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Cue and Target Processing Modulate the Onset of Inhibition of Return

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Inhibition of return (IOR) is modulated by task set and appears later in discrimination tasks than in detection tasks. Several hypotheses have been suggested to account for this difference. We tested three of these hypotheses in two experiments by examining the influence of cue and target level of processing on the onset of IOR. In the first experiment, participants were required to respond to both the cue and target. The pattern of results showed that deeper processing of the cue or target advanced the onset of IOR. In the second experiment, participants were not required to respond to the cue and a reverse pattern of results emerged, which replicated the general findings in cuing tasks. We conclude that in more-demanding tasks, an additional process slows down the processing of a nonpredictive cue in order to enhance the processing of the target.

Keywords: exogenous orienting, IOR, cue processing

The mechanism underlying the relation between processing demands related to the task at hand (e.g., detection vs. discrimination tasks) and the time course of attentional effects is unclear. There are several proposals regarding potential mechanisms, although they have never been empirically examined in the same study. This work aimed at investigating the effects of processing demands of a nonpredictive cue and target on the deployment of spatial attention.

In exogenous spatial cueing (Posner & Cohen, 1984), the typical pattern of results is an early facilitation followed by inhibition. That is, at short stimulus onset asynchronies (SOAs), reaction time (RT) for valid trials (i.e., target and cue presented at the same spatial location) is faster than for invalid trials (i.e., target and cue presented at opposite locations). At longer SOAs, however, RT is slower for valid than for invalid trials. The latter effect was termed inhibition of return (IOR) and has been the focus of research since it was discovered by Posner and Cohen (1984).

A suggested mechanism underlying IOR has been proposed by the *reorienting* hypothesis. According to this view, once attention has been engaged in a spatial location, an inhibitory mechanism emerges, favoring the processing of novel and nonpreviously attended locations (Klein, 2000). Several studies have weakened the reorienting theory by demonstrating that IOR can appear at locations from which attention has not been disengaged. Some have demonstrated the appearance of IOR at fixated locations (Maylor & Hockey, 1985; Rafal, Davies, & Lauder, 2006), while others have demonstrated that IOR can be observed at endogenously attended locations (Berger, Henik, & Rafal, 2005; Chica, Lupiáñez, & Bartolomeo, 2006; Lupiáñez et al., 2004). Recently, Chica and Lupiáñez (2009) used event-related potentials to demonstrate that the physiological marker of IOR (a reduced P100 at valid as compared to invalid locations, which correlates with IOR) can be observed even when attention is endogenously oriented to the cued location. This suggests that IOR may occur regardless of the endogenous allocation of attention. The reorienting hypothesis could survive this challenge if one proposes that attention has to be exogenously disengaged from the cued location to observe IOR. Disengagement from the cued location was also suggested to explain the difference in the onset time of IOR as a product of task demands (see below).

Many studies have examined the causes and time course of IOR (see Klein, 2000, for a review), but several questions still remain unanswered. One remaining issue concerns the effect of task demands on the time course of IOR. It was originally assumed that IOR did not appear in discrimination tasks (Terry, Valdes, & Neill, 1994), although a later work by Lupiáñez and coworkers (Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997) showed that IOR is observed in discrimination tasks, although its onset was delayed as compared to detection tasks. Several theoretical suggestions have been proposed to explain this time course difference. For example, based on the reorienting hypothesis, Klein (2000) suggested that the difference in time course between the tasks is a

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product of a change in attentional control. In a more-demanding task (such as in discrimination tasks), participants have to pay more attention to the target. Changing the attentional set between the cue and target is unlikely, given that in the kind of paradigms used to explore validity effects, the time between the cue and target is normally short, usually ranging between 100 ms and 1,000 ms (see Lupiáñez et al., 2006 and Klein, 2000, for reviews). Therefore, the same attentional control required for target processing would also be applied to cue processing. This increased attentional focusing on the cue would delay the disengagement of attention from the cued location and, as a result, delay the appearance of IOR in discrimination tasks as compared to less demanding detection tasks.

A different hypothesis was proposed by Lupiáñez and his coworkers (Luo, Lupiáñez, Fu, & Weng, 2010; Lupiáñez, Ruz, Funes, & Milliken, 2007; Ruz & Lupiáñez, 2002). Lupiáñez (2010) used Kahenman, Treisman, and Gibbs' (1992) terminology of object files to account for cuing effects. They propose that the peripheral cue is an event occupying a specific location, which can lead to perceptual effects on the processing of subsequent stimuli appearing at the same location. Targets appearing in close spatiotemporal proximity might be integrated within the same object file (Kahneman, Treisman, & Gibbs, 1992), thus being more easily selected for further analysis. Hence, cue-target integration would facilitate processing by helping select the target location in advance, an effect termed "spatial selection" benefit. Since the primary goal in discrimination tasks is to identify the stimulus, then cue-target integration into the same object file would facilitate processing by helping select the target location in advance (Lupiáñez, 2010). This process was suggested to be responsible for larger facilitatory effects in discrimination than in detection tasks, delaying IOR. In the case of discrimination tasks, the cue and target do not usually share any task-relevant features, and therefore, cue-target integration should not interfere with the discrimination of target features. In contrast, in a detection task, the cue and target usually share the most important feature necessary to respond to the target. They usually are both onsets, and therefore, in order to perform the task, segregation of cue and target into different object files is necessary in order to avoid confusion on whether an onset cue or an onset target occurred in a given trial, an effect termed "detection cost." The segregation of cue and target into separate object files accelerates the onset of IOR. Thus, this proposal assumes that participants adopt a mental set to integrate the cue and target into the same object file during discrimination, but not during detection tasks. In the latter, a segregation of cue and target into separate object files occurs, and the formation of a separate object file for the cue accelerates the onset of IOR.

