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## The manifestation of attentional capture: facilitation or IOR depending on task demands

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**Abstract** Orienting attention exogenously to a location can have two different consequences on processing subsequent stimuli appearing at that location: positive (facilitation) at short intervals and negative (inhibition of return) at long ones. In the present experiments, we manipulated the frequency of targets and responses associated with them. Results showed that, even at long SOAs, where IOR is usually observed, facilitation was observed for infrequent targets at the same time that IOR was measured for frequent targets. These results are difficult to explain on the basis of either task set modulation of attentional capture or task set modulation of subsequent orienting processes. In contrast, we offer an explanation by which the different cuing effects can be considered as different manifestations of attentional capture on target processing, depending on the task set.

Orienting attention to the location at which a relevant stimulus will appear plays an important role in the rapid and efficient scanning of visual environments. Attention can be oriented endogenously in accord with the intention of the observer, or exogenously in response to a salient stimulus (e.g., an abrupt visual onset). The latter, involuntary, mode of orienting attention has been thoroughly investigated during the last two decades in the exogenous cuing and attentional capture literatures. Although exogenous orienting is often considered to be automatic in nature, some researchers have argued that it can be modulated endogenously, as a function of the

task set of the observer (Folk, Remington & Johnston, 1992; see Ruz & Lupiáñez, 2002, for a review).

The present paper is concerned with the effect of task demands on exogenous orienting effects. However, our focus is not on how task demands influence attentional capture itself, but rather on how task demands can influence the manifestation of the capture of attention on behavior. In other words, we were interested in whether two different target task demands can produce different cuing effects when processing of the cue itself (i.e., attention capture) is held constant across the two task demands. We used a cost-benefit paradigm (Posner, 1980) with exogenous cues and manipulated the nature of a choice RT discrimination task. The critical question was whether the capture of attention by an exogenous cue would manifest itself in behavior differently as a function of the set adopted to deal with particular task and stimulus properties.

### Exogenous orienting: the role of task set

Exogenous orienting has been widely investigated with the cost-benefit paradigm (Posner, 1980). In a typical study, participants are to respond to a target appearing in one of two possible locations and, before the target appears, attention is summoned to one of the two locations by an abrupt onset cue. The cue is uninformative in that it appears with equal probability at the cued and uncued locations. When the time interval between cue onset and target onset (cue–target SOA) is manipulated, responses are faster for cued than for uncued trials at short SOAs, and slower for cued than for uncued trials at long SOAs. The former result is usually called facilitation whereas the latter is called inhibition of return (IOR; e.g., Posner, Rafal, Choate, & Vaughan, 1985). Since Posner and Cohen (1984) first reported this result, the IOR effect has been measured using a variety of dependent variables and tasks (see Klein, 2000; Lupiáñez, Tudela & Rueda, 1999; Taylor & Klein, 1998, for reviews).

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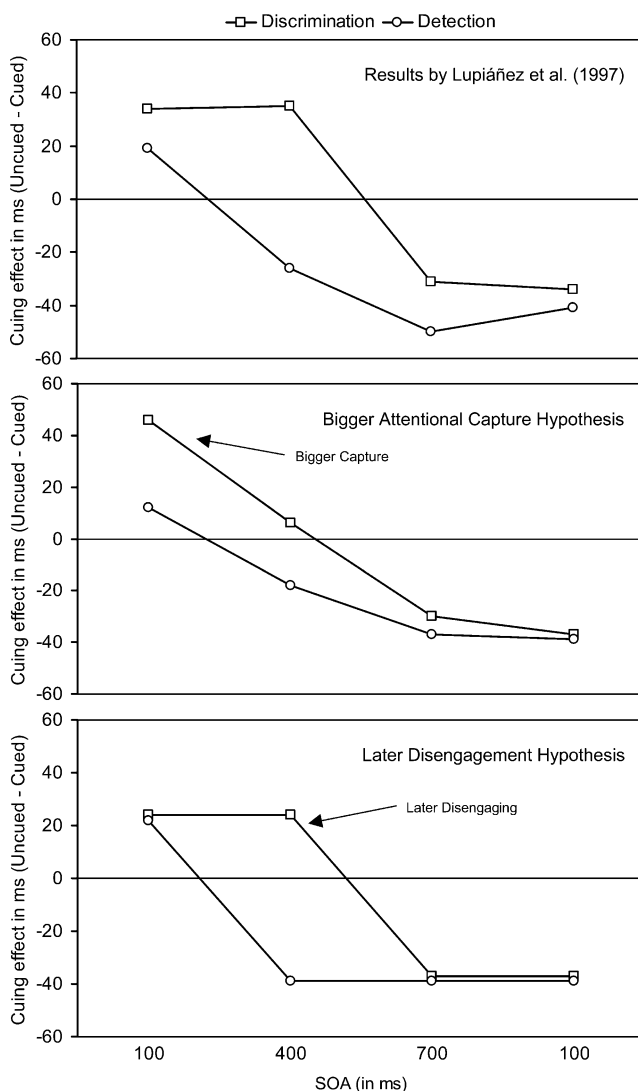
The usual facilitation-IOR time course observed by Posner and Cohen (1984) in a detection task was initially assumed to be a fixed, hard-wired, characteristic of the exogenous orienting mechanism, which ought to manifest in the same way regardless of the task participants are required to perform on the target. However, Lupiáñez, Tornay, Milán, Madrid and Tudela (1997) showed that the time course of cuing effects depends on the task at hand; whereas IOR was present at the 400 ms SOA in this study when a detection task was used, it did not appear until the 700 ms SOA when a discrimination task was used (see Fig. 1). Importantly, this difference in the time course of cuing effects in detection and discrimination tasks shows that, although abrupt onsets might capture attention automatically (Jonides &

Yantis, 1988), the effect that this capture of attention produces on processing of subsequent targets is modulated by the nature of the task that observers are to perform on the target.

Two ways by which task sets might modulate exogenous cuing effects have been described previously in the literature. On the one hand, task sets might modulate attentional capture itself (Folk, et al., 1992; Klein, 2000). By this view, the capture of attention (cue processing) might be stronger for discrimination than for detection tasks, and accordingly it may take longer for the process responsible for IOR to counteract this facilitatory influence of attention capture. The result would be facilitatory effects that persist to longer SOAs in discrimination tasks than in detection tasks. On the other hand, task sets might modulate how quickly attention is removed from the cued location after attentional capture takes place (Lupiáñez, Milliken, Solano, Weaver & Tipper, 2001). By this view, the cue captures the same amount of attentional resources in detection and discrimination tasks, but attention disengages from the cue more quickly in detection than in discrimination tasks. Again, this difference in the speed of disengagement would lead to a later appearance of IOR in discrimination tasks. These two hypotheses are depicted in Fig. 1 and discussed in more detail below.

The “*bigger capture*” hypothesis hinges on research reported initially by Folk et al. (1992). These authors showed that when participants were to respond to color-singleton targets, color-singleton cues but not onset-singleton cues captured attention. Similarly, when responding to onset-singleton targets, onset-singleton cues but not color-singleton cues captured attention. From these results, they concluded that attentional capture is not an automatic process but depends on attentional control settings: only cues sharing relevant attributes with the target capture attention exogenously. Following this line of thought, Klein (2000) suggested that a delayed appearance of IOR in discrimination tasks relative to detection tasks could be caused by a bigger attentional capture effect when participants are prepared for a discrimination task. According to this view, discrimination tasks are more demanding of attention than detection tasks and, therefore, the task set for a discrimination task involves preparation of more resources. Because a change in mental set such as that between cue and target is difficult to achieve in a short period of time, the resources prepared to process the target are allocated to the cue. In this way, the cue produces a bigger capture of attention (more resources are allocated to the cue) in discrimination than in detection tasks. This bigger capture, as can be seen in Fig. 1, leads then to a greater facilitation effect at short SOAs, and so also to a later appearance of IOR.

The alternative “*later disengaging*” hypothesis assumes that attention is disengaged from the cue at different points in detection and discrimination tasks. Lupiáñez, et al. (2001) argued that detection tasks require sensitivity to the onset of the target.



