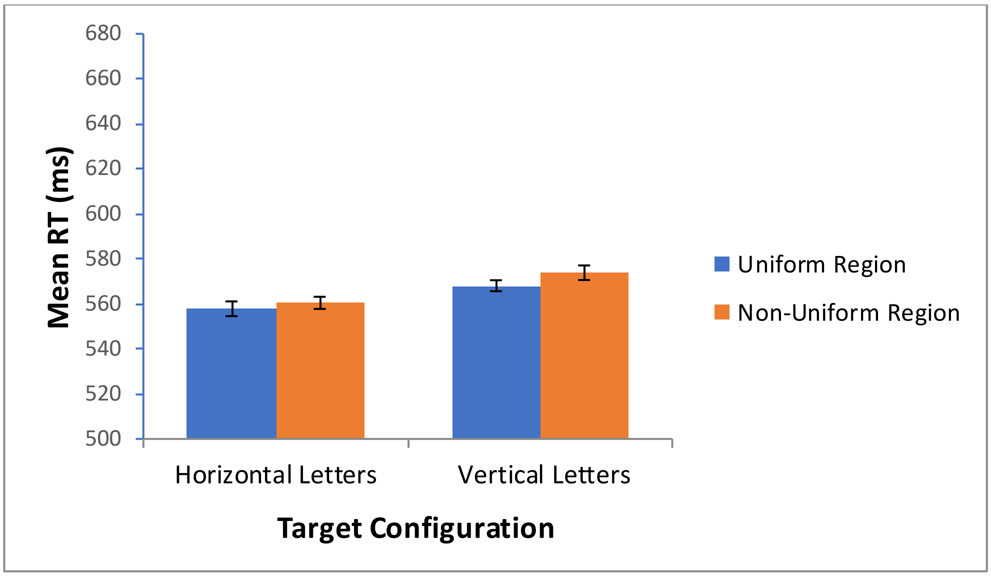


Figure. 10. Mean RT results from the 2Small object condition in Experiment 3.

Table 5

Mean error rates (percent incorrect) as a function of target configuration and the number of objects on which the targets were presented in the 2Small object condition in Experiment 3. Within-subject standard errors are in the parentheses.

Target Configuration	**Horizontal**		**Vertical**	
Object	**Same**	**Different**	**Same**	**Different**
	6.3 (0.4)	5.9 (0.5)	7.9 (0.5)	7.9 (0.6)

A similar 2 x 2 ANOVA was conducted on the error rates. The results showed a significant effect of target configuration F (1, 22) = 11.64, p < .01, MSe = 6.1, η_p^2 = 0.35. Once again, no significant effect was found for the number of objects or its interaction with target configuration.

Experiment 3 was a critical experiment. In the 2Small object trials, performance in the same object condition with a non-uniform region between the targets (i.e., the 2Small same condition) was compared directly with the performance in the different object condition (i.e., the 2Small different condition), and no difference was found. This pattern of data is consistent with the idea that the object effect in spatial cuing studies can be explained, at least to a large extent, by the additional cost in shifting or spreading attention from one location to another.

The results in the 1Large object trials replicated those found in Experiment 2. Once again, RT was faster in the uniform condition than in the non-uniform condition. A reliable horizontal benefit was also found, both in the 1Large and 2Small object conditions. These results provided converging evidence to the horizontal benefit found in previous research.