A third hypothesis about the later appearance of IOR in discrimination than in detection tasks proposes that different tasks recruit different activation patterns of the locus coeruleus-norepinephrine (LC-NE) system (Gabay & Henik, 2010; Gabay, Pertzov, & Henik, 2011). Aston-Jones and Cohen (2005) presented a theory that suggests two different modes of activity—tonic and phasic—of the LC. In the tonic mode, LC neurons fire constantly. This mode is efficient during exploration for new rewards. In contrast, the phasic firing mode causes specific activation for rewarding targets but not for distractors (such as a nonpredictive cue). The shift between the two modes is guided by the anterior cingulate (ACC) and orbitofrontal (OFC) cortices, both of which are considered to be involved in monitoring the utility of stimuli for goal-directed behavior and external feedback. It has been demonstrated that simple discrimination tasks (e.g., discriminating between horizontal and vertical lines) produce phasic firing of the LC in nonhuman primates (Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994; Clayton, Rajkowski, Cohen, & Aston-Jones, 2004). It has also been suggested that the phasic firing mode promotes focused selective attention and the tonic firing mode promotes scanning, labile attention (Aston-Jones, Rajkowski, & Cohen, 2000). Gabay et al. (2011) suggested that different modes of activity of the LC-NE system are employed during different attentional tasks. Specifically, during a demanding discrimination task, the LC-NE system functions in a phasic mode, since more resources are required in order to process the target and no resources are spared to process irrelevant information. In contrast, during an easier detection/localization task, the LC-NE system is activated in a tonic firing mode. According to Aston-Jones and Cohen (2005), the phasic mode also acts as a temporal filter for distractors; hence, in this mode the LC-NE system releases lower levels of tonic NE during the presentation of distractors. The nonpredictive cue in an exogenous orienting task may be considered as a distractor. According to this view, the reduced tonic firing of the LC at the moment of cue presentation can account for the delayed appearance of IOR in discrimination tasks. Such lower levels of NE during the presentation of the cue might slow down its processing and the attentional effects associated with its appearance (e.g., IOR). This view implies that in discrimination tasks, the processing of the exogenous cue is reduced as compared to in a detection/localization task, in which processing of the target is less demanding. According to this logic, deeper processing of the cue accelerates the onset of IOR (in contrast to Klein, 2000).

The Current Work

The purpose of this work was to study the mechanism that underlies the influence of the cue and target level of processing on the time course of IOR. We manipulated the level of cue and target processing (localization vs. discrimination) using a factorial design. The use of localization and not detection tasks in this work was intended to maintain equivalent motor demands in both tasks (two forced-choice responses). We employed a cuing task, in which both cues and targets were letters. During the task, participants were presented with a cue (the letter X or O in a specific color, e.g., green), followed by a target (the letter X or O in a different color, e.g., red). Participants were asked to respond to both cue and target. They responded to the target first, as fast and as accurately as possible. After responding to the target, participants were asked to answer a *yes/no* question regarding the cue. The crucial manipulation here involves the level of processing of the cue and target. We manipulated target and cue level of processing (between participants) by changing the property of the stimuli to which participants responded to. When target discrimination was required, participants were asked to identify the letter by pressing one button for an X and another for an O. When target localization was required, participants were asked to press a left button for targets appearing on the left and a right button for targets appearing on the right. These two tasks were also used for the cue, so that participants were required to respond to either the identity of the cue (i.e., the discrimination task) or the location of the cue (i.e., the localization task). Accordingly, there were four experimental groups: (a) cue discrimination and target localization (Dis-Loc), (b) cue discrimination and target discrimination (Dis-Dis), (c) cue localization and target localization (Loc-Loc), and (d) cue localization and target discrimination (Loc-Dis).

As mentioned before, several predictions can be made about the influence of cue and target level of processing on the onset of IOR. According to Klein (2000), when a deeper level of cue or target processing is required, IOR should appear later (higher processing requirements delay attentional disengagement from the cued location). If this suggestion is correct, we would expect to find an effect of processing requirements. That is, a relatively late onset of IOR when discriminating either the cue or target (i.e., earlier IOR for localization vs. discrimination of both cue and target; Loc-Loc < Loc-Dis, Dis-Loc < Dis-Dis). On the other hand, according to the object file segregation/integration hypothesis proposed by Lupiáñez (2010), the IOR time course should be accelerated when cue and target processing are equivalent (Loc-Loc and Dis-Dis). That is, when cue and target require identical processing, two different object files must be represented (i.e., event segregation), and IOR would onset earlier (i.e., this hypothesis predicts an interaction between cue and target processing, earlier IOR for Loc-Loc and Dis-Dis than for Loc-Dis and for Dis-Loc). Other possible predictions might also be suggested based on the object file segregation/integration hypothesis (Lupiáñez, 2010). For instance, one might suggest that if participants need to respond to different dimensions of the cue and the target as in the Loc-Dis and Dis-Loc conditions, participants might have a stronger (rather than a weaker) tendency for object segregation in order to avoid confusion between cue and target processing. Although other suggestions are possible, it is reasonable to assume that Lupiáñez's (2010) claim predicts an interaction between cue and target processing.

Finally, in accordance with Gabay et al. (2011), it is possible that the LC-NE mode of activation is sensitive to task requirements. In the more-demanding task (discrimination), the phasic activation of the LC-NE system filters out (i.e., reduces) the processing of the cue. This implies that IOR should be delayed in discrimination tasks because the cue is less processed. This theory predicts that higher processing of the cue will accelerate the onset of IOR. In our experiment we made cue processing a necessary aspect of the task. Since participants know that they will be required to respond to the cue, they should not inhibit its processing. Assuming that participants do process the cue, deeper processing demands for the cue should accelerate IOR onset. In the absence of filtering processes, it is possible that enhanced processing demands (of both cue and target) will produce higher attentional focusing for all stimuli, which will accelerate the attentional effects. This account predicts earlier IOR when cue or target processing is deeper (i.e., earlier IOR for discrimination than for localization conditions).

The presented theories concerned the onset of IOR. It should be noted that several researchers have suggested that exogenous facilitation and IOR overlap in time (Chica & Lupiáñez, 2009; Lupiáñez & Weaver, 1998; Posner & Cohen, 1984; Tassinari, Aglioti, Chelazzi, Peru, & Berlucchi, 1994). Hence, these two effects (i.e., facilitation and IOR) are dissociable. A double dissociation was demonstrated in neuropsychological research. On the one hand, specific brain lesions disrupt IOR but not facilitation (Sapir, Soroker, Berger, & Henik, 1999), and on the other hand, deficits in eye movement performance influence facilitation but not IOR (Gabay, Henik, & Gradstein, 2010). This might imply that delaying IOR should allow the facilitatory effect to be fully presented. According to this assumption, when IOR is delayed, bigger facilitation should emerge. The predictions of the three theoretical accounts under this assumption are illustrated in Figure 1.

Experiment 1

In this experiment we examined the influence of cue and target level of processing on the onset of IOR while participants responded to both the cue and the target.

Method

Participants. Forty-eight students from the University of Granada participated in the experiment in exchange for course-credit. Participants were randomly divided into four groups according to the task required for the cue and target (Loc-Loc, Dis-Loc, Loc-Dis, Dis-Dis).

Apparatus and stimuli. The sequence of events in a typical trial is depicted in Figure 2. The stimuli were presented on a black background, consisting of a fixation dot (0.3°) at the center of the computer screen, and two square boxes (2.5° each side), centered 5° to the left and right. The cue letter (1.5°) appeared in the center of one of the peripheral boxes, followed by a target letter (1.5°) that appeared in the center of one of the peripheral boxes. The target and cue appeared in different colors (green or red; the colors were fixed throughout the whole experiment and were counterbalanced between participants).