**Fig. 1** Representation of the different time course of cuing effects observed by Lupiáñez, et al. (1997) for detection and discrimination task (*top panel*). Two different hypotheses for explaining the data are depicted: Smaller versus bigger capture (Klein, 2000; *middle panel*) and early versus late disengaging (Lupiáñez, et al., 2001; *bottom panel*). See text for details

Consequently, participants adopt a set to segment cue and target representations in time (an ‘event-segregation’ set). This set works in opposition to the tendency of the system to automatically integrate consecutive stimuli into a single event representation (Hommel, Muesseler, Aschersleben & Prinz, 2001; Hommel, 2005), or object file (Kahneman, Treisman, & Gibbs, 1992). Clearly, the integration of two stimuli into a single event representation would make detection of the second of two stimuli difficult. In contrast, discrimination tasks may require a richer target representation to perform the task. Thus the appropriate set for a discrimination task may prepare participants to integrate information across time within a single object file. Or alternatively, if the default tendency of the system is to integrate within a single event representation, then it may be more appropriate to describe discrimination tasks as relying on this default setting (an ‘event-integration’ set) rather than the event segregation set engaged to prepare for a detection task. Assuming that disengaging attention is a tool used to segregate events in time, one would expect participants to disengage attention more quickly in detection tasks, thus leading to an earlier appearance of IOR.

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### Overview of the present research

To this point, it has been suggested that task set can have an influence either on how many attentional resources are mobilized by an exogenous cue (task-set modulation of attentional capture), or on the time course of the orienting–disengaging processes taking place after the exogenous capture of attention (task-set modulation of disengagement). Note that both of these hypotheses predict that cuing effects are modulated by a task set that is put into play before the target appears. In other words, task set modulation of capture itself and task set modulation of disengagement following capture are two hypotheses that explain how spatial cuing effects can change as a function of processing modulations that occur prior to the appearance of the target. The empirical focus of this paper is a set of findings that cannot be explained by either of these two hypotheses. In particular, we describe several experiments in which spatial cuing effects are modulated by task set, but in which the appropriate task set is not defined at the time of cue onset, and still not defined at the point in time at which disengagement from the cue presumably appears. As the task set that is appropriate for a trial is undefined at the moment the cue appears, as well as during the period of time that disengagement is presumed to appear, the results we report cannot be attributed to influences of task set on either the degree of attention capture or the point in time that attention is disengaged. Rather, the present results force us to consider how task set might influence performance across different performance contexts in which attention capture and subsequent orienting strategies are held constant. In other words, we ask whether task set can modulate how attentional

capture is manifest in performance without altering attention capture itself. We refer to this putative influence as a task-set modulation of the manifestation of attentional capture.

To investigate task-set modulations on the manifestation of attentional capture, we measured RT and errors in a standard exogenous cuing procedure in which one of the possible targets within a block of trials was more frequent than the other/s. The idea was to encourage participants to adopt a set favoring the most frequent target. In this way, we assumed that participants would be ready to *detect* the more frequent target feature, while having to engage in further feature *discrimination* for the less frequent targets. One property of this experimental manipulation is especially crucial to our research strategy. In particular, manipulating the relative frequencies of two targets within a block of trials renders it impossible for participants to know in advance of target onset whether they will encounter a frequent or infrequent target. If these two types of targets require the implementation of different task sets, as hypothesized above, then any difference between the cuing effect for frequent and infrequent targets cannot be explained by processes occurring before the appearance of the target (i.e., attentional capture, attention disengagement.)

To foreshadow the results, in Experiments 1 and 3, the cuing effects were significantly different for frequent and infrequent target/s, showing that the same attentional capture can manifest differently depending on task set. Experiments 2a and 2b provide evidence that a complete stimulus–response set is necessary for this modulation to take place. In the general discussion, we provide a plausible explanation for the observed differences in manifestation of attentional capture, which also accounts for previous findings in the literature.

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### Experiment 1

In this experiment, we used a discrimination task similar to the one used in previous studies (Lupianez, et al., 2001), but one of the targets (either the letter X or the O) and its corresponding response was more frequent than the other. Participants were informed of the asymmetry in frequency of targets, and were asked to give priority to the most frequent one. We expected participants to adopt a feature “detection mode”, with the purpose of making detection responses to the most frequent target very fast, as requested. Thus, we anticipated the time course of cuing effects in this discrimination task to be broadly similar to the one usually observed for detection tasks (i.e., IOR at the 400 ms SOA).

However, our most interesting prediction concerned the differences in cuing effects for frequent and the infrequent targets. If task set modulations of exogenous cuing effects necessarily owe to task set effects on either attentional capture or disengagement processes as outlined above, then we should expect similar cuing effects

for the frequent and the infrequent targets. However, if cuing effects can vary as a function of processes that occur after target onset, then we might expect cuing effects to be different for the frequent and the infrequent targets. In this case, differences in cuing effects would suggest that the manifestation of attentional capture on performance depends on processes that occur at or after the appearance of the target.

## Method

### *Participants*

Thirty-three psychology students from the Facultad de Psicología of the Universidad de Granada participated in the experiment. All of them were naive as to the purpose of the experiment, and participated voluntarily for course credits. Data from one participant were eliminated from the analyses due to a high error rate (higher than 50% for the infrequent target trials).

### *Apparatus and stimuli*

Stimuli were presented on a 15-in. color VGA monitor. An IBM compatible PC running MEL software (Schneider, 1988) controlled the presentation of stimuli, timing operations and data collection. Responses were made by pressing either the “x” key or the “m” key on the computer keyboard.

The target on each trial appeared in the center of one of two boxes, displayed to the left and right of fixation, which remained on the screen throughout the whole trial and only disappeared between trials. The boxes were 17 mm in height by 14 mm in width (subtending 1.62 and 1.33° of visual angle at a viewing distance of 60 cm), and were displayed in dark gray on a light gray background. The inner edge of each box was 77 mm (7.31°) from the fixation point (a plus sign “+” displayed in black). The target was either the letter “X” or the letter “O”. On every trial, at varying temporal intervals before presentation of the target, one of the two boxes was presented in white for 50 ms before returning to its original dark gray. This increase in luminance gave the impression of a brief flicker, which is referred to hereafter as the cue.

### *Procedure*

The sequence of events on each trial is depicted in Fig. 2. A fixation point was displayed together with the two boxes for 1,000 ms, and then the cue appeared for 50 ms. Following the cue, the fixation point and the empty boxes remained on the screen for either 50, 350, 650 or 950 ms, depending on the SOA for that trial. The target was then displayed for 100 ms, after which the fixation point and boxes were again displayed alone until participants’ response, or for a maximum of

2,000 ms. If no response was obtained within 2,000 ms after target offset, then the next trial began. The interval between the trials was 1,000 ms in duration, and the screen remained light gray throughout this interval. Auditory feedback (a 400 Hz computer-generated tone 100 ms in duration) was provided when an error was made.

Participants were informed neither of the presence of the cue nor of the SOA manipulation. They were instructed to press the response key as quickly as possible while avoiding errors. Both the letter-key mapping and the letter-frequency assignment were counterbalanced. Thus, half of the participants were to press the “x” key (marked on the keyboard as “left response”) for the letter “X” and the “m” key (marked on the keyboard as “right response”) for the letter “O”, whereas the other half received the opposite mapping. Within each of these halves, for half of the participants, the letter “X” was more frequent than the letter “O” (75 vs. 25% of the trials), whereas for the other half the letter “O” was more frequent. Participants were informed which letter was most frequent, and they were given instructions to give priority to the frequent target and its response.

All possible combinations of the cue location and target location variables were presented randomly within a block of trials. The experiment was interrupted every 32 trials to allow the participants to rest. Participants were instructed to press the space bar to continue the experimental session.