3. General Discussion

The primary goals of this study were to investigate the cost of shifting attention across a uniform vs a non-uniform region as a function of target configuration, and the degree to which the object effect can be explained by the cost in shifting attention across a non-uniform region. There are three main findings. First, participants consistently performed better on stimulus comparison tasks when the stimuli were aligned horizontally rather than vertically, and this horizontal benefit did not interact with the type of region (uniform or non-uniform) between the targets or with the requirement of attention (required or not required by the task). This result provides additional evidence to the robustness of the horizontal benefit reported in previous research (Barnas & Greenberg, 2016, Chen & Cave, in press; Harrison & Feldman, 2009). Second, performance was impaired when the region between the targets was not uniform, but this only occurred when shifting of attention was required to perform the task (i.e., in Experiments 2 and 3, but not in Experiment 1). This result indicates that shifting or spreading attention across a non-uniform region incurs an additional cost. Third, when shifts or spreading of attention was required, the time needed to respond to two targets in different objects (the 2Small different condition) was about the same as the time required to respond to the targets in the same object when the region between the targets was non-uniform (the 2Small same condition). This result suggests that the object effects in previous spatial cuing studies may be caused by shifting or spreading of attention across a non-uniform region rather than object-based guidance of attention.

3.1 Horizontal Benefit

Across the three experiments, participants responded more quickly when the targets to be compared were aligned horizontally than vertically. Experiment 1 demonstrated that this horizontal benefit was seen irrespective of the shape of the background object on which targets were displayed. Experiment 2 demonstrated the robustness of this effect – even when participants had more time to process the first target before the appearance of the second target, the effect was present, and this effect was found regardless of whether the region between the targets was uniform or not. The results of Experiment 3 replicated the finding of Experiment 2. In addition, a horizontal benefit was found regardless of whether the targets were within an object or across two objects. Furthermore, no interactions involving the horizontal benefit were found in any of the three experiments. These results indicate the prevalence of the horizontal benefit, whose magnitude is not influenced by the requirement of the attentional shift or the number of objects involved in the shift.

The horizontal benefit seen in the present study may arise from the separation between the different cortical visual areas (Sereno and Kosslyn, 1991). When targets are horizontally aligned, they are on either side of the vertical midline, and thus represented in separate regions in the early stages of cortical processing (Chen & Cave, in press). Sereno and Kosslyn (1991) conducted two experiments in which participants made faster comparisons when stimuli were presented in different hemifields (opposite sides of a midline) than in the same hemifield. Their explanation of this finding was that two stimuli may be competing for resources when they were both presented in the same hemifield; conversely, not competing for resources when they were presented on opposite sides of a midline, hence leading to a “different-hemifield advantage”.

Harrison and Feldman (2009) and Davis and Holmes (2005) used feature comparison tasks in which observers had to identify matching features that belonged to either the same object or to different objects. A horizontal benefit was found in both studies. These authors explained the horizontal benefit in terms of symmetry detection, as symmetry is detected across the vertical midline more easily than across the horizontal midline (Pashler, 1990; Wagemans, 1997). Keeping this in mind, an important avenue for future research is to study the role of symmetry detection in comparison tasks. As pointed out by Chen and Cave (in press), Donovan, Pratt, and Shomstein (2017) did not find a horizontal benefit in a temporal judgment task, possibly because symmetry detection would not play a role in such a task.

Barnas and Greenberg (2016) focused specifically on the influence of attention crossing the meridians on object-based attention. Their results provide strong evidence for the horizontal benefit because they found that regardless of attention shifting within the same object or between different objects, an advantage was seen when this shift was horizontal rather than vertical. In a spatial cuing experiment, they found that RTs for comparing horizontally aligned stimuli were quicker than vertically aligned stimuli only when stimuli were near fixation, and this effect disappeared when stimuli were in the same quadrant of the visual field but the locations of the stimuli were relatively far from the fixation. Importantly, in neither condition, the target crossed the meridian from the cue. Thus, the presence or absence of the horizontal benefit does not depend on the crossing of the meridian.

3.2 Object Effects and the Uniform vs Non-Uniform Region

Previous studies have shown that object effects are modulated by the type of region between the targets. Kramer and Watson (1996) explored the effect of ‘uniform connectedness’ on object-based effects. They used wrench shaped stimuli. The task was to determine whether two predefined properties were present or not. In one condition, the wrenches had uniform surface in both colour and texture. In another condition, they had non-uniform surface with the middle part being different in colour and texture. An object effect was found in the uniform surface condition but not in the non-uniform surface condition. A similar result was found in Watson and Kramer (1999).

