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Acta Psychologica 113 (2003) 133–145

acta psychologica

www.elsevier.com/locate/actpsy

Attentional capture within and between objects

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Received 16 February 2002; accepted 20 January 2003

Abstract

The present study addressed the question whether attentional capture by abrupt onsets is affected by object-like properties of the stimulus field. Observers searched for a target circle at one of four ends of two solid rectangles. In the focused attention condition the location of the upcoming target was cued by means of a central arrowhead, whereas in the divided attention condition, the target location was not cued. Irrelevant abrupt onsets could appear either within the attended or within the non-attended object. The results showed that in the focused attention condition, onsets ceased to capture attention irrespective of whether the onset appeared within an attended object or within a non-attended object.

Keywords: Attentional capture; Object-based attention; Abrupt onsets; Visual search

1. Introduction

There is ample evidence that abrupt onsets capture attention in an involuntary stimulus-driven manner (e.g., Breitmeyer & Ganz, 1976; Jonides, 1981; Müller & Rabbitt, 1989; Remington, Johnston, & Yantis, 1992; Theeuwes, 1991, 1994; Yantis & Jonides, 1984). Jonides (1981) used peripheral cues with abrupt onsets which provided no predictive information about the likely target location. Even when participants were explicitly told to ignore these uninformative abrupt onset cues, the results indicated that participants were unable to do so. It was concluded that abrupt onset cues direct attention to their location even when participants deliberately

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0001-6918/03/$ - see front matter
doi:10.1016/S0001-6918(03)00024-6

attempt to ignore them. Remington et al. (1992) provided even stronger evidence that abrupt onsets capture attention in an involuntary, stimulus-driven manner. In Jonides (1981) the cue indicated the likely target position at chance level. In Remington et al. (1992) the abrupt onset cue never indicated the target location, and participants were explicitly told to ignore the abrupt onset. The results showed that observers were slower in the condition with the invalid abrupt onset cue than in the condition in which no cue occurred, suggesting that attention was drawn to the abrupt onset even when participants knew it was irrelevant to the task.

Even though these findings suggest that abrupt onsets capture attention in an involuntary automatic fashion, Theeuwes (1991) has shown that abrupt transient onsets cease to capture attention when attention is focused on a location in space (see also Yantis & Jonides, 1990). In Theeuwes' study, participants searched for a target letter among three non-target letters which were equally distant from the central fixation point. At different SOAs an abrupt onset was randomly presented near one of the four locations. In addition, in the so-called focused attention condition, a central arrow indicated the location of the upcoming target with 100% validity. In this condition in which attention was endogenously directed to the target location prior to display onset, the peripheral onset did not capture attention whereas it did in another condition in which no central cue was presented prior to display presentation. Focusing attention to a location in space prevented the exogenous capture of attention by a peripheral onset. Theeuwes argued that events outside the attentional window cease to capture attention.

The present study addresses the question whether the extent to which one is able to prevent attentional capture by abrupt onsets is affected by object-like properties of the display. It is well known that the attentional window may select objects rather than locations in space (Baylis & Driver, 1993; Driver & Baylis, 1989; Duncan, 1984; Kramer & Jacobson, 1991; Tipper, Driver, & Weaver, 1991; Vecera & Farah, 1994, for a review see Scholl, 2001) [1]. For example, Kramer and Jacobson (1991) had participants to indicate whether a central vertical line was dashed or dotted. The central line was presented concurrently with irrelevant flankers that could, among other things, be embedded in the same object as the target line was or in different objects. The irrelevant flankers could be compatible, incompatible, or neutral with respect to the response to the target. The results showed a flanker compatibility effect if target and flankers were embedded in the same object. If target and flankers were part of different objects no compatibility effects were found. These results strongly suggest that objects rather than locations in space are selected.

Given the evidence that abrupt onsets can capture attention in a strongly involuntary and stimulus-driven manner (e.g., Remington et al., 1992) the question arises

[1] Although an extreme object-based view on selective attention asserts that locations plays absolutely no role in the selected representations, usually a less extreme view is advocated asserting that attention selects those locations in the visual field that correspond to an object's shape (Egly, Driver, & Rafal, 1994; Kramer, Weber, & Watson, 1997; Vecera & Farah, 1994). In the present article, object-based attention is interpreted in the latter sense.