### *Design*

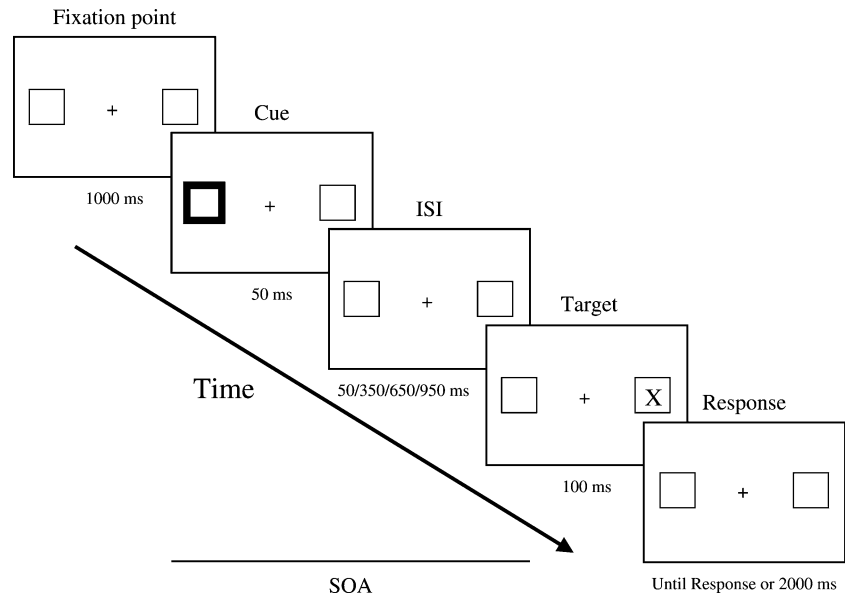
The experiment had a three-factor (cuing  $\times$  SOA  $\times$  frequency) repeated measures design. The cuing variable had two levels: on cued trials the target and cue appeared at the same location, and on uncued trials they appeared at opposite locations. SOA had four levels; 100, 400, 700 and 1,000 ms. Frequency had two levels: the frequent target appeared on 75% of the trials within each block, whereas the infrequent target appeared on the remaining 25%.

The experiment consisted of seven blocks of 64 trials, with the first one considered as practice. Within each block, the infrequent target appeared on 16 trials and the frequent target appeared on 48 trials. Within each condition, there was the same number of cued and uncued trials at each SOA. Thus, there were 12 observations for each experimental condition with the infrequent target (2 per block) and 36 with the frequent target (6 per block).

## Results

Trials with RTs faster than 200 ms or slower than 1,000 ms (0.34 and 1.87% of the trials, respectively) and trials on which an error was made, were excluded from

**Fig. 2** Graphic representation of the procedure used in the three experiments. Sequence of events, from *top-left* to *bottom-right*. The only difference across experiments was the type and proportion of targets, and the responses assigned to each one. See text for details



the RT analysis. Means were computed for both RTs and error rates, and introduced into repeated measures ANOVAs, with cuing (cued and uncued), SOA (100, 400, 700 and 1,000 ms) and frequency (75 and 25%) as factors. Mean RTs and error rates for each experimental condition are presented in Table 1.

#### Analysis of RTs

As expected, participants responded 75 ms faster to the frequent target than to the infrequent target,  $F(1,31)=103.18$ ,  $MSE=7,370.09$ ,  $P<.0001$ . The main effect of SOA was also highly significant,  $F(3, 93)=39.93$ ,  $MSE=703.38$ ,  $P<.0001$ , indicating that RT decreased as SOA increased, particularly between the 100 and 400 ms SOAs. The SOA effect was bigger for the more frequent target (particularly for the longer three SOAs), as revealed by the SOA  $\times$  frequency interaction,  $F(3, 93)=3.11$ ,  $MSE=678.47$ ,  $P<.05$ .

Interestingly, the cuing  $\times$  SOA interaction was significant,  $F(3, 93)=5.43$ ,  $MSE=504.86$ ,  $P<.005$ . A positive 10 ms cuing effect was obtained at the 100 ms SOA, which turned into a  $-11$  ms effect (IOR) at the 400 ms SOA ( $-4$  and  $-8$  ms at the SOAs of 700 and 1,000 ms SOAs). Thus, a fast transition from facilitation to IOR, like the one usually obtained in detection tasks, was observed in our discrimination task.

Of further interest, the effect of cuing was significantly modulated by the frequency of the target,  $F(1, 31)=7.03$ ,  $MSE=708.13$ ,  $P<.05$ , with the cuing effect being more negative in general for the frequent target ( $-9$  ms, IOR) than for the infrequent target (3 ms, facilitation). However, the SOA  $\times$  cuing interaction was not modulated by frequency ( $F<1$ ). As can be seen in Fig. 3, the biggest change in the cuing effect across SOAs occurred between the 100 and 400 ms SOA, both for the frequent and for the infrequent target conditions.

An ANOVA performed on the data from the shortest SOA revealed that, although the facilitation effect for the infrequent target (16 ms) was not significantly larger than that for the frequent target (4 ms), LSD tests revealed that the facilitation effect was significant for the infrequent target,  $P<.05$ , but not for the frequent one,  $P>.50$ . An ANOVA performed on the data from the three longest SOAs (where IOR is usually observed in detection tasks) revealed a significant frequency  $\times$  cuing interaction,  $F(2, 62)=5.00$ ,  $MSE=778.33$ ,  $P<.05$ , with a significant IOR effect obtained for the frequent target,  $F(1, 31)=9.16$ ,  $MSE=1,012.81$ ,  $P<.005$  ( $-14$  ms, independent of SOA,  $F<1$ ), and no effect for the infrequent target ( $-1$  ms;  $F<1$ ).

#### Analysis of the error rates

As in the analysis of RT, responses to the infrequent targets were less precise (.135 error rate) than responses to the more frequent targets (.030 error rate),  $F(1, 31)=34.80$ ,  $MSE=.040$ ,  $P<.0001$ . The effect of cuing was also significant,  $F(1, 31)=7.78$ ,  $MSE=.009$ ,  $P<.01$ , and again was modulated by target frequency,  $F(1, 31)=10.71$ ,  $MSE=.006$ ,  $P<.005$ . The positive cuing effect (.045 difference between cued and uncued trials) observed for the less frequent target,  $F(1, 31)=9.57$ ,  $MSE=.014$ ,  $P<.005$ , was not significant for the more frequent target, (.002 error rate,  $F<1$ ).

#### Discussion

The goal of this experiment was to examine whether an exogenous peripheral cue can have different consequences on target processing, depending on the nature of the processing to be performed on the target. Unlike prior studies of task set influences on cuing effects, we were particularly interested in whether

**Table 1** Mean correct RTs and error rates (in parenthesis) for each experimental condition in each experiment

Experiment	Frequency	SOA						Cuing effect					
		100 ms		400 ms		700 ms		1,000 ms		100 ms	400 ms	700 ms	1,000 ms
		Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
1	Infrequent target/response	599 (0.13)	615 (0.13)	582 (0.09)	574 (0.16)	578 (0.10)	583 (0.17)	581 (0.12)	581 (0.17)	16 (0.00)	-9 (0.07)	5 (0.07)	0 (0.04)
	Frequent target/response	531 (0.04)	535 (0.04)	518 (0.02)	504 (0.03)	504 (0.02)	492 (0.02)	504 (0.03)	489 (0.03)	4 (0.00)	-14 (0.01)	-12 (0.00)	-16 -(0.01)
2a	Infrequent target	640 (0.11)	665 (0.16)	626 (0.10)	645 (0.15)	637 (0.13)	611 (0.13)	642 (0.14)	641 (0.13)	25 (0.04)	19 (0.05)	-26 (0.00)	-1 -(0.01)
	Frequent target	626 (0.18)	646 (0.19)	596 (0.17)	618 (0.20)	616 (0.21)	602 (0.19)	606 (0.22)	596 (0.17)	19 (0.02)	22 (0.03)	-14 -(0.02)	-10 -(0.05)
2b	Infrequent response	687 (0.31)	708 (0.32)	679 (0.27)	678 (0.41)	674 (0.34)	652 (0.28)	684 (0.37)	664 (0.31)	21 (0.01)	-1 (0.14)	-22 -(0.06)	-20 -(0.06)
	Frequent response	634 (0.08)	629 (0.09)	608 (0.08)	607 (0.07)	600 (0.09)	574 (0.08)	602 (0.08)	587 (0.07)	-5 (0.01)	-1 -(0.01)	-26 -(0.01)	-15 -(0.01)
3	Infrequent target/response	828 (0.29)	831 (0.33)	778 (0.24)	812 (0.31)	775 (0.25)	789 (0.29)	795 (0.29)	808 (0.28)	3 (0.03)	35 (0.08)	14 (0.04)	13 -(0.01)
	Frequent target/response	601 (0.05)	587 (0.05)	557 (0.05)	554 (0.06)	569 (0.05)	543 (0.03)	558 (0.05)	543 (0.03)	-14 (0.00)	-3 (0.02)	-26 -(0.02)	-15 -(0.02)

processes occurring after onset of the target itself could modulate cuing effects. In this respect, the critical result in Experiment 1 was that cuing effects were more negative for the frequent targets than for the infrequent targets, a result that is consistent with the results obtained by Ivanoff and Klein (2004). In two experiments, they manipulated the frequency of the target and observed bigger IOR effects for the frequent target than for the infrequent one.