Matsukura and Vecera’s (2006) study sheds some more light on uniform and non-uniform regions as it pertains to object-based effects. Using stimuli similar to Watson and Kramer (1999, Experiment 1), they found that object-based effects were strong in conditions using uniform region stimuli but not significant in conditions using non-uniform region stimuli. Modifying their stimulus such that in follow-up experiments participants were more likely to group non-uniform regions together (in terms of edge continuation and occlusion cues), they found that object-based effects were significant in conditions with non-uniform region stimuli. These results indicate that object effects are sensitive to the type of region between the targets. Object effects can occur with a non-uniform region in between, but only when strong perceptual grouping cues are present to group the different sections within the region together.

3.3 Object Effects and Object-Based Attention

In previous research, three main mechanisms have been proposed to explain object effects, and one of them is shifts of attention. As noted in the introduction, Lamy and Egeth (2002) demonstrated the necessity of attentional shifts for object-based effects to manifest. They showed that an object effect was found when the targets were presented sequentially (requiring attentional shift) but not when they were presented simultaneously (requiring no attentional shift). They proposed that shifting attention was more difficult between objects than within an object, and this gave rise to the object effect.

According to Posner and colleagues (Posner & Cohen, 1984; Posner & Peterson, 1990), attentional shift comprises three operation components: disengagement of attention from a current location, redirecting attention to another location, and reengagement of attention at the new location. Brown and Denney (2007) carried out a study to investigate how the separate components in attentional shift contribute to the same-object benefit. They used a two rectangle paradigm with a spatial cue similar to the paradigm used in Egly et al. (1994). The presence of the spatial cue led to the need to shift attention. In the baseline experiment which was similar to that in Egly et al., they found a significant same-object effect. To test whether this result was modulated by shifts of attention across visual meridians, they rotated their stimuli by 45° either clockwise or anticlockwise in a follow-up experiment, so that shifts of attention were not confounded with shifts across visual meridians. Once again, the same-object benefit was found. In a further experiment, the target appeared directly against the background while the cue was on an object. RT was faster when the target was on the same object as the cue compared with when the target was against the background. These results suggest that when shifting attention is required, the disengage and engage operations between different objects take longer than the disengage and engage operations between locations within an object. Based on these results, they proposed that this difference can explain the same-object benefit seen across many studies.

Another mechanism that has been proposed to explain the object effect is referred to as the sensory enhancement mechanism. According to its proponents (Chen & Cave, 2006; Martínez, Teder- Sälejärvi, & Hillyard, 2007; Richard, Lee, & Vecera, 2008), object effects are caused by improved sensory representation of the selected object. In studies with spatial cues, the spread of attentional resources respects object boundaries, and this enhances the sensory representation of the stimuli in the selected object. Thus, features belonging to a cued object are more quickly and/or more accurately responded to than features belonging to different objects.

A third mechanism is known as attentional prioritisation (Shomstein & Yantis, 2002, 2004). According to this account, visual search is prioritised to an already attended object. Therefore, in studies with spatial cues, visual search would begin from the object within or near which a spatial cue was present, and any target features within or part of this object would be attended to first, before features within or part of unattended objects (Shomstein & Yantis, 2002). As a result, processing is more efficient in the same object condition compared to the different object condition.

None of these accounts can adequately explain the results found in Experiment 3 of the present study. In the 2Small object trials, the targets were either within the same object with a non-uniform region in between or between two different objects, yet no difference was found between these two conditions. Note that in the two different object condition, the region between the targets was also non-uniform, as the targets were separated by object boundaries. The results from Experiment 3 show that whether the non-uniform region between targets is within one object or between different objects does not matter. So long as the task requires shifts of attention, responding to targets with a non-uniform region in between will take longer than responding to targets with a uniform region in between. These findings are important, because they suggest that the same-object benefit seen in previous research using a spatial cuing paradigm may simply be the result of shifting attention across a uniform region rather than shifting attention across a non-uniform region. If that is the case, then the object effects reported in the literature may have little to do with object-based guidance of attention, prioritization in visual search strategy, or the disengage and engage operations in attentional shifts.