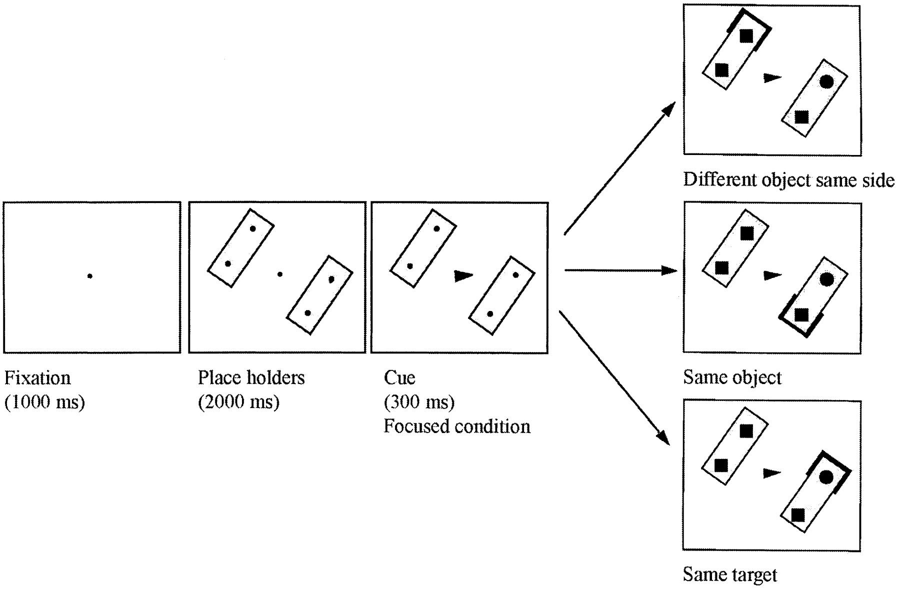

Fig. 1. The sequence of events during a trial in Experiment 1 (focused attention condition). The cue indicated validly (100%) the targets position, in the target-present trials. There were 20% catch trials. Same-target trials (the onset at the target location); same-object trials (the onset at the opposite side of the target location in the same object); different object same-side trials (the onset appeared in the other object at the same end of the target). The actual stimuli were presented against a black background with white luminance changes.

whether abrupt onsets that appear within an attended object have a differential effect on attentional capture than onsets appearing outside an attended object.

To address this question, we used in the present study the same set-up as Theeuwes (1991). Participants were reliably cued to focus attention to a location in space. Instead of focusing attention to a single location, subjects now directed their attention to a location within a rectangle-like object (see Fig. 1). An irrelevant onset could appear either within the attended rectangle or outside the attended rectangle at equidistant locations.

If one assumes that directing attention to an object or part of an object would give rise to attentional priority of the whole object one would expect that abrupt onsets presented within the attended object would result in stronger capture of attention than abrupt onsets outside the attended object. For example, Egly et al. (1994) provided evidence for object-based effects with a predictive exogenous cue. [1] In Egly et al. (1994) participants were shown two rectangles that appeared either above and below fixation or to the left and right of fixation. One rectangle end was peripherally precued (validity of 75%) by a brightening flash. Participants were required to respond to the presence of the target that could occur in either end of both rectangles. The exogenous cue was either valid (cue and target were at the same corner) or invalid (cue and target at different corners). Costs for invalidly cued trials were larger if the target appeared at the uncued rectangle than at the cued rectangle. This difference was interpreted in terms of the time needed to shift attention from one to the other rectangle. So participants were faster to reorient their attention to another location in the same object than to another location in a different object.

Abrams and Law (2000) replicated the findings of Egly et al. (1994) and extended them by showing that a central cue (cue validity of 71.4%) had basically the same effect as a peripheral cue (but see Macquistan, 1997). Abrams and Law interpreted these results in terms of attentional radiation, that is, the spreading of attention from a cued location throughout an object on which the location is positioned.

Even though these results strongly suggest that object-based effects occur under conditions of focused attention, other studies fail to provide evidence for this. For example, Lavie and Driver (1996) had observers to indicate whether two odd elements within a display were the same or different. The elements could be part of the same object (i.e., one line) or two different objects (i.e., two lines). The results of their Experiments 1–3 showed that if the odd elements were embedded in the same objects, judgments were faster than if they were embedded in different objects. In Experiment 4 they demonstrated that precueing the location of the odd elements (with a cue validity of 70%) completely eliminated the object-based effects as observed in Experiments 1–3. These results suggest that the advance focusing of attention prevents object-based effects to occur. At this point, it should be noted that in Lavie and Driver's study the objects (i.e., the lines) were not presented prior to the target elements as was the case in, for example, Egly et al. (1994). Possibly, subjects did not have enough time to develop an object-based representation strong enough to affect attentional selection (but see Atchley & Kramer, 2001, for a failure to replicate the results of Lavie & Driver, 1996).