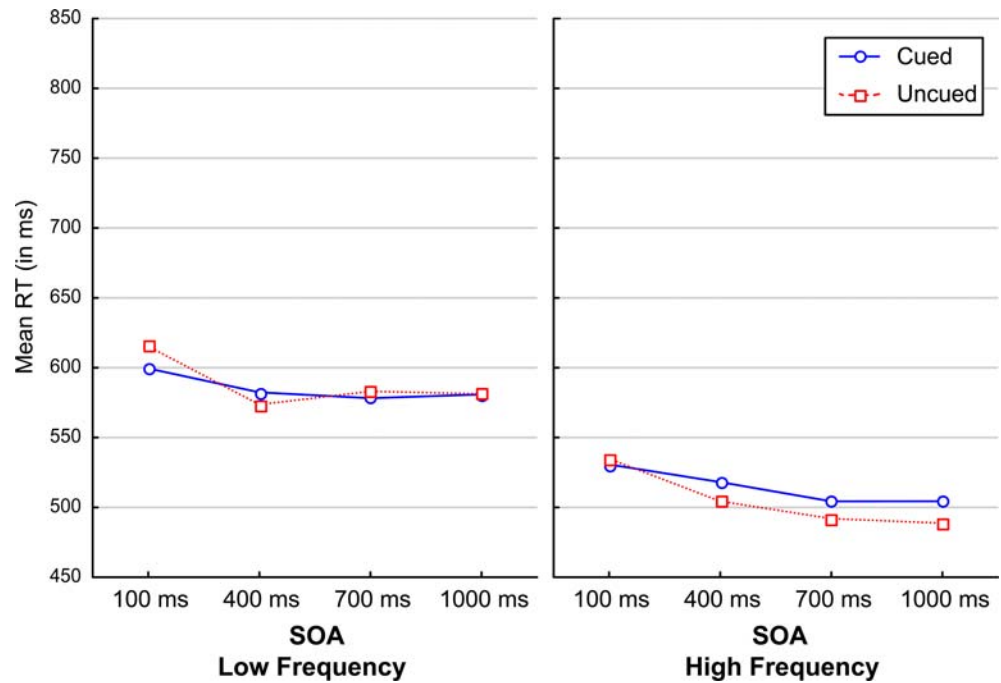
On the other hand, the time course of cuing effects in our modified discrimination task was very similar to that observed in detection tasks (compare Fig. 2 with detection data of Fig. 1); that is, the shift from facilitation to IOR occurred between the SOAs of 100 and 400 ms, so that IOR was already present in the 400 ms SOA. The fact that participants were set to detect the more frequent feature target probably led them to adopt a strategy like the one adopted naturally in a detection task (detection mode), which could be related to a fast disengagement of attention from the cued location.

Clearly, however, the difference in cuing effects for the frequent and the infrequent targets cannot be explained by positing different disengagement and re-orienting strategies (Lupiáñez, et al., 2001), nor by positing different attentional capture effects (Klein, 2000). Both of these explanations are ruled out by the fact that frequent and infrequent target conditions are identical up to the point in time at which the target itself appears. Thus, processes in the two conditions that differed at the time of onset of the target must be capable of affecting cuing effects.

A general framework for understanding this type of result assumes that an exogenous peripheral cue affects one or more processes, and that changes in task variables defined at target onset can alter how those cue-affected processes ultimately shape performance for the target. The implication of this general framework is that cuing effects are undefined until all of the parameters of target processing are set. If there is flexibility in these parameters after target onset, then theoretical accounts of cuing effects that focus only on processes that occur prior to target onset may be in error.

For example, consider the different time courses of cuing effects in detection and discrimination tasks (see Fig. 1). As said before, researchers have speculated that these different time courses could occur because attentional capture by the cue differs when one prepares for a detection task as compared to the preparation for a discrimination task (Klein, 2000), or because disengagement and re-orienting strategies differ in detection and discrimination tasks (Lupiáñez, et al., 2001). Both of these explanations focus on processes that occur prior to target onset. Consequently, these explanations overlook the interaction between task parameters at the time of target onset and prior cue-initiated processes. If those task parameters can be set on-line, and thereby produce different interactions with cue-initiated processes on-line, differences in cuing effects for detection and

**Fig. 3** Representation of the mean RT data obtained in Experiment 1. Note that the cuing effect across SOAs is different for the frequent and infrequent target–response assignments (stimulus–response mapping) (more negative for the frequent one)



discrimination tasks may be unrelated to processes that occur prior to target onset.

In sum, the most important result of this experiment was that cuing effects were significantly different for the frequent and the infrequent target trials. This result has important implications for our understanding of exogenous cuing, as it cannot be explained solely on the basis of any process occurring before the target onset. In contrast, the result can be accommodated by assuming that the processes triggered by an abrupt onset peripheral cue can manifest in different ways depending on processes that occur after target onset, and on their interaction with cue-initiated processes. In the [General discussion](#) we will elaborate on this idea.

## Experiments 2a and 2b

In Experiment 1, one of the targets was more frequent than the other, and different cuing effects were observed for frequent and infrequent targets. At the same time, one response was made to the frequent target and a different response was made to the infrequent target. Thus, the observed differences in cuing effects could be due to different target frequencies, different response frequencies, or to different frequencies of target–response mappings. To address this issue, we carried out two experiments in which frequency of target and frequency of response were manipulated orthogonally. In Experiment 2a, frequency of the target was manipulated while keeping response frequency equal for all targets, whereas in Experiment 2b, frequency of response was manipulated while keeping target frequency constant.

If target frequency alone was responsible for the pattern of results observed in Experiment 1, then a

similar pattern of results ought to be observed when target frequency is manipulated and response frequency is held constant (Experiment 2a). However, if response frequency is critical, then manipulating response frequency and holding target frequency constant (Experiment 2b) should produce the pattern of results observed in Experiment 1. A third possibility is that the pattern of results obtained in Experiment 1 depends on frequency of particular target–response mappings, in which case neither target frequency nor response frequency manipulations on their own will be sufficient to produce the same pattern of results. In this third case, one would expect the time course of cuing effects to be similar for frequent and infrequent targets, and the time course of cuing to be similar to that often observed in discrimination tasks (i.e., late appearance of IOR).

## Method

### Participants

Two groups of 32 psychology students from the Facultad de Psicología of the Universidad de Granada participated, one group in Experiment 2a and the other in Experiment 2b. Data from one participant in Experiment 2a were excluded from analyses because their responses to all trials in one condition were either incorrect or excessively slow.

### Procedure

The procedure was the same as in Experiment 1, apart from the following changes. To dissociate target

frequency and response frequency, the frequency of the target was manipulated in Experiment 2a (keeping response frequency constant), whereas the frequency of the response was manipulated in Experiment 2b (keeping target frequency constant). In Experiment 2a, for one group of participants the letter “X” appeared on 50% of the trials, whereas one of the letters “A”, “E”, “I”, “O” or “U” appeared on the remaining 50% of the trials (10% for each of five vowels). Participants were instructed to give priority to giving quick responses to the target X, which they did by pressing the ‘x’ key on the computer keyboard. Participants responded by hitting the ‘m’ key on the keyboard for any of the five vowel targets. For the other group of participants, a similar procedure was used, but the letter “O” appeared on 50% of the trials, whereas one of the consonants “X”, “G”, “F”, “L”, or “R” appeared on the remaining 50% of the trials (10% for each of five consonants). Note that this procedure ensured that each of two possible responses was equally frequent (50%), although one target was more frequent than the others (50 vs. 10%).

In Experiment 2b, each of four targets was equally frequent (25% of the trials). However, to manipulate the frequency of the response, three targets (“A”, “E”, “O” for half of the participants, and “X”, “G”, or “R” for the other half) were assigned the same response key, whereas a single target (the “X”, or the “O”, respectively) was assigned the other key. This way, all targets were equally frequent (25% each) although one response was more frequent than the other (75 vs. 25%).

### Design

As in Experiment 1, both Experiments 2a and 2b had a 2 (frequency; frequent, infrequent)  $\times$  4 (SOA; 100, 400, 700, 1,000 ms)  $\times$  2 (cuing; cued, uncued) within participants design. The only difference between Experiments 2a and 2b was that frequency meant frequency of the target in the former and frequency of the response in the latter. In contrast, in Experiment 1, frequency referred to frequency of target + response (i.e., target–response mapping).