Procedure. In target discrimination tasks, participants identified the target by pressing one of two buttons of a keyboard (either Z or M) according to target identity (either O or X). Responses were counterbalanced between participants. In target localization tasks, participants responded to the target by pressing one of two buttons of a keyboard according to the target location (Z for targets appearing on the left box and M for targets on the right box). The cue letter was not predictive regarding target location (the target appeared with the same probability in either the cued or uncued locations) or target identity.

After participants responded to the target letter, a question regarding the cue letter was displayed. In cue discrimination tasks, participants were required to answer a *yes/no* question about the identity of the cue (e.g., Was the cue an X?). In half of the trials participants were asked whether the cue letter was an X and in the other half, whether the cue letter was an O (this was done in order to prevent motor preparation after cue presentation). In cue localization tasks, participants were required to answer a *yes/no* question about the location of the cue (e.g., Was the cue presented on the left?). In half of the trials participants were asked whether the cue letter appeared on the left and in the other half, whether it appeared on the right. For both cue discrimination and localization tasks, the keys for yes and no responses were Z and M, and were counterbalanced between participants. Each participant was presented with 512 trials, divided over four experimental blocks, each containing 128 trials. Each block contained four different SOAs (100 ms, 300 ms, 600 ms, or 1,000 ms) and two validity conditions (valid, invalid). Prior to the experimental blocks, participants preformed 32 practice trials.

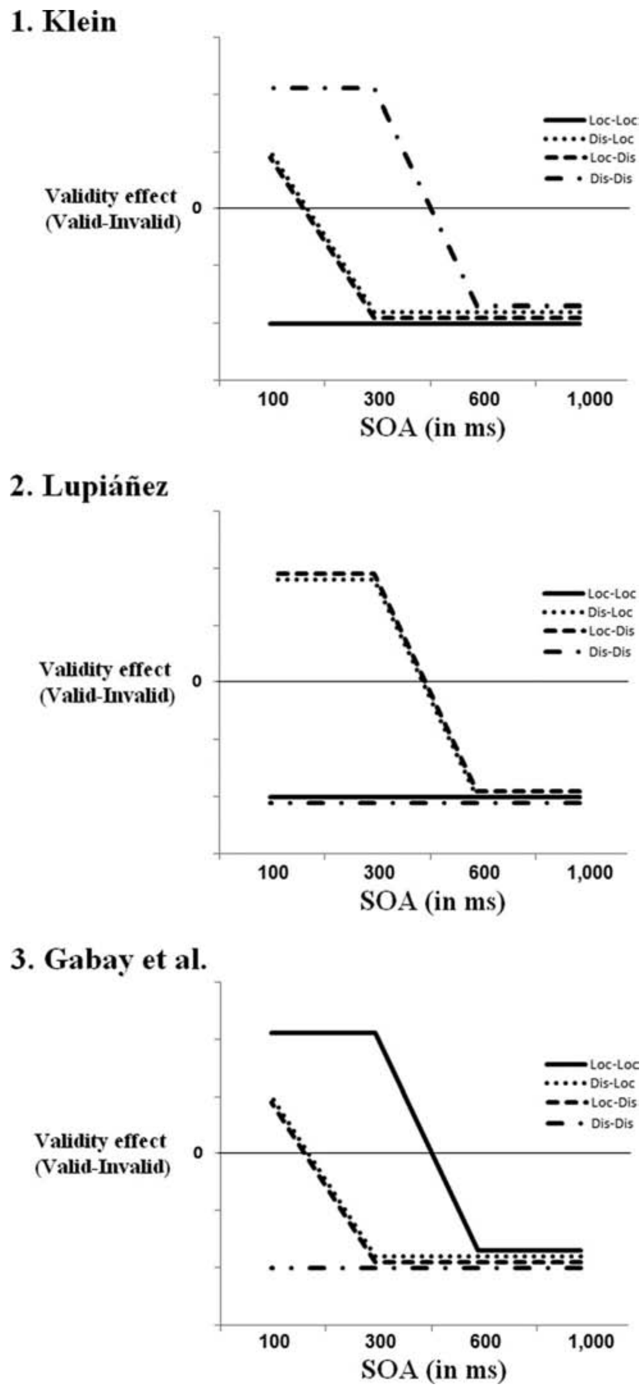

Figure 1. Predicted validity effect (under the assumption of a dissociation between IOR and validity) as a function of SOA for the four experimental groups (a, b, c, and *d* indicate Dis-Dis, Dis-Loc, Loc-Dis, Loc-Loc, respectively) according to each theoretical account (i.e., Klein, 2000; Lupiáñez, 2010; and Gabay et al., 2011). Dis = discrimination; Loc = localization.

Participants were tested in a dimly illuminated room. They were seated 57 cm from the computer monitor. Participants were instructed to maintain fixation throughout the experiment. They were informed that the cue letter was not informative regarding target location and were asked to press the correct key as fast as possible when the target letter appeared. Each trial began with the appearance of a fixation dot for 750 ms. Afterward, a cue letter (an X or an O, written in either green or red) appeared for 100 ms. After a variable SOA (100 ms, 300 ms, 600 ms, or 1,000 ms) the target letter appeared for 1,500 ms or until a response was detected. After the target disappeared, a question about the cue letter was presented and remained visible until participants responded. A 1,500-ms black screen interval was presented between trials. An auditory feedback was presented for wrong, missing or premature responses (less than 100 ms).

Results

Trials in which participants responded incorrectly to the cue (4%) or target (4%) and trials in which RTs were longer than 1,500 ms or faster than 100 ms (less than 1%) were excluded from the analyses. One participant was excluded from the analysis because of her high error rate (over 50%).

As indicated earlier, we used the same two letters as cues and targets (in different colors). In half of the trials, the target and cue were the same letter. This similarity might have made it more difficult to dissociate between cue and target, mostly in valid trials at the first SOA. In this condition the target letter was presented immediately after the cue letter offset (only differing in color). We wanted to examine whether the similarity between target and cue letters might influence our results. In order to do this, we entered target and cue similarity (same, different) as an additional factor in our analyses.