Other evidence for the absence of object-based effects under focused attention conditions stems from more recent studies (Goldsmith & Yeari, submitted for publication; Shomstein & Yantis, 2002). For example, Shomstein and Yantis (2002, Experiments 1–4) had observers to identify a centrally located target. The target was presented concurrently with irrelevant flankers, which could be embedded in the same object as the target or in a different object. The flankers were either compatible or incompatible with respect to the response to the target. They found a compatibility effect, but no difference when target and flankers were in the same compared to in different objects. However, in Experiment 5 in which participants did not know the target location in advance, an object-based modulation of the compatibility effect was obtained. Shomstein and Yantis (2002) concluded that object-based selection may reflect an object-specific attentional prioritization strategy rather than an obligatory spread of attention over the object. As a consequence, advance focusing of attention might completely abolish object-based effects.

2. Experiment 1

In Experiment 1, observers searched for a target circle at one of four ends of two solid rectangles. One rectangle end was reliably cued by a central arrowhead (cue validity is 100%). The arrowhead was presented before (focused attention condition) or after (divided attention condition) the onset of the search display. At different SOAs an uninformative peripheral onset was presented at one of the four possible target locations. Of primary interest was whether an irrelevant onset presented within the attended object would affect reaction time differently than an abrupt onset outside the attended object.

3. Method

3.1. Participants

Twenty-two undergraduates, ranging in age from 19 to 26 years, participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment. The experiment consisted of two sessions on two separate days.

3.2. Apparatus

Participants were seated in front of a computer monitor with their heads fixed on a chinrest. Viewing distance was approximately 75 cm. Participants' eye movements were recorded using an Intelligent Eye Tracking System (Eyelink, 250 Hz temporal resolution and 0.2° spatial resolution). This system made use of infrared cameras which were mounted on a headband. A third camera on the headband tracked four markers on the corners of the display in order to correct for head-movements. Saccades were identified by means of a velocity threshold (35°/s) and an acceleration threshold ($9500°/s^2$). The eye-tracking system was calibrated at the start of the experiment and after the break. All participants were instructed not to move their eyes during the trials. Trials in which an eye movement of 1° or more was made, were removed from the data analysis. Between the trials, participants were allowed to move their eyes.

3.3. Procedure and stimuli

Fig. 1 depicts the sequence of event during a trial, in the focused attention condition. A 200 ms warning signal of 5000 Hz indicated the beginning of each trial. Participants began each trial by fixating a central fixation dot (diameter of 0.15° at an observation distance of 75 cm). After 1000 ms, two solid grey ($1.58\ cd/m^2$) rectangles (each of which subtended $6.84° \times 1.6°$) were presented during 2000 ms on a black background. The rectangles were presented to fit in an imaginary diamond shape ($6.84° \times 6.84°$). Rectangles could be oriented to the left or the right. Each rectangle contained two black dots, one at each rectangle-end, corresponding to the possible target positions. There were two conditions: the focused attention condition and the divided attention condition. In the focused attention condition, the fixation point changed into an arrowhead (0.382° × 0.267°) before the search display was presented. This arrowhead served as a central cue, which pointed to one of the four possible target positions. In order to minimize possible attention-capturing effects, the central cue was gradually presented during 100 ms (with an increment of 0.2 cd/m^2 each step). Three hundred milliseconds after the onset of the central cue, the dot-placeholders were replaced by the search items consisting of either four squares (0.458° × 0.458°) or three squares and one circle (0.496°). In the divided attention condition, the central cue appeared 200 ms after presentation of the search items.

In both conditions, a peripheral onset was presented which was uninformative with respect to the location of the target and therefore irrelevant to the task. The peripheral onset consisted of the brightening of one of the four rectangle-ends. The brightening extended over two strokes of 3.05° and one stroke of 1.6° of visual angle (see Fig. 1).

Onsets were presented at three peripheral onset-to-search display SOAs: −160, −80 and 0 ms during 200 ms. The peripheral onset appeared equally often at each location resulting in four different types of trials: in the *same-target trials*, the onset appeared at the target location, in the *same-object trials*, the onset appeared at the opposite side of the target location in the same object. In the *different-object same-side* trials, the onset appeared in the other object at the same end of the target. Finally, in the *different-object different-side trials*, the onset appeared in the other object at the opposite end of the target location.