### Results

As in Experiment 1, some trials with extreme values were considered outliers and eliminated from the RT analyses; trials with RTs faster than 200 ms or slower than 1,200 ms (0.30 and 2.93% of the trials, and 0.49 and 2.34%, respectively, for Experiments 2a and 2b). Trials on which an error was made were also excluded from the RT analysis. Means were computed for both RTs and error rates, and introduced into repeated measures ANOVAs, with Cuing (cued and uncued), SOA (100, 400, 700 and 1,000 ms) and frequency as factors. Note that frequency means target frequency in Experiment 2a

and response frequency in Experiment 2b. Mean RTs and error rates for each experimental condition and experiment are presented in Table 1.

### Analysis of RTs

In the ANOVA performed on the data from Experiment 2a, the main effects of target frequency and SOA were both significant,  $F(1, 30) = 7.94$ ,  $MSE = 9,667.67$ ,  $P < .01$ , and  $F(3, 90) = 11.83$ ,  $MSE = 1,613.64$ ,  $P < .0001$ , respectively, as was the interaction between these two factors,  $F(3, 90) = 3.07$ ,  $MSE = 1,485.57$ ,  $P < .05$ . As in Experiment 1, responses were faster for the frequent target, and decreased with SOA, in particular for the most frequent target. The cuing  $\times$  SOA interaction was significant,  $F(3, 90) = .13$ ,  $MSE = 2,168.16$ ,  $P < .001$ , showing the usual time course of cuing effects in discrimination tasks: facilitation at the 100 and 400 ms SOAs, and IOR at the 700 and 1,000 ms SOAs. An ANOVA performed on data from the two shortest SOAs revealed a significant facilitation effect,  $F(1, 30) = 11.68$ ,  $MSE = 2,452.44$ ,  $P < .005$ , that was independent of SOA ( $F < 1$ ). An ANOVA performed on data from the two longest SOAs revealed a significant IOR effect,  $F(1, 30) = 4.25$ ,  $MSE = 2,426.44$ ,  $P < .05$ , that was also independent of SOA ( $P > .25$ ). However, the most critical result was that cuing did not interact significantly with frequency in either of these analyses, ( $F < 1$  in both cases).

The analysis of the data from Experiment 2b also revealed significant main effects of response frequency,  $F(1, 31) = 61.52$ ,  $MSE = 11,193.85$ ,  $P < .0001$ , and SOA,  $F(3, 93) = 22.83$ ,  $MSE = 1,601.29$ ,  $P < .0001$ . Apart from these two effects, only the main effect of cuing and the SOA  $\times$  cuing interaction approached significance,  $F(1, 31) = 3.96$ ,  $MSE = 2,422.67$ ,  $P = .055$ , and  $F(3, 90) = 2.39$ ,  $MSE = 2,858.71$ ,  $P = .073$ , respectively. An ANOVA performed on data from the two shortest SOAs revealed neither a significant effect of cuing nor a significant interaction between cuing and SOA. An ANOVA performed on data from the two longest SOAs revealed a significant IOR effect,  $F(1, 31) = 11.85$ ,  $MSE = 2,315.29$ ,  $P < .05$ , that was independent of SOA ( $F < 1$ ). Again, the most critical result was that cuing did not interact significantly with frequency in either of these analyses, ( $F < 1$  in both cases).

### Analysis of the error rates

In the analysis of the error rates of Experiment 2a, the only significant effect was the interaction between SOA and cuing,  $F(3, 90) = 4.66$ ,  $MSE = .008$ ,  $P < .005$ , reflecting the usual facilitation effect at the 100 and 400 ms SOAs, and IOR at the two longest SOAs. The analysis of the data from Experiment 2b revealed a significant main effect of response frequency,  $F(1, 31) = 52.76$ ,  $MSE = .146$ ,  $P < .0001$ , and significant SOA  $\times$  cuing, and SOA  $\times$  cuing  $\times$



response frequency interactions,  $F(3, 93)=8.15$ ,  $MSE=.009$ ,  $P<.0001$ , and  $F(3,93)=7.57$ ,  $MSE=.010$ ,  $P<.0005$ . Generally speaking, the pattern of errors was consistent with that of the response times described above.

## Discussion

The goal of this experiment was to distinguish between target frequency and response frequency as an explanation for the pattern of results obtained in Experiment 1. This goal was accomplished by orthogonally manipulating these two factors in Experiments 2a and 2b. In neither experiment was the pattern of results similar to that obtained in Experiment 1: As can be seen in Fig. 4, IOR was not present until the 700 ms SOA, and it was not different for the frequent and infrequent target/response conditions.

However, the general time course of cuing effects observed in Experiments 2a and 2b was different to that observed in Experiment 1, and more similar to the time course usually observed in a discrimination task (compare Figs. 2 and 3). This was confirmed in an ANOVA performed on the data from Experiments 1 and 2 that included experiment as a between participants variable. This analysis revealed a significant Experiment  $\times$  SOA  $\times$  cuing interaction,  $F(3, 279)=3.13$ ,  $MSE=1,829.98$ ,  $P<.05$ . Whereas in Experiment 1 the shift from facilitation to IOR occurred between the 100 and 400 ms SOAs, as is usual in a detection task (see Fig. 1), in Experiment 2 this shift occurred between the 400 and 700 ms SOAs, as is usual in a discrimination task (see Fig. 1). In fact, the only SOA at which the cuing effect was significantly different

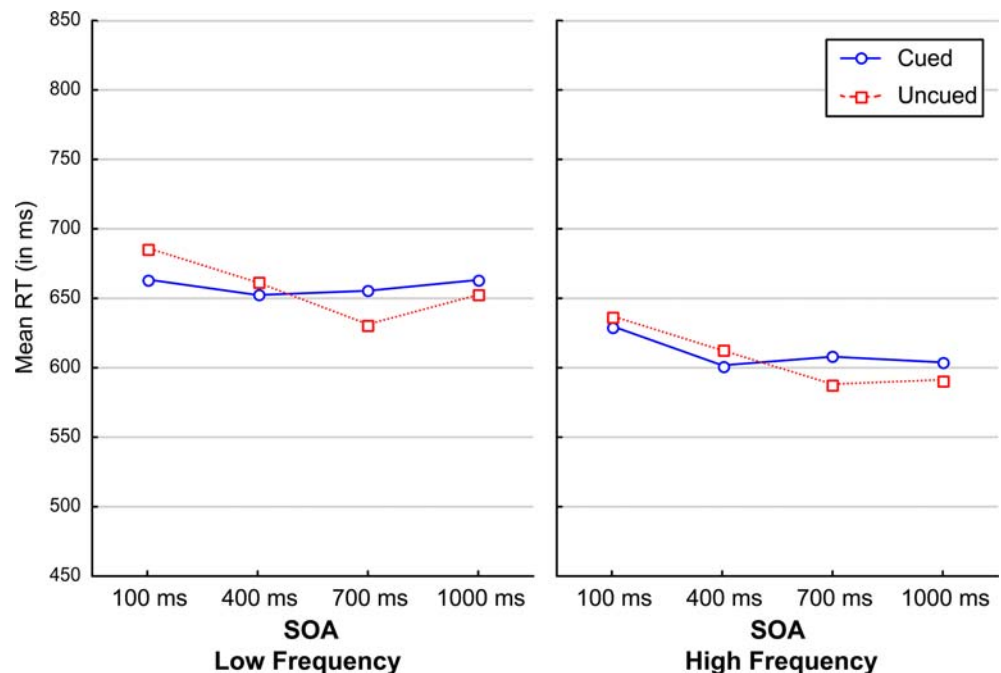
between Experiments 1 and 2 was that of 400 ms,  $F(1, 93)=4.30$ ,  $MSE=2,163.48$ ,  $P<.05$ .

Thus, the detection-like time course of the cuing effects observed in the discrimination task of Experiment 1 seems to be due to the adoption of a feature “detection mode”, in which both a specific target (unique feature) and a simple response are anticipated. The critical characteristic of Experiment 1 that induced participants to adopt this “detection mode” seems to have been the high frequency of a specific target–response mapping. This result is consistent with the results reported by Briand and collaborators (Briand, Larrison & Sereno, 2000; Khatoon, Briand & Sereno, 2002), who have shown that IOR appears earlier for more direct stimulus–response mappings (e.g., ocular rather than manual localization, or saccade rather than antisaccade localization).