An analysis of variance (ANOVA) of target task (localization, discrimination), cue task (localization, discrimination), SOA (100 ms, 300 ms, 600 ms, or 1,000 ms), validity (valid, invalid), and similarity (same, different) was conducted (see Table 1). Figure 3

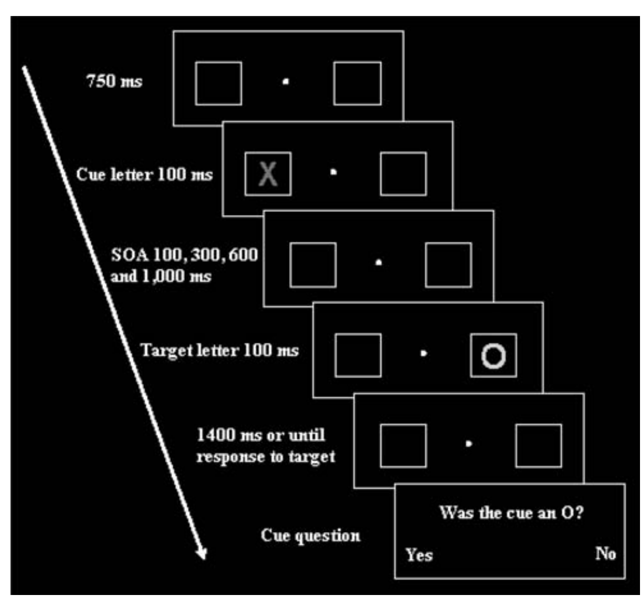

Figure 2. Sequence of events in a typical experimental trial. The cue question in the example refers to the cue discrimination task. Cue localization task questions were also possible (e.g., Was the cue on the left?). In Experiment 2, no question about the cue was presented.

Table 1
RT, and Target and Cue Error Rates for All Experimental Groups, SOAs, and Validities, for the Two Similarity Conditions in Experiment 1

	SOA 100		SOA 300		SOA 600		SOA 1,000	
	Invalid	Valid	Invalid	Valid	Invalid	Valid	Invalid	Valid
Same similarity								
Dis-Dis								
RT	745.7	789.4	699.0	724.0	690.0	722.4	694.3	703.9
Target Acc	6.5	5.9	6.7	3.6	3.5	2.9	3.4	3.0
Cue Acc	3.00	2.91	2.18	2.00	3.27	2.18	1.36	0.55
Dis-Loc								
RT	561.1	544.5	494.0	486.2	481.1	491.0	469.3	488.6
Target Acc	1.3	0.3	1.0	0.5	0.5	0.0	0.3	0.5
Cue Acc	1.25	1.50	1.25	1.25	2.25	1.75	2.25	1.75
Loc-Dis								
RT	789.5	795.6	719.2	730.7	707.1	742.4	723.6	727.8
Target Acc	8.6	5.8	7.4	4.3	4.6	5.7	3.6	3.8
Cue Acc	3.58	3.67	6.33	2.75	4.17	4.50	5.08	3.75
Loc-Loc								
RT	564.9	552.9	503.4	475.7	473.5	487.1	471.8	474.7
Target Acc	1.8	0.0	0.7	0.7	0.6	0.0	0.5	0.0
Cue Acc	2.42	4.25	2.75	3.25	4.75	2.25	3.83	1.25
Different similarity								
Dis-Dis								
RT	831.6	892.9	789.0	794.2	721.6	746.2	710.3	733.3
Target Acc	7.7	6.4	4.5	2.8	4.7	4.5	3.6	3.2
Cue Acc	5.64	6.36	3.45	4.45	3.09	3.36	5.64	3.55
Dis-Loc								
RT	591.3	613.8	516.4	512.3	487.1	515.5	464.9	495.9
Target Acc	4.1	0.3	0.7	0.3	0.0	0.5	0.0	0.0
Cue Acc	4.67	7.25	5.50	4.92	3.00	4.25	4.33	3.00
Loc-Dis								
RT	819.1	817.2	733.9	736.3	707.6	729.6	683.4	726.3
Target Acc	9.6	9.0	5.4	6.1	6.1	4.8	5.2	4.4
Cue Acc	3.25	4.75	5.08	3.58	5.00	3.83	4.33	1.83
Loc-Loc								
RT	585.4	528.4	498.9	478.1	477.0	482.2	458.6	480.6
Target Acc	0.8	0.0	1.2	0.7	0.2	0.5	0.0	0.0
Cue Acc	4.17	4.00	4.33	2.83	3.25	3.92	3.33	3.33

Note. RT and SOA in milliseconds, Acc = accuracy in percentages; Dis = discrimination; Loc = localization.

presents RTs as a function of SOA and validity for each experimental group. In the following analyses, IOR onset is defined as the first SOA at which invalid trials produce significantly slower RT than valid trials. As expected, main effects for target task (faster RT for localization than for discrimination), SOA (a decline in RT with the increase in SOA), and validity (faster RT for invalid trials than for valid trials) were found, $F(1, 43) = 51.5$, $MSE = 189{,}150$, $p < .001$; $F(3, 129) = 133$, $MSE = 2{,}755$, $p < .001$; $F(1, 43) = 4.4$, $MSE = 5{,}486$, $p < .05$, respectively. A main effect of similarity (faster RT for repeating vs. different letters) was also significant, $F(1, 43) = 21.5$, $MSE = 3{,}431$, $p < .001$. As expected, the interaction between SOA and validity was significant, $F(3, 129) = 6.5$, $MSE = 965$, $p < .001$, indicating the appearance of IOR at the later two SOAs, $F(1, 43) = 19.6$, $MSE = 2{,}137$, $p < .001$. The two-way interactions between SOA and similarity, $F(1, 129) = 16.3$, $MSE = 1{,}110$, $p < .001$, similarity and cue task, $F(1, 43) = 21$, $MSE = 3{,}431$, $p < .001$, and similarity and target task, $F(1, 43) = 4.8$, $MSE = 3{,}431$, $p < .05$, were all significant.

The cue task, SOA, and similarity interaction, $F(3, 129) = 2.8$, $MSE = 1{,}110$, $p < .05$, was a result of a bigger difference in the linear trend of RT as a function of SOA (steeper function for the different similarity condition as compared to the same similarity condition) for the cue discrimination task as compared to the cue localization task, $F(1, 43) = 5.1$, $MSE = 1{,}672$, $p < .05$. The target task, SOA, and similarity interaction was also significant, $F(3, 129) = 3.1$, $MSE = 1{,}110$, $p < .05$. This interaction was a result of a bigger difference in the linear trend of RT as a function of SOA (steeper function for the different similarity condition compared to the same condition) for the target discrimination task as compared to the target localization task, $F(1, 43) = 5.2$, $MSE = 1{,}672$, $p < .05$.