The task of the participants was to press the spacebar as rapidly as possible whenever they detected the presence of a circle (target). Twenty percent of the trials were *catch trials* in which no circle was present. It was stressed not to make a response before the circle was detected. The search display remained visible until a response was made. The intertrial interval was 3000 ms during which the screen was blank. When participants made a false alarm or when their reaction time was longer than 2000 ms, an error message (i.e., the word "fout") was presented on the centre of the screen. Participants were instructed to remain fixated on the central fixation dot throughout each trial. Eye movements were recorded so as to enable exclusion of those trials in which eye movements were made.

3.4. Design

The conditions were blocked in two sessions. The order of the sessions was counterbalanced over participants. Each session contained 480 trials with 80% experimental trials and 20% catch trials. In one session, participants received 40 practice trials, followed by eight experimental blocks. Each block comprised 40 trials. After four blocks there was a break and the fifth block started with 10 practice trials. There was a total of 480 experimental trials consisting of 96 same-target trials, 96 same-object, 96 different-object same side, 96 different-object different side and 96 catch trials. Each cue-direction (left, up, right, down) as well as each rectangle orientation (left vs right) occurred equally often in each type of trial.

4. Results

Reaction times from incorrect response trials and trials in which an eye movement was made, were excluded from the analysis (<10%). The data of two participants were not included because of too many false alarms (>20%).

An analysis of variance (ANOVA) was performed on the individual median reaction times with the variables Trial Type (relative onset position: target location, same object, different object; different target–different object trials were excluded from the analysis) and onset SOA (−160, −80, and 0 ms) separate for the focused attention condition and the divided attention condition (see Fig. 2).

In the focused attention condition, there was no effect of Trial Type, $F(2,38) < 1$. There was also no effect of the peripheral onset SOA [$F(2,38) < 1$]. Furthermore, there was no interaction between peripheral onset SOA and Trial Type [$F(4,28) = 1.25$].

For the divided attention condition, there was a significant main effect of Trial Type [$F(2,38) = 21.82; p < 0.001$]. Also, there was a significant effect of peripheral onset SOA [$F(2,38) = 11.73; p < 0.001$]. Furthermore, there was a significant interaction between peripheral onset SOA and Trial Type [$F(4,76) = 6.15; p < 0.001$]. Trials with an onset at target location differed significantly from trials with an onset elsewhere, $F(1,19) = 30.86$; $p < 0.001$, indicating a reliable exogenous cueing effect (see e.g., Theeuwes, 1991).

Importantly, there was also a reliable difference between trials with an onset presented at the same object (non-target) location (at a non-target location within the

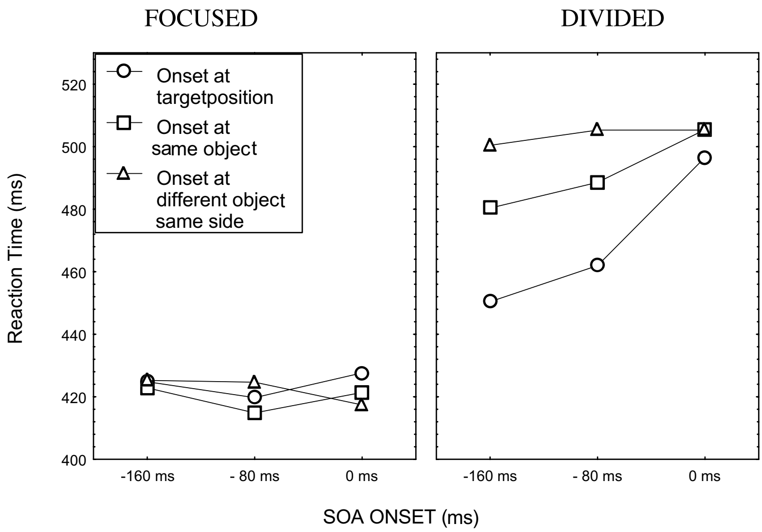

Fig. 2. Experiment 1: Median reaction times (in ms) for Trial Type (onset at same target position, at same object or at different object same-side) as a function of peripheral onset-to-display SOA (−160, −80 or 0 ms) for the two conditions (focused or divided).

object in which the target was presented) and the trials with an onset presented at the different object location (no target was presented in this object) at both peripheral onset SOA's of −160 ms [$F(1,19) = 5.76; p < 0.05$] and −80 ms [$F(1,19) = 5.76; p < 0.05$].