## Experiment 3

Given the theoretical importance of the target frequency modulation of cuing effects obtained in Experiment 1, a replication seems necessary. Taking into account the results from Experiments 2a and 2b, we have proposed that this target frequency modulation is related to knowledge of both a likely target feature and the response to be made to that target. This knowledge lends itself to adoption of what we refer to as a detection mode, in which a likely stimulus–response mapping is prepared prior to target onset. Under these conditions, it is, therefore, not surprising that the time course of cuing effects corresponds to that often observed in detection tasks, with IOR emerging at relatively short SOAs. In

**Fig. 4** Representation of the mean RT data obtained in Experiment 2. Data from Experiments 2a and 2b are collapsed as the results were very similar regarding our main interest. Note that the cuing effect across SOAs is the same for the frequent and the infrequent trials in this experiment, where frequency meant frequency of either the target or the response



contrast, when a likely stimulus–response mapping cannot be prepared prior to the target, the time course of cuing effects corresponds more closely to that typically observed in discrimination tasks, with IOR emerging at relatively long SOAs.

In the present experiment, we aimed to highlight the different processes underlying cuing effects for different target types by using a qualitative differences approach. Specifically, our objective was to illustrate that cuing effects for frequent and infrequent targets can differ not only quantitatively, as in Experiment 1, but also qualitatively. To test this hypothesis, we manipulated frequency of the target and response (stimulus–response mapping), as in Experiment 1. At the same time, we increased the level of discrimination that was necessary for responding on infrequent target trials. The frequent target trials were exactly the same as in Experiment 1: either an X or an O served as the frequent target, requiring the same simple response as in Experiment 1. For the infrequent target trials, however, one of two difficult-to-discriminate targets appeared. Thus, participants responded to the frequent targets on the majority of trials, but were required to discriminate between two potential infrequent targets on the remainder of the trials.

With this manipulation we expected participants to adopt the same feature detection mode as in Experiment 1, but they would have to perform a more difficult discrimination on infrequent trials. Thus, we expected a fast transition from facilitation to IOR, and different cuing effects for frequent and infrequent targets. More important, by increasing the discrimination difficulty associated with infrequent targets, we predicted that the difference in cuing effects between frequent and infrequent targets would be amplified relative to Experiment 1, revealing IOR for frequent targets and the opposite result for infrequent targets. Note that the observation of qualitatively different results is crucial for our theoretical argument that attentional capture can manifest differently depending on target processing requirements. Otherwise, the results of Experiment 1 could be easily explained by assuming that different tasks are more or less affected (quantitatively) by allocation of attentional resources.

## Method

### *Participants*

Thirty-three psychology students from the Facultad de Psicología of the Universidad de Granada participated in the experiment. Data from one participant, who made either excessively long or incorrect responses on all trials in several infrequent experimental conditions, were eliminated from the analyses.

### *Materials and procedure*

These were the same as in Experiment 1, apart from the fact that there were two different infrequent targets and

responses. Thus, for the group for which the letter “X” appeared on 75% of the trials, the letters “O” and “U” each appeared on 12.5 % of the trials. For the group for which the letter “O” appeared on 75% of the trials, the letters “X” and “F” each appeared on 12.5% of the trials. As in Experiment 1, participants were given instructions to give priority to the most frequent target. Half of the participants responded to the most frequent target by pressing the “m” key on the keyboard, with the index finger of their right hand, and the “z” or “x” key (left hand) for each of the infrequent targets; the other half responded by pressing the “x” key (left hand) for the frequent target, and the “m” or “n” key (right hand) for the infrequent targets.

### *Design*

As in all the previous experiments, this experiment had a 2 (Frequency; frequent, infrequent)  $\times$  4 (SOA; 100, 400, 700, 1,000 ms)  $\times$  2 (cuing; cued, uncued) within participants design. As in Experiment 1, frequency referred to frequency of both target and response, with the infrequent target being even less frequent than in Experiment 1 (12.5 vs. 25%).

## Results

As in previous experiments, trials with extreme values were considered outliers<sup>1</sup>. Thus, trials with RTs faster than 200 ms or slower than 1,550 ms (.33 and .90% of the trials, respectively), and trials on which an error was made, were excluded from the RT analysis. Means were computed for both RTs and error rates, and introduced into repeated measures ANOVAs, with cuing (cued and uncued), SOA (100, 400, 700, and 1,000 ms) and Frequency as factors. Mean RTs and error rates for each experimental condition are presented in Table 1.

### *Analysis of RTs*

The ANOVA revealed significant main effects of both Frequency and SOA,  $F(1, 31) = 227.61$ ,  $MSE = 31,850.51$ ,  $P < .0001$ , and  $F(3, 93) = 23.48$ ,  $MSE = 2,031.68$ ,  $P < .0001$ , respectively. Responses were faster on the frequent target–response trials and at longer SOAs.

Interestingly, as can be observed in Fig. 5, we replicated the frequency  $\times$  cuing interaction obtained in Experiment 1,  $F(1, 31) = 9.91$ ,  $MSE = 3,022.74$ ,  $P < .005$ . Even more interesting was the analysis of this interaction with LSD tests, which, as predicted, showed a significant positive effect (16 ms; faster RT for cued than for uncued trials,  $P < .05$ ) for infrequent target–response trials, and IOR (–14 ms; slower RT for cued than for uncued trials,  $P < .05$ ) for the more frequent target–response trials. No

<sup>1</sup>A different cut-off was used given that RT was quite higher in this experiment.

other effect was significant. The  $SOA \times$  cuing interaction was not significant, as the same cuing effect was obtained at all SOAs.

#### Analysis of the error rates

In the analysis of the error rates, the only significant main effect was that of frequency,  $F(1,31)=74.86$ ,  $MSE=.095$ ,  $P<.0001$ . Although a high error rate was observed in responses to the infrequent targets (see Table 1), the accuracy (.72) was far above chance levels (.125 for each of the infrequent target conditions).

As in the RT analysis, frequency also modulated the cuing effect, although the interaction was only marginally significant,  $F(1, 31)=3.34$ ,  $MSE=.014$ ,  $P=.077$ . Responses were more precise for cued than for uncued trials in the trials with the infrequent target–response (.035 error rate), and less precise (–.004 error rate; IOR) in the trials with the frequent target–response, although only the former reached significance in the corresponding analyses with the LSD test,  $P<.05$ .

#### Discussion

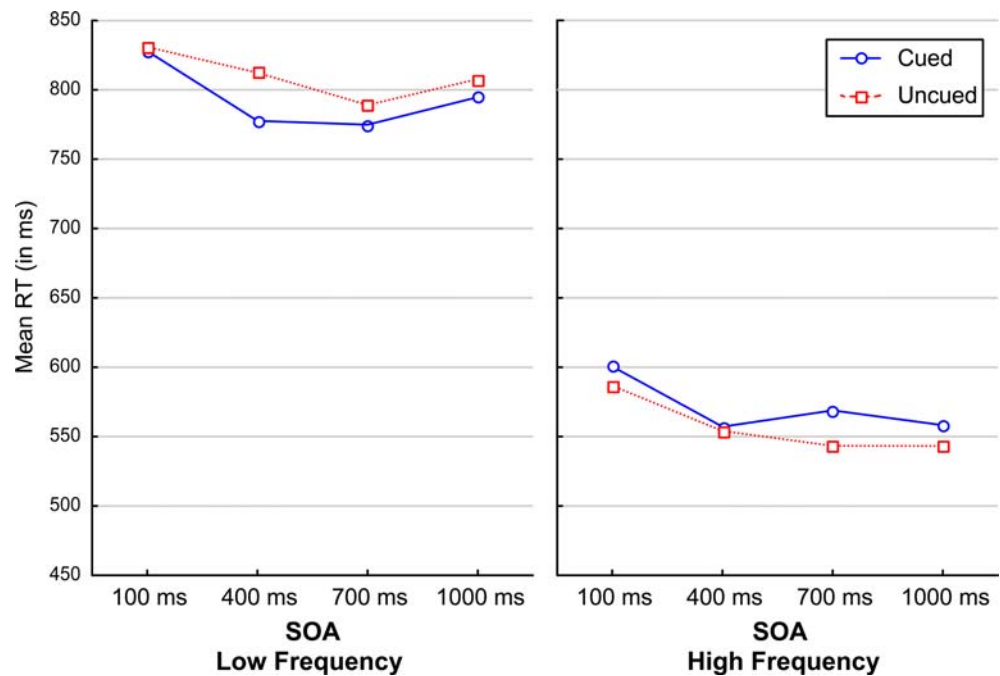
The pattern of results obtained in Experiment 1 was replicated in this experiment, in which target–response frequency (stimulus–response mapping) was manipulated within a block of trials. Thus, when participants were expecting a unique target feature, to be responded to by emitting an already prepared simple response, an IOR effect that was constant across SOA was observed. According to the usual interpretation of the  $SOA \times$  cuing interaction, this result implies that attention was