Importantly, discrimination of either the cue or target accelerated the onset of IOR as compared to either cue or target localization. There was a significant cue task, SOA, and validity interaction, $F(3, 129) = 5.3$, $MSE = 965$, $p < .01$. This interaction was a result of an earlier IOR for cue discrimination as compared to cue localization (see Figure 3). Examination of validity effects for the various SOAs indicated that IOR onsets from the first SOA (IOR was significant at all SOAs except for the second one for cue discrimination), $F(1, 43) = 6.3$, $MSE = 2{,}791$, $p < .05$; $F(1, 43) =$

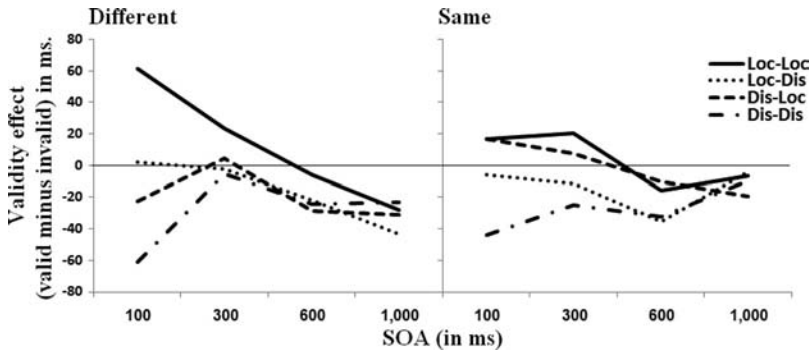

Figure 3. Results of Experiment 1 (responses required to both cue and target). Validity effect as a function of SOA for the four experimental groups and for each similarity condition separately. Dis = discrimination, Loc = localization.

0.1, p = .6, *ns*; F(1, 43) = 6.5, *MSE* = 1976, p < .05; F(1, 43) = 11.2, *MSE* = 875, p < .01, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, whereas it emerged only from the third SOA for cue localization, F(1, 43) = 2.9, p = .09, *ns*; F(1, 43) = 0.4, p = .5, *ns*; F(1, 43) = 4.6, *MSE* = 1,796, p < .05; F(1, 43) = 11.4, *MSE* = 875, p < .01, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively. The target task, SOA, and validity interaction was also significant, F(3, 129) = 4.6, *MSE* = 965, p < .01. Similar to the previous interaction, this interaction revealed an earlier onset of IOR for target discrimination as compared to target localization (see Figure 3). Examination of validity effects for the various SOAs indicated that IOR was apparent from the first SOA (significant IOR at all SOAs but one for target discrimination), F(1, 43) = 6.1, *MSE* = 2,791, p < .05; F(1, 43) = 1, p = .3, *ns*; F(1, 43) = 9.4, *MSE* = 1,796, p < .01; F(1, 43) = 10.4, *MSE* = 875, p < .01, for the 100 ms, 300 ms, 600 ms and 1,000 ms SOAs, respectively, but only emerged at the fourth SOA for target localization, F(1, 43) = 2.7, p = .1, *ns*; F(1, 43) = 1.6, p = .2, *ns*; F(1, 43) = 2.7, p = .1, *ns*; F(1, 43) = 12.3, *MSE* = 875, p < .01, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively.

The four-way interaction between cue task, SOA, validity, and similarity was marginally significant, F(3, 129) = 2.6, *MSE* = 1,059, p = .051. In order to analyze this interaction, we examined the three-way interaction between cue task, SOA, and validity for each similarity condition separately. For the different similarity condition, there was a significant interaction between cue task, validity, and SOA, F(3, 129) = 6.24, *MSE* = 2,549, p < .001. Examination of the validity effects for the various SOAs indicated that IOR was significant from the first SOA (IOR was significant at all SOAs except for the second one) for cue discrimination, F(1, 43) = 5.9, *MSE* = 3,402, p < .05; F(1, 43) = 0.01, p = .9, *ns*; F(1, 43) = 6.4, *MSE* = 1,234, p < .05; F(1, 43) = 11.3, *MSE* = 733, p < .01, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, whereas for cue localization a marginally significant facilitatory effect was observed at the first SOA and IOR emerged only at the fourth SOA, F(1, 43) = 3.5, *MSE* = 3,402, p = .06; F(1, 43) = 0.7, p = .5, *ns*; F(1, 43) = 1.8, p = .1, *ns*; F(1, 43) = 20.4, *MSE* = 733, p < .001, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively. For the same similarity condition, the time course of validity effects did not depend on cue task (interaction between cue task, validity and SOA, F<1). Examination of the validity effects for the various SOAs indicated that IOR was significant at the third SOA and marginally significant at the fourth SOA for cue discrimination, F(1, 43) = 1.6, p = .2, *ns*; F(1, 43) = 0.3, p = .5, *ns*; F(1, 43) = 4.1, *MSE* = 1,227, p < .05; F(1, 43) = 3.3, *MSE* = 714, p = .07, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, whereas for cue localization IOR emerged also at the third SOA, F(1, 43) = 0.2, p = .6, *ns*; F(1, 43) = 0.1, p = .7, *ns*; F(1, 43) = 6.3, *MSE* = 1,227, p < .05; F(1, 43) = 0.5, p = .4, *ns*, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively.

Error analyses. These analyses were conducted in two separate ANOVAs, one for target response errors and another one for cue response errors. We will start by describing the analysis of the target.

Target task. We conducted an ANOVA of target task, cue task, SOA, validity, and similarity. The significant main effect of validity, F(1, 43) = 7.4, *MSE* = 0.001, p < .01, was a result of higher accuracy for valid than for invalid trials. The main effect of SOA, F(3, 129) = 20, *MSE* = 0.0009, p < .001, was a result of higher accuracy for long SOAs. The linear trend for SOA was significant, F(1, 43) = 54, *MSE* = 0.0009, p <.001. No other trends were significant. A main effect of target task was significant, F(1, 43) = 48, *MSE* = 0.008, p < .001, with higher accuracy for localization than for discrimination tasks. The SOA by target interaction was significant, F(1, 129) = 7.3, *MSE* = 0.0009, p < .001. This was due to a steeper linear trend, as SOA increased, for discrimination as compared to localization tasks, F(1, 43) = 17.3, *MSE* = 0.0009, p < .001.

Cue task. We conducted an ANOVA of target task, cue task, SOA, validity and similarity. A main effect of similarity was significant, F(1, 43) = 25, *MSE* = 0.001, p < .001, as a result of higher accuracy rates when cue and target had the same identity. The interaction between similarity and cue task was also significant, F(1, 43) = 16.9, *MSE* = 0.001, p < .001. This interaction was a result of higher accuracy rates when cue and target had the same identity as compared to when they had different identities for the cue discrimination task, F(1, 43) = 40.7, *MSE* = 0.001, p < 0.001, but not for the localization task, F(1, 43) < 1, *ns*. A significant SOA by validity interaction, F(3, 129) = 3.4, *MSE* = 0.001, p < .05, was a result of a positive slope in accuracy for valid trials and a negative one for invalid trials. In order to further examine this interaction, we compared the linear trend for valid versus invalid trials as a function of SOA. This yielded a significant result , $F(1, 43) = 9.4$, $MSE = 0.001$, $p < .01$. No other trends were significant in this comparison.