5. Discussion

Experiment 1 shows that, when attention was divided, the onset that we employed was able to capture attention exogenously. However, if attention was highly focused to one particular location of an object, onsets elsewhere in the visual field did not affect search performance. Moreover, the inability to capture attention does not depend on whether this onset appeared within the attended object or within the unattended object.

The results are similar to those obtained by Yantis and Jonides (1990) and Theeuwes (1991) who also reported that RT is unaffected by irrelevant peripheral onsets outside the focus of attention. However, in their study search displays did not contain any objects. The present study shows that irrespective of the presence of objects, attention can be focused such that abrupt onsets are prevented to disrupt performance. In the divided attention condition, performance was affected by the presence of an irrelevant onset. Performance was better when the peripheral onset occurred at the target location compared to the non-target locations. The onset clearly captured attention. Furthermore, the peripheral onset elicited an object-based effect at both the peripheral onset SOA −160 and −80 ms. Participants responded faster to the presence of the target if it occurred in the same rectangle as the onset compared to if it occurred in the other rectangle.

The results of Experiment 1 provide evidence that onsets do not act in a different manner when targets and distractors are presented in objects compared to when no objects are present. However, the validity of this conclusion is strongly dependent on the assumption that the objects used in the present experiment were actually perceived as such. Possibly, the objects used in the present experiment were not object-like enough with the result that no object-based effects were obtained in the focused attention condition. To test this possibility, a second experiment was executed.

6. Experiment 2

The aim of Experiment 2 was to investigate whether the stimuli used in Experiment 1 yield the usual object-based effects. In Experiment 2, the likely target position was centrally cued with a cue validity of 75%. On the invalid-cue trials, the target appeared either at the uncued position within the same rectangle as the cued position was, the same-object trials, or at the equidistant end of the other rectangle, the different-object trials. If the rectangles used in Experiment 1 are perceived as objects, it is expected that in comparison to the valid trials, the costs of invalid cueing are less in the same-object trials than in the different-object trials.

7. Method

7.1. Participants

Twenty-eight undergraduates, ranging in age from 18 to 29 years participated as paid volunteers. All participants had normal or corrected-to-normal vision and were naive as to the purposes of the experiment.

7.2. Procedure, apparatus and stimuli

Procedure, apparatus and stimuli were the same as in Experiment 1 except for the following changes. First, there was no peripheral onset. Second, there was only one condition, in which the dot-placeholders were replaced by the search items 300 ms after the onset of the central cue. Third, cue validity was 75% instead of 100% resulting in four different trials: in the *valid trials*, the target (circle) always appeared at the cued position. In the *invalid same-object trials,* the target was presented at the uncued position in the same rectangle as the cued position. In the *invalid different-object trials*, the target appeared at the equidistant location within the other rectangle. Finally, in 20% of all trials no target was presented (*catch trials*). It is important to note that the distance between target and cued location was the same for invalid same-object trials as for invalid different-object trials. The task of the participants was to press the spacebar as rapidly as possible whenever they detected the presence of the target. It was stressed not to make a response before the circle was detected. The search display remained visible until a response was made. The intertrial interval was 3000 ms during which the screen was blank. When participants made a false alarm or when their reaction time was longer than 2000 ms, an error message (i.e., the word "fout") was presented on the centre of the screen.

7.3. Design

A within-subjects design was used. Of the experimental trials, 75% were valid, 12.5% were invalid same-object, and 12.5% were invalid different-object. In addition there were 20% catch trials. Participants received 40 practice trials, [2] followed by eight experimental blocks. Each block comprised 40 trials. After four blocks there was a break and the fifth block started with 10 practice trials. Each subject performed in 320 experimental trials consisting of 192 valid trials, 32 invalid same-object, 32 invalid different-object and 64 catch trials.

8. Results

Reaction times from incorrect response trials and trials in which participants made an eye movement were excluded from the analysis (<2%). The data of two

[2] Ten participants received 80 practice trials.

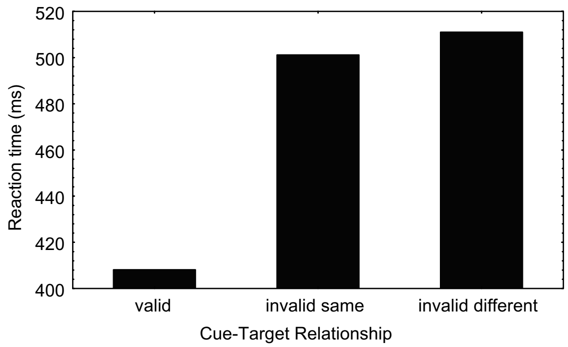

Fig. 3. Experiment 2: Median reaction times (in ms) for valid cue, invalid cue same object and invalid cue different object conditions.

participants were not included because of too many false alarms (>20%) and data of one subject was excluded because of too slow reaction times.