captured at the cued location but it was reoriented to fixation very quickly, even prior to onset of the target in the 100 ms SOA condition. Although this result seems at odds with the time course of cuing effects often observed (Posner & Cohen, 1984), there are several findings in the literature that are consistent with our results. Indeed, with a variety of procedures, IOR has been obtained by other researchers at SOAs as short as 100 ms (Briand, et al., 2000; Danziger & Kingstone, 1999; Tassinari, Aglioti, Chelazzi, Peru & Berlucchi, 1994). Thus, the fact that our participants were instructed to prepare themselves for detecting the frequent target feature, and to respond as fast as possible to it, seems to have led them to adopt a strategy to detect the frequent target and emit an already prepared response. We have argued that this strategy might be implemented by quickly disengaging attention from the cued location. The purpose of this quick disengagement is presumably to segment in time the cue and target representations so as to be maximally sensitive to onset of a new event.

The most important result, however, was that cuing effects for the infrequent targets were qualitatively different from those observed for frequent targets. Whereas IOR effects were observed in the frequent target condition, facilitation effects were observed in the infrequent target condition. That is, even when participants were set to detect the frequent target, on those trials where the expected target feature was not detected, participants had to shift their set to solve the task, which in this case allowed cue-initiated processes to have a positive rather than negative influence on performance.

As we have mentioned before, these results are consistent with the results obtained by Ivanoff and Klein (2004). The fact that they observed IOR for both frequent and infrequent targets (although smaller for the

**Fig. 5** Representation of the mean RT data obtained in Experiment 3. Note that the cuing effect does not change much across SOAs. However, it is qualitatively different for the frequent and the infrequent target–response assignment (IOR vs. facilitation, respectively)



infrequent one), whereas we observed facilitation for the infrequent targets, might be due to the great perceptual difficulty of the discrimination that was necessary for our infrequent targets. Alternatively, the discrepancy might be due to the fact that, unlike us, Ivanoff and Klein used a cue-back-to-fixation procedure. In any case, it is noteworthy that they did observe a facilitatory effect for the infrequent target in Experiment 2, as reflected by a significantly smaller error rate for the cued infrequent target than for the uncued infrequent target.

As stated before, qualitatively different cuing effects for frequent and infrequent targets cannot be attributed to differences in attentional capture or to differences in orienting–reorienting of attention after capture. Any modulation of these two types of processes ought to be the same for the two targets, as frequent and infrequent target trials are indistinguishable until the target appears. Instead, we propose that the qualitatively different cuing effects have to be explained as different manifestations of attentional capture and orienting, depending on the processes being tapped by target–response processing on frequent and infrequent target trials.

Given the strategy we followed to measure qualitative differences in cuing effects (i.e., making one of the targets and its paired response highly infrequent), there was a high error rate in the infrequent condition, which could pose interpretational problems for the RT data. Note however, that the interpretational problems are minimized by the fact that, in spite of responses being inaccurate, they are well above chance levels. The error rates are especially high in the infrequent condition, where it is quite unlikely to give the correct response by chance. Nevertheless, an important issue for future research will be to demonstrate that these qualitative differences in cuing effects as a function of target type replicate without high error rates for one of the target types.

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### Overall analysis of Experiment 1–3

To test the reliability of our two main findings, we conducted an overall analysis of the data from the three experiments<sup>2</sup>.

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<sup>2</sup>A similar analysis was performed on the mean RTs in order to study the role of target frequency on the S–R compatibility or Simon effect. This mixed ANOVA treated frequency, S–R compatibility (ipsilateral vs. contralateral), and SOA as within participants variables, and nature of frequency (target-plus-response, i.e., Experiments 1 and 3, vs. target-or-response, i.e., Experiments 2a and 2b) as a between participants variable. The analysis showed a significant Simon effect,  $F(1, 125) = 24.52$ ,  $MSE = 137,888,320.54$ ,  $P < .0001$ , which was significantly modulated by Frequency,  $F(1, 125) = 4.20$ ,  $MSE = 20,658.43$ ,  $P < .05$ . The Simon effect observed for the frequent targets (23 ms faster RT for ipsilateral than contralateral targets) was reduced to 10 ms for the infrequent targets. However, in contrast to cuing, the modulation of frequency on the Simon effect was independent of the nature of frequency ( $F < 1$ ).

These data were introduced into a mixed ANOVA that treated frequency, cuing, and SOA as within participants variables, and nature of frequency (target-plus-response, i.e., Experiments 1 and 3, vs. target-or-response, i.e., Experiments 2a and 2b) as a between participants variable. The analysis of the RTs showed that the nature of frequency modulated both the frequency  $\times$  cuing and the cuing  $\times$  SOA interactions,  $F(1, 125) = 5.72$ ,  $MSE = 1,940.87$ ,  $P < .02$ , and  $F(3, 375) = 2.77$ ,  $MSE = 2,155.80$ ,  $P < .05$ , respectively.

Importantly, in the target-plus-response experiments (Experiment 1 and 3), frequency modulated cuing,  $F(1, 63) = 15.47$ ,  $MSE = 1,919.27$ ,  $P < .0005$ , whereas in the target-or-response experiments frequency did not interact with cuing ( $F < 1$ ). In the former group, responses were 10 ms faster for cued than for uncued trials ( $P < .02$ , by LSD test) in the infrequent target trials, whereas the opposite result ( $-12$  ms IOR,  $P < .005$ ) was observed in the frequent target trials.

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### General discussion

Prior studies have demonstrated that the time course of exogenous spatial cuing effects is not hard-wired, but rather depends on endogenous factors such as the task to be performed with the target (Briand, et al., 2000; Lupiáñez, et al., 1997; Lupiáñez & Milliken, 1999; see Klein, 2000, for a review). At a descriptive level, the differences in the time course of cuing effects (transition from facilitation to IOR) as a function of task can take on two forms (Lupiáñez, et al., 2001): a) cuing effects can differ for two tasks consistently across all SOAs, or b) cuing effects can differ for two tasks because a shift from facilitation to IOR, perhaps associated with disengaging attention from the cue, differs between tasks. Interestingly, both of these task influences on cuing effects can alter the SOA at which IOR emerges (compare Figs. 3 and 4 in this paper, or detection vs. discrimination in Lupiáñez, et al., 1997, Fig. 1 in this paper; see also Khatoon, et al., 2002).

At a theoretical level, two explanations can be forwarded for the observed differences in the time-course of cuing across task sets (see Khatoon, et al., 2002, for a different exposition): the *bigger capture* hypothesis, and the *later disengaging* hypothesis. As stated in the introduction (see Fig. 1), the later appearance of IOR in discrimination-like tasks, or tasks that use indirect stimulus–response mappings (Khatoon, et al., 2002), could be caused by a bigger attentional capture by the cue for more difficult tasks (Klein, 2000). This explanation would easily account for the first pattern of data described above (a). Alternatively, the later appearance of IOR might be due to a later disengaging of attention in difficult tasks. This explanation would easily account for the second pattern of data described above (2). Importantly, this explanation elegantly accommodates the different time-courses of cuing observed in Experiment 2 on the one hand (in which the transition from

facilitation to IOR occurred between 400 and 700 ms), and in the Experiments 1 and 3 on the other hand (in which the transition occurred much earlier). Note that, in our experiments, the SOA  $\times$  cuing interaction (and not just the main effect of cuing) was modulated by task set, a result that is explained nicely by the late disengaging hypothesis.

However, our second important finding can be accommodated neither by the “bigger capture” nor by the “later disengaging” hypothesis. Even when attentional capture and disengaging are controlled by manipulating task set randomly within a block of trials, as in our experiments, the measured cuing effect depended on the kind of target to which participants had to respond. Especially relevant to this issue are the data from Experiment 3 (or the re-analysis of Experiments 1 and 3), in which we observed qualitative differences: significant facilitation for one kind of target but IOR for the other. These differences cannot be explained by the two outlined hypotheses, because both assume that the critical difference across task set (either in the capture or the disengaging of attention) occurs before the target appears, whereas these processes are held constant in our procedure.