Discussion

The results of the first experiment demonstrate that deeper processing of either the cue or target produces an earlier onset of IOR. This effect was more robust when the cue and target were different letters (different similarity condition). It is important to note that the different similarity condition is more similar to the common tasks used to explore the time course of IOR, in which the cue and target are different stimuli (the cue is usually the brightening of one of the peripheral boxes while the target is a stimulus presented inside the box). As proposed by Lupiáñez and Weaver (1998), detecting two stimuli at the same location when the SOA is too short (the first interstimuli interval in our task was 0 ms, i.e., the target appeared immediately after cue disappearance) might be especially difficult. Target detection might be hard in the same similarity condition for valid trials, delaying participants' responses and masking the facilitatory effect usually observed at short SOAs. Importantly, this facilitatory effect was indeed observed in the different similarity condition.

Our finding is in contrast with Klein's (2000) suggestion that the longer attending time at the cued location in a more-demanding task is the cause for the delayed onset of IOR in discrimination tasks as compared to less demanding tasks. We also did not observe an interaction between cue and target task conditions as can be inferred from the object file hypothesis suggested by Lupiáñez (2010). We elaborate on these two theoretical suggestions in the General Discussion.

Our results are in accordance with the suggestion that in a demanding task cue processing is filtered out, which in turn delays the onset of IOR (Gabay & Henik, 2010; Gabay et al., 2011). According to this view, when more processing of the cue is required, IOR should appear earlier. In our experiment we made the cue a relevant property of the task; even though not predictive of target localization or identity, participants were required to process the cue in order to correctly respond to the "cue" question. Hence, cue processing could not be filtered out (i.e., reduced). When the filtering process is prevented by making the cue relevant for the task, the pattern of results is opposite to what is generally observed, that is, a more perceptually demanding task (discrimination of either the cue and/or the target) produced an earlier onset of IOR. So, we can conclude that more attentional deployment produces larger and earlier IOR. The reason why our pattern of results does not fit the pattern in previous studies comparing discrimination versus detection tasks might be due to the occurrence of a cue-filtering process for discrimination but not for localization tasks.

In the following experiment we used the same paradigm, but participants were not required to respond to the cue. Hence, the task allowed participants to filter out (i.e., reduce) cue processing (as might be commonly done in standard spatial cueing tasks). If the above-mentioned suggestion is correct, we would expect to find a reverse pattern of results, that is, later onset of IOR in more-demanding tasks.

Experiment 2

In the following experiment participants were required to respond only to the target and not to the cue. These task demands made the cue irrelevant to the task and allowed participants to filter it out.

Method

Participants. Twenty-four participants from Ben-Gurion University of the Negev participated in the experiment in exchange for a course credit. Participants were randomly divided into two groups according to the response required for target: localization or discrimination.

Apparatus and stimuli. All apparatus and stimuli were identical to those used in the first experiment.

Procedure. The procedure was identical to that of the first experiment with the exception that there was no question about the cue.

Results

Trials in which participants responded incorrectly to the target (2%) and trials in which RTs were longer than 1,500 ms or faster than 100 ms (less than 1%) were excluded from the analyses. An ANOVA of target task (localization, discrimination), SOA (100 ms, 300 ms, 600 ms, or 1,000 ms), validity (valid, invalid) and similarity (same, different) was conducted (see Table 2). Figure 4 presents RTs as a function of target condition, SOA, and validity. Main effects for target task (faster RT for localization than for discrimination), SOA (a decline in RT as SOA became longer) and validity (faster RT for invalid trials than for valid trials) were found: $F(1, 22) = 37.21$, $MSE = 35{,}303$, $p < .001$; $F(3, 66) = 49.64$, $MSE = 620$, $p < .001$; $F(1, 22) = 42.1$, $MSE = 736$, $p < .001$, respectively. The interaction between validity and target task was significant, $F(1, 22) = 4.7$, $MSE = 736$, $p < .05$, which indicated a larger IOR for the localization than for the discrimination task. The interaction between task and similarity was significant, $F(1, 22) = 13$, $MSE = 816$, $p < .01$. The interaction was a result of an effect of similarity (faster RT for repeating stimuli compared to non repeating stimuli) for the discrimination task, $F(1, 22) = 15.8$, $MSE = 816$, $p < .01$, but not for the localization task, $F(1, 43) = 1.2$, $p = .2$, *ns*. Although the three-way interaction of target condition, SOA, and validity was not significant, $F(3, 66) < 1$, we analyzed it for its theoretical importance. Examination of validity effects for the various SOAs in the discrimination task indicated that IOR was significant only from the third SOA, $F(1, 22) = 2.5$, $p = .1$, *ns*; $F(1, 22) = 3.4$, $p = .07$, *ns*; $F(1, 22) = 6.2$, $MSE = 1{,}071$, $p < .05$; $F(1, 22) = 5.3$, $MSE = 601$, $p < .05$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, although it emerged from the first SOA in the target localization task ($F(1, 22) = 5.6$, $MSE = 1{,}038$, $p < .05$; $F(1, 22) = 18.5$, $MSE = 500$, $p < .001$; $F(1, 22) = 22$, $MSE = 1{,}071$, $p < .001$; $F(1, 22) = 35$, $MSE = 601$, $p < .001$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively). The triple interaction between SOA, validity, and similarity was significant, $F(3, 66) = 7$, $MSE = 567$, $p < .001$. The four-way interaction was marginally significant, $F(3, 66) = 2.6$, $MSE = 567$, $p = .056$. In order to analyze this interaction, we conducted the same analysis we per-

Table 2
RT and Target Error Rates for All Experimental Groups, SOAs, Validities, and Similarity in Experiment 2

	SOA 100		SOA 300		SOA 600		SOA 1,000	
	Invalid	Valid	Invalid	Valid	Invalid	Valid	Invalid	Valid
Same similarity								
Target Dis								
RT	555.8	605.6	530.2	549.1	535.0	546.9	533.0	547.7
Target Acc	2.5	3.4	2.3	1.3	2.0	1.8	2.5	2.3
Target Loc								
RT	414.8	452.1	365.7	397.7	362.1	413.4	359.5	397.7
Target Acc	1.3	0.3	0.5	0.3	0.7	0.2	0.0	0.5
Different similarity								
Target Dis								
RT	622.4	602.6	557.5	562.7	535.7	571.3	532.1	550.3
Target Acc	4.5	2.0	2.3	2.0	1.5	1.3	1.5	1.3
Target Loc								
RT	424.4	431.3	368.2	391.9	363.3	400.5	350.4	396.1
Target Acc	1.0	0.2	0.2	0.7	0.3	0.5	0.5	1.3

Note. RT and SOA in milliseconds, Acc = accuracy in percentages; Dis = discrimination; Loc = localization.