An ANOVA was performed on the individual median reaction times of the target present trials with the variable type of trial (valid, invalid same object, invalid different object). Type of trial affected reaction times $[F(2,48) = 163.83, p < 0.001]$. Planned comparison between valid trials and invalid trials (same object and different object) showed a significant effect of 98 ms $[F(1,24) = 228.46, p < 0.001]$. Reaction times were faster in the valid trials (408 ms) than in the invalid same-object trials (501 ms) $[F(1,24) = 202.48, p < 0.001]$. A comparison between invalid same-object and invalid different-object trials showed a benefit for the same object of 10 ms, $[F(1,24) = 4.28,\ p < 0.05]$ (see Fig. 3).

9. Discussion

The conventional benefit of valid cueing was observed. Participants were faster in the valid trials compared to the invalid trials. Therefore, the central cue was effective in directing the participants' attention to the cued location. Also, there was an object-advantage of 10 ms, showing that participants were faster to respond to the presence of a target if the target occurred at a non-cued position within the same object as the cued position was than if it occurred at a non-cued position within another object. Even though the object-based effect in the current experiment is relatively small, it should be noted that the effect size is similar to object-based effects obtained in other studies (e.g., Abrams & Law, 2000; Egly et al., 1994). The present experiment shows that observers perceived the rectangles as objects.

10. General discussion

Experiment 2 established that the rectangles used in our experiments were perceived as objects. As noted the effects were small but in line with earlier object-based effects. Our findings extend earlier object-based effects reported by Abrams and Law (2000), Egly et al. (1994), Lamy and Tsal (2000) and Vecera (1994).

Experiment 1 shows that the onsets were effective in capturing attention when observers were not focusing attention to a location in space. In this condition, for both the −80 and −160 ms SOA's there was a clear object-based effect: when the onset was presented within the same object as the target response times were significantly faster than when the onset was presented at the object not containing the target. It seems that attention is captured by the onset and then spreads automatically within the object.

The focused attention condition, however, shows a quite different result. When highly focused on a location in space, all other areas, irrespective of whether they are within the same or within different objects, cease to capture attention. This implies that in a focused attentional state there is no attentional spreading or even occasional attentional leakage to adjacent object-like areas. This provides strong evidence for the claim that space-based selection overrides object-based selection especially given the strong stimulus driven character of abrupt onset stimuli.

The results provide support for the claim that the initial selection of objects from the visual environment occurs on the basis of space and not on the basis of objects. Recently, Schendel, Robertson, and Treisman (2001) suggested that attention is initially allocated to locations rather than objects occupying those locations. Schendel et al. (2001) developed a task in which the role of exogenous location and object cueing could be separately examined for both short and long SOAs between cue and target. Typically, location cueing resulted in facilitation at short SOAs and inhibition at long SOAs. Object cueing on the other hand only yielded facilitation at long SOAs in particular for targets occurring at the cued locations and not for those occurring at the uncued locations. Schendel et al. (2001) concluded that in exogenous orienting, the allocation of attention is most likely location mediated. Our results suggest that this is also the case in endogenous cueing.

It should be realized that in Experiment 1, we used a 100% valid endogenous cue. Because the cue is 100% reliable observers may have engaged in a highly focused state in which only the attended region in space receives attentional resources. In fact, one could argue that in such a highly focused state objects outside the attended area cease to exist. The notion that being focused may result in the inability to detect conspicuous objects or events is confirmed by studies such as Joseph, Chun, and Nakayama (1996) who showed that observers cannot detect pop-out targets in the periphery when they are engaged in an attentionally demanding letter task. Also, more recent studies concerning object-based attention showed that the typical object-based advantage disappeared when attention was focused (Goldsmith & Yeari, submitted for publication; Lamy & Egeth, 2002; Shomstein & Yantis, 2002).

In sum, our results show that when we are highly focused on one location of a particular object, abrupt onsets presented within that object do not capture our attention. In addition, regardless of whether the onset appears within the attended or within the non-attended object it does not disrupt performance.

Acknowledgements

We like to thank Art Kramer and several anonymous reviewers.

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