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Note:

1. Two sets of 2 x 2 repeated-measures ANOVAs instead of a 2 x 2 x 2 repeated-measures ANOVA were performed on the data. This is because in the 1Large condition, the manipulation concerned the region between the targets (uniform vs non-uniform) while in the 2Small condition the manipulation concerned the number of objects on which the targets appeared (one object vs two objects).

Appendix

The results of all statistical analyses reported in this study are shown below.

Experiment 1

Table 1A. Results of a 2 (object shape) x 2 (target configuration) repeated-measured ANOVA on the overall RT data.

	F (1, 23)	*p*	*partial η^2*
Object Shape	0.26	0.613	0.01
Target Configuration	30.92	0.000	0.57
Object Shape x Target Configuration	0.76	0.394	0.03

Table 1B. Results of a 2 (object shape) x 2 (target configuration) repeated-measured ANOVA on the overall error data.

	F (1, 23)	*p*	*partial η^2*
Object Shape	0.07	0.794	0.00
Target Configuration	12.10	0.002	0.34
Object Shape x Target Configuration	0.49	0.493	0.021

Table 1C. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the concave trials RT data.

	F (1, 23)	*p*	*partial* η^2
Target Configuration	15.73	0.000	0.40
Type of Region	0.03	0.868	0.00
Target Configuration x Type of Region	0.19	0.667	0.01

Table 1D. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the concave trials error data.

	F (1, 23)	*p*	*partial* η^2
Target Configuration	3.02	0.096	0.12
Type of Region	1.21	0.283	0.05
Target Configuration x Type of Region	0.43	0.518	0.02

Experiment 2

Table 2A. Results of a 2 (SOA) x 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the overall RT data.

	F (1, 23)	*p*	*partial η^2*
SOA	30.01	0.000	0.57
Target Configuration	36.13	0.000	0.61
Type of Region	17.11	0.000	0.43
SOA X Target Configuration	3.00	0.097	0.12
SOA X Type of Region	0.01	0.930	0.00
Target Configuration x Type of Region	0.19	0.668	0.01
SOA X Target Configuration x Type of Region	2.66	0.117	0.10

Table 2B. Results of a 2 (SOA) x 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the overall error data.

	F (1, 23)	*p*	*partial η^2*
SOA	0.25	0.625	0.01
Target Configuration	4.81	0.039	0.17
Type of Region	1.04	0.318	0.04
SOA X Target Configuration	0.28	0.599	0.01
SOA X Type of Region	0.70	0.411	0.03
Target Configuration x Type of Region	2.95	0.099	0.11
SOA X Target Configuration x Type of Region	0.03	0.857	0.00

Experiment 3

Table 3A. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the 1Large object RT data.

	F (1, 22)	*p*	*partial η^2*
Target Configuration	10.81	0.003	0.33
Type of Region	10.93	0.003	0.33
Target Configuration x Type of Region	0.01	0.917	0.00

Table 3B. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the 1Large object error data.

	F (1, 22)	*p*	*partial η^2*
Target Configuration	4.77	0.040	0.18
Type of Region	1.89	0.183	0.08
Target Configuration x Type of Region	3.01	0.096	0.12

Table 3C. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the 2Small object RT data.

	F (1, 22)	*p*	*partial* η^2
Target Configuration	13.63	0.001	0.38
Type of Region	1.29	0.269	0.06
Target Configuration x Type of Region	0.29	0.597	0.01

Table 3D. Results of a 2 (target configuration) x 2 (type of region) repeated-measured ANOVA on the 2Small object error data.

	F (1, 22)	*p*	*partial* η^2
Target Configuration	11.64	0.002	0.35
Type of Region	0.05	0.817	0.00
Target Configuration x Type of Region	0.15	0.700	0.01