formed for the target condition, SOA, and validity interaction for each similarity condition separately. For the different similarity condition, examination of validity effects for the various SOAs in the discrimination task indicated that a significant facilitation was observed at the first SOA and IOR was significant only from the third SOA, $F(1, 22) = 5.1$, $MSE = 459$, $p < .05$; $F(1, 22) = .5$, $p = .4$, *ns*; $F(1, 22) = 22.6$, $MSE = 334$, $p < .001$; $F(1, 22) = 4$, $MSE = 493$, $p = .057$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, although it emerged from the second SOA in the target localization task, $F(1, 22) = .6$, $p = .4$, *ns*; $F(1, 22) = 10$, $MSE = 323$, $p < .01$; $F(1, 22) = 24$, $MSE = 334$, $p < .001$; $F(1, 22) = 25$, $MSE = 493$, $p < .001$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively. This analysis demonstrated that for the different similarity Condition IOR was observed earlier in the target localization task than in the discrimination task. For the same similarity condition, examination of validity effects for the various SOAs in the discrimination task indicated that a significant IOR was observed only at the first SOA, $F(1, 22) = 10$, $MSE = 1{,}482$, $p < .01$; $F(1, 22) = 4$, $p = .056$, *ns*; $F(1, 22) = .5$, $p = .4$, *ns*; $F(1, 22) = 2.1$, $MSE = 613$, $p = .16$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively, although it was significant for all SOAs in the target localization task, $F(1, 22) = 5.6$, $MSE = 1{,}482$, $p < .05$; $F(1, 22) = 11$, $MSE = 528$, $p < .01$; $F(1, 22) = 10.9$, $MSE = 1{,}439$, $p < .01$; $F(1, 22) = 14$, $MSE = 613$, $p < .01$, for the 100-ms, 300-ms, 600-ms, and 1,000-ms SOAs, respectively. This analysis demonstrated that when the cue and target were similar, IOR was observed at all SOAs in the localization task, but only at the first SOA in the discrimination task.

Error analyses. We conducted an ANOVA of target condition, SOA, validity, and similarity. The significant main effect of SOA, $F(3, 66) = 3.3$, $MSE = 0.004$, $p < .05$, was a result of higher accuracy at the middle SOAs. The quadratic trend for SOA was significant, $F(1, 22) = 7.9$, $MSE = 0.0002$, $p < .01$. No other trends were significant. A main effect of target task was significant, $F(1, 22) = 18.6$, $MSE = 0.001$, $p < .001$, with higher accuracy for the localization than for the discrimination task.

Discussion

The results of this experiment replicate many previous studies (Lupiáñez et al., 1997; Terry et al., 1994; see Klein, 2000, for a review) and demonstrate that deeper processing of the target delays the onset of IOR. This finding is in contrast with the results

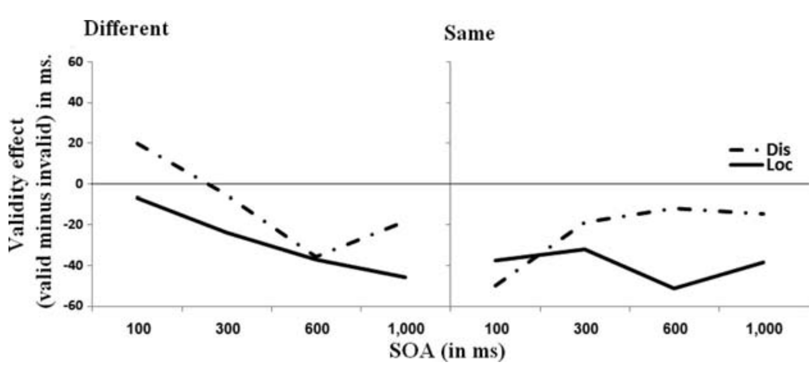

Figure 4. Results of Experiment 2 (responses only required to the target). Validity effect as a function of target condition and SOA for each similarity condition separately. Dis = discrimination; Loc = localization.

of the first experiment, in which deeper processing of cue or target produced an earlier onset of IOR. Our results are in accordance with the claim that an additional process that weakens cue processing is involved when the task is more demanding. In this case, the processing of the cue is filtered out in order to improve target processing. This additional process delays the onset of IOR. When the cue and target were the same letter in the discrimination task, longer RT was observed for valid trials than for invalid trials at the first SOA. As suggested earlier, this pattern is most likely a result of some confusion between the cue and target in this condition (in which the target appeared immediately after cue disappearance). This explanation is also supported by the fact that this pattern of results was not apparent at the later SOAs. When the cue and target were different letters (as in the majority of previous studies; Lupiáñez et al., 1997; Terry et al., 1994; see Klein, 2000, for a review), a facilitatory effect was observed for the discrimination task, which reversed into IOR at the third SOA. For the localization task, IOR was apparent at all SOAs.

General Discussion

The present experiments demonstrate that cue and target level of processing modulates the onset of IOR. In the first experiment, in which participants responded to both the cue and target, we found that a deep processing of the target or cue advanced the onset of IOR. In the second experiment, in which the cue could be filtered out because no response was required, deeper target processing led to a later appearance of IOR, as previously shown in many studies (Lupiáñez et al., 1997; Terry et al., 1994; see Klein, 2000, for a review).

Several authors have tried to explain the different onset times of IOR depending on task demands. Klein (2000) suggested that in a more difficult task (discrimination), participants allocate more attention to all stimuli (target and cue), and the sustained attention at the cued location delays the appearance of IOR. The results of our first experiment demonstrate that this might not be the case because IOR appeared earlier in the more difficult task. It has to be noted however, that in Klein's proposal, target processing difficulty is just one of the factors that might affect the timing of attentional disengagement. As an example, the presence versus absence of a distractor accompanying the target can be considered[1] (Lupiáñez & Milliken, 1999). In a block of trials where the target is never accompanied by a distractor, the target is located by its discrete onset. A control setting to find onsets would also apply to the onset of the cue, thus causing a strong attentional engagement, a long attending time, and hence a late onset of IOR. By contrast, when the target is always accompanied by a distractor, luminance onset no longer provides the signal that will locate the target. Hence, the control setting needed to locate the target is less likely to result in strong attentional capture, and IOR will appear sooner. Finally, when the probability of a distractor is neither zero nor one but somewhere in between, the onset of IOR should depend more on this probability than on the presence of a distractor. While this proposal clearly predicts delayed IOR for the Dis-Dis condition than for the Loc-Loc condition of our first experiment, the predictions for the remaining conditions (that involve a task switch between the cue and target) are more indeterminate. Under Klein's proposal, the requirement to switch tasks rapidly between the cue and target may be accomplished by an especially rapid attentional disengagement from the cue. However, our results did not reveal an earlier IOR in task switching conditions.