To make this point clear, consider the idea that the different cuing effects for the different target types can be explained by a task set that contains conditional rules, with frequent targets eliciting different task-related processes than infrequent targets. Within this general framework, it is not difficult to imagine that there could be quite different performance effects for target types that elicit different task-related processes. However, it is difficult to imagine how the “bigger capture” or “later disengaging” hypotheses would be incorporated in these conditional rules, as these hypotheses refer to how the attentional cue is encoded and how long attention dwells on the attentional cue, respectively. Different target types mixed randomly within the experimental session cannot elicit different ways of encoding the attentional cue, or different strategies related to disengagement, as both encoding of the cue and disengagement from the cue occur prior to target onset. Alternatively, if the notion of task set is to be used to explain the present results, it must incorporate the idea that the same “cue processing” can interact in different ways with different task-related processes elicited at the time of target onset. In effect, task set may be a useful construct to explain the present results but only if such a task set specifies how target and preceding cue representations are to be integrated, rather how a cue is to be encoded. As most theoretical account of spatial cuing effects focus on processes that occur prior to target onset, the merit in the present results is that they force consideration of cue–target integration processes that can be altered dynamically in response to target task demands. Put differently, what has to be explained is how one and the same attentional capture can manifest itself in opposite effects as a function of the target that has to be processed and responded to. In the following we forward such an explanation.

At the heart of our theoretical account is the idea that a cue can trigger multiple processes (likely in multiple brain areas), and that each of these processes can have either a positive or negative influence on various stages of target processing. By manipulating the nature of the target, the contribution of each of these processes to a target response varies, thus leading to a net effect of cueing that can be positive or negative, depending on the relative contribution of each process.

In particular, we propose that processes elicited by an exogenous cue can hinder processes required to detect a following target at that location. Note that for uncued trials, onset of the target is spatially distinct from that of the cue, and this distinctive onset may provide a robust signal of the presence of the target. In contrast, for cued trials, the onset of the target is not spatially distinct from that of the cue, and this absence of spatial distinctiveness may produce perceptual confusion in target detection. The mechanism that underlies this perceptual confusion may be related to the requirement to integrate a single spatial location with two different event representations, a possibility that points to a link between IOR and action-induced blindness effects (see Müsseler & Hommel, 1997; Oriet, Stevanovski, & Jolicoeur, 2005). In any case, distinctly different spatial codes for cue and target are presumed to underlie faster detection of a target in an uncued (new) location than in a cued (old) location. A reasonable neural substrate for this “detection cost” for cued trials would be areas of the dorsal stream, which are known to be important for transient processing of visual information.

At the same time, we propose that an exogenous cue can facilitate other aspects of processing a target at the same location, in particular those required to discriminate the identity of a target. More specifically, the cue might help to spatially select the cued object representation as a target for more analytic processes. A reasonable neural substrate for this “spatial selection benefit” would be areas of the ventral stream, which are known to be important for the more sustained processing required in fine perceptual discriminations.

Depending on the relative contribution of these areas and processes, which express different consequences of attentional capture on performance (a “detection cost” vs. “spatial selection benefit”), the net cuing effect that is measured on RT to the target can be either negative or positive. In a situation that supports the processing of different kind of targets using qualitatively different processes, perhaps also tapping different brain areas, it is possible that the same capture of attention could manifest itself in qualitatively opposite effects, as observed in Experiment 3. Responding to a frequent easy-to-detect target (or using a direct stimulus–response mapping) emphasizes the processes normally required in a detection task; a perceptual template is readied in anticipation of a particular target feature and an already-prepared response. Thus, the biggest contribution to target RT would be that of areas suffering from the “detection cost”, while not much contribution would be measured

from the areas benefiting from the “spatial selection benefit”. As a result, the net effect of cueing would be negative. In contrast, the areas responsible for the spatial selection benefit would contribute most strongly for infrequent targets (fine discrimination is needed), thus leading to a positive net effect of cueing.

Our hypothesis is related to that of Tipper, et al. (1997) (as stated in Khatoon, et al., 2002), who explicitly state that the cuing effect that is measured in a cuing paradigm is the additive effect of two cuing components: decreasing facilitation and increasing inhibition across SOA. Also, it is related to Khatoon, et al.’s (2002) hypothesis, which is a more neurologically specified version of the facilitatory and inhibitory components of the Tipper, et al. account. However, our understanding of these two hypotheses is that the influence of the cue (excitatory or inhibitory) is set before the target appears (during the interval between cue and target), and what is measured in the RT to the target is the net result of the excitatory and inhibitory forces on the representation that is needed to process the target. Thus, different forces add (facilitation) or subtract (inhibition) activation to a representation whose net activation value at the moment the target appears (positive or negative) will determine the nature of the cuing effect that is measured (facilitation or IOR).

Note, however, that this explanation would not be able to account for our results (positive or negative cuing effect depending on the target). Furthermore, our hypothesis does not require a specific brain area or representation to be inhibited when the target appears in order to observe an IOR effect. In fact, this idea would be at odds with our results, given that it would imply that the cuing effect at long SOAs should always be measured as IOR (negative for the frequent and the infrequent target). Instead, we only have to assume that activation of a given representation is detrimental for some processes needed for the task to be performed with a given target, leading to what we have called a “detection cost”. In fact, a recent finding by Dorris, Klein, Everling and Munoz, (2002) might be interpreted this way. They found that neurons of the superficial and intermediate layers of the superior colliculus, which show an attenuated visual response to a target preceded by a peripheral non-informative cue (i.e., which show IOR), were not inhibited at the time of target onset. Rather, their activity was actually elevated above baseline level.

Clearly, this finding is difficult to reconcile with a strictly inhibitory hypothesis of IOR. If there is activation at the superior colliculus at the moment the target appears, the net effect of this activation should be positive. However, we suggest that activation of the superior colliculus at the moment the target appears may have two different consequences, depending on the task required. On the one hand, this small activation could lead to a loss of attentional capture by the target (i.e., the sudden increase in activation produced by the target is masked by the previous activation of the cue). In

contrast, the target might capture attention at the uncued location, given that in its corresponding superior colliculus, which is at baseline, an increase in activation would be easily detected. Note that this attentional capture is all that is necessary for performing a detection task (or to respond to the frequent target in our experiments). Thus, the cost measured at the cued location can be considered a “detection cost”, as outlined in our hypothesis.

However, the same collicular activation (and its connections to cortical areas) might have a positive consequence on target discrimination, by aiding in the selection of the spatial location where the discrimination must be performed. This process could comprise the “spatial selection benefit” that we outlined earlier. Again, depending on the relative contribution of these two kinds of processes to overall target processing, the measured cuing effect can be either positive or negative. In this way, it is possible to observe qualitatively different cuing effects (facilitation vs. IOR) for different targets, which require completely different processes, as occurred in our Experiment 3.

In summary, in the present paper we have outlined three different types of processes that could contribute independently to exogenous cuing and attentional capture effects, at least when a cue–target procedure is used: Attentional capture itself, subsequent orienting processes, and cue–target integration processes that affect the manifestation of attentional capture in performance. An observed difference in performance between cuing conditions (cued vs. uncued) cannot be directly attributed to the size of the attentional capture, or to the speed of disengaging of attention after the capture, without also considering the role of processes related to the manifestation of attentional capture in performance that occur upon onset of the target. This notion that spatial cuing effects can only be fully understood by considering the processes tapped by target processing is very similar to a theme that has characterized memory research for the past 30 years. In particular, memory researchers discovered some time ago that the “strength” of a memory trace was not an overly useful construct without also specifying the retrieval parameters (cues) inherent to an attempt to retrieve that memory trace.

Thus, when investigating endogenous factors that modulate exogenous cuing or attentional capture (see Ruz & Lupiáñez, 2002, for a review) it is important to dissociate the contribution to performance of attentional capture itself, attentional reorienting processes, and other processes more related to the manifestation of attentional capture. These dissociations may prove to be an interesting focus of future research. One empirical approach is to keep one or more factors constant, as in the present experiments, while manipulating others. An alternative approach would be to take different measures of the various processes, such as event related potentials (ERPs; Arnott, Pratt, Shore & Alain, 2001), to get a direct measure of the processing of the cue (and processing during

the cue–target interval), without the necessity of an overt response.

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