A different view proposed by Lupiáñez et al. (2007; see Lupiáñez, 2010, for a recent review on this account) suggests that different task sets can modulate attentional effects. Because the primary goal in discrimination tasks is to identify the stimulus, cue—target integration would facilitate processing by helping to select the target location in advance—an effect known as the "spatial selection" benefit (Lupiáñez, 2010). This process might be responsible for larger facilitatory effects, delaying IOR. In contrast, detection tasks require segregation of the cue and target into different object files in order to avoid confusion as to whether an onset cue or an onset target occurred in a given trial—an effect called "detection cost." The segregation of the cue and target into separate object files accelerates the onset of IOR. One of the predictions made by this suggestion is an interaction between the cue and target level of processing. That is, if the defining property for the cue and the target is the same (Loc-Loc and Disk-Disk conditions) cue-target integration within the same object file would be harmful. Thus, a set for cue-target segregation would be adopted and IOR should appear earlier in those conditions. Our results do not support this prediction. Indeed, both the cue and target discrimination produced an earlier onset of IOR as compared to localization tasks. Although our main result (earlier IOR for more-demanding discrimination vs. localization tasks when responses to the cue were required) did not support Lupiáñez et al.'s (2010) theory, additional predictions from his theory could be suggested. Lupiáñez's theory clearly predicts that when the cue and target are similar, earlier IOR should be observed because cue-target segregation might be especially necessary. A similar prediction is made in a recent proposal (Dukewich, 2009) in which IOR is explained as an instance of high order habituation. The more similar the cue and target, the more habituation will occur and the more IOR should be observed. We clearly found larger IOR for similar versus dissimilar cues and targets, which indicates that although these proposals cannot account for all the results observed in the present study, some of their assumptions are clearly confirmed. Another prediction that can be drawn from Lupiáñez et al.'s view is that in our first experiment (in which participants responded to both the cue and target), cue and target integration was more harmful than in the common cuing tasks where no response to the cue is required (similar to the influence of adding distractors when the target is presented, as in Lupiáñez & Milliken, 1999). This suggestion would surely predict earlier onset of IOR in the first experiment as compared to the second experiment. This was observed for the discrimination task but not for the localization task. Additionally, according to Lupiáñez's theory (2010), in common detection tasks there is more risk for cue-target integration than in discrimination tasks, just because the most important aspect of the target is its sudden appearance. This indicates that the most dominant aspect of the target, regarding onset of IOR, is the property to which participants are required to respond and not task difficulty. This suggestion does not seem to have any clear predictions regarding the different cue and target conditions in our first experiment. If any, it would still be more

[1] We thank Raymond Klein and Matthew Hilchey for introducing these ideas in a previous revision of this article.

likely to predict earlier onset of IOR for the Loc-Loc and Dis-Dis conditions compared to the Loc-Dis and Dis-Loc conditions, since there is higher risk for cue and target integration in those conditions.

There are two main differences between the task used in our first experiment and the commonly used cuing tasks. The first difference is the use of a letter as an exogenous cue. The use of a letter cue might make the cue and target more physically similar and could have made it more difficult discriminating between them. The cue-target similarity might have produced an inhibitory process that was different from IOR, mostly when the cue and target were similar and presented at the short SOA (Lupiáñez & Weaver, 1998). In a recent paper, Hu, Samuel, and Chan (2011) have demonstrated that repetition of color or shape at the same spatial location produces an inhibitory effect. Hommel (2004) has also suggested that object files might be addressed not only by location but through any feature (possibly also through identity), which might have implications regarding Lupiáñez's theory. In order to examine the influence of cue-target similarity in our work, we analyzed our results separately for each similarity condition. Our results confirmed previous findings by showing larger overall inhibitory effects when cues and targets were identical than when they were different. The expected interactions between cue-target task and validity effects were mostly observed for different cues and targets.

A second difference between our first experiment and the commonly used cueing tasks is the involvement of working memory (WM). The task in our first experiment involves higher requirements on WM than the typical tasks used to examine orienting of attention. In our first experiment participants were required to maintain cue location or identity in WM while responding to the target. Yet, there is no clear reason why the involvement of WM should produce the specific pattern of results observed in the first experiment. Even with an influence of WM, according to Lupiáñez's theory, one still predicts earlier IOR when response for the same property of cue and target is required (Loc-Loc and Dis-Dis) compared to when response for different properties of cue and target is required (Loc-Dis or Dis-Loc).

The theoretical view that seemed to be reinforced by our results postulates that different tasks recruit different firing modes of the LC-NE. Gabay et al. (2011) suggested that a possible mechanism that can work as a temporal filter and can influence the processing of a nonpredictive cue is the LC-NE system. According to this view, participants will be more likely to use the phasic LC mode when tasks are more demanding and require higher accuracy (like in a discrimination task). According to this suggestion, the LC-NE system works in a phasic mode during discrimination tasks and in a tonic mode during detection or localization tasks. In turn, this explains the difference in onset time of IOR between detection and discrimination tasks and in the present results (localization vs. discrimination tasks). This view implies that in less demanding tasks, cues are actually processed more deeply and produce an earlier onset of IOR. Pupil size was suggested to correlate with LC activity (Aston-Jones & Cohen, 2005). We have recently examined pupil size in a cuing task (Gabay et al., 2011) and found support for this suggestion. Specifically, pupil size at the time of cue presentation was correlated with the size of IOR (i.e., wider pupil size during cue presentation resulted in a bigger IOR).

In conclusion, our work suggests that the time course differences in the onset of IOR might be influenced by the LC-NE system. The involvement of processes that have a global influence (e.g., release of NE) on more specific processes (e.g., orienting of attention) should be considered in future work. We suggest that the brain adapts itself according to the task at hand. When changing task demands, one not only changes the difficulty of the task but might also change the way in which the brain processes information, and this might have behavioral consequences. Our work is in line with several recent studies that give the alerting system a central role in attentional effects that so far have been related to cognitive control. For instance, Nieuwenhuis, Gilzenrat, Holmes, and Cohen (2005) argue that attentional blink (a temporary deficit in processing of a target stimulus following successful processing of a previous target) is a result of a refractory-like period caused by local NE release within the LC in response to the first target. According to Verguts and Notebaert (2009), the Graton effect (smaller congruency effect following an incongruent trial), which is usually considered a result of attentional control, is actually a product of an interaction between binding processes and activation of the LC-NE system (see also Tzelgov & Cohen Kadosh, 2009). According to this account, there is a phasic burst of NE during incongruent trials that increases Hebbian learning. These recent studies emphasize the role of the LC-NE system in many different cognitive processes. Future work is necessary to increase our understanding of the underlying neural and physiological mechanisms of the LC-NE system and how they interact with attention and other higher cognitive systems.

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