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The presence of a nonresponding effector increases inhibition of return

JASON IVANOFF and RAYMOND M. KLEIN
Dalhousie University, Halifax, Nova Scotia, Canada

Inhibition of return (IOR) refers to the performance disadvantage for targets presented at an exogenously cued location, relative to an uncued location, at relatively long cue–target onset asynchronies. In this experiment, we investigated the influence on IOR of a nonresponding effector (i.e., the index finger of the nonresponding hand) placed on a response key in a simple-RT task. With peripheral cues and targets, IOR and spatial stimulus–response compatibility effects were larger when the nonresponding hand was placed on a response key. IOR—the slowed responding to go signals at the cued location—was accompanied by a lower false alarm rate when no-go signals were presented there. These findings provide direct evidence for a motoric component to IOR wherein some portion of the inhibition is observed as a criterion shift against responding to the cued location.

When a target is preceded by a spatially noninformative cue, and the time between the cue and the target is greater than approximately 250 msec, performance is generally worse when the cue and the target are in the same spatial location than when they are not. This effect is referred to as *inhibition of return* (IOR; Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). Early interpretations favored an attentional account of the effect. It was thought that IOR reflected the buildup of inhibition after attention left the location of the cue, and the slowed responses were the result of a delay in attention returning to a previously visited location. On this view, IOR acts to bias attention toward new locations.

The effect of IOR on cognitive processing has recently been a matter of much controversy (see Klein, 2000, and Taylor & Klein, 1998, for reviews). Many researchers have argued for an attentional-perceptual effect (e.g., Handy, Jha, & Mangun, 1999; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Posner & Cohen, 1984; Pratt, Kingstone, & Khoe, 1997; Reuter-Lorenz, Jha, & Rosenquist, 1996). The idea that IOR affects attention is supported by the absence of an IOR effect during parallel search and its presence during serial search (Klein, 1988; Klein & MacInnes, 1999; Takeda & Yagi, 1998, 2000), presumably because attention is not needed during parallel ("pop-out") searches. Further support for an effect of IOR on perception comes from the finding that the magnitude of IOR increases with increasing target luminance (presumably a variable that primarily affects perception) and its magnitude is about the same whether it is measured with saccades or manual keypress (Reuter-Lorenz et al., 1996). Despite this evidence that IOR may hamper shifts of attention, IOR has not been observed in perceptual tasks involving illusory line motion (ILM; Schmidt, 1996)[1] or temporal-order judgments (Klein, Schmidt, & Müller, 1998). The absence of an effect of IOR on these perceptual judgments has been used as indirect support for the view that IOR affects motoric processes. What is needed, however, is more direct evidence that IOR affects motoric processes (e.g., Abrams & Dobkin, 1994; Klein & Taylor, 1994).

Is IOR Inhibition of Action?

Noting that IOR was not found with discrimination tasks (Pontefract & Klein, 1988, as cited in Klein & Taylor, 1994; Terry, Valdes, & Neill, 1994) but that it was found with target detection and localization tasks, Klein and Taylor (1994) proposed that IOR affects neither attention nor perception but instead reflects a bias against responding toward the cued location. Klein and Taylor's response bias account of IOR was partly motivated by the failure to obtain IOR using discrimination tasks based on nonspatial attributes, such as size, color, and form. They suggested that these nonspatial discriminations should have been affected by IOR if attentional or perceptual pathways were inhibited. However, according to their response bias account, IOR might not be observed in nonspatial discriminations because responses in such tasks are not spatially directed "toward" targets.

Contrary to the evidence marshaled by Klein and Taylor (1994), several subsequent studies have found IOR in nonspatial discrimination tasks (e.g., Cheal, Chastain, & Lyon, 1998; Lupiáñez et al., 1997; Pratt & Abrams, 1999; Pratt et al., 1997). Pratt et al. (1997) compared IOR in localization and identification discrimination tasks. For the localization task, subjects were required to press a

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left or right key in response to the location of the target. For the identification task, subjects were required to press one of two buttons depending on the form of the target. IOR was present in both types of task, and it was of almost equal value when the tasks were visually similar. Lupiáñez et al. (1997) conducted 10 experiments comparing IOR in detection (simple-RT) and discrimination (choice-RT) tasks. In the discrimination task, subjects made left- or right-key presses to the color of the target. IOR was found in both the detection task and the discrimination task, although its presence was delayed for the discrimination task. Had the cuing experiments reported by Klein and Taylor used longer cue–target intervals, according to Lupiáñez et al., IOR would have been observed. These findings counter Klein and Taylor's original observation that IOR does not occur in nondiscrimination tasks. Furthermore, it has been interpreted by some as contrary to a motor view of IOR: "[T]he finding of robust inhibition of return effects with choice response tasks based on the identity of the stimuli is strongly inconsistent with the motor explanation [of IOR]" (Pratt et al., 1997, p. 970).

Direct Tests of a Motoric Component to IOR

Experiments that have attempted to discount a response bias account of IOR have typically approached the problem by providing positive support for an attentional account of IOR without directly testing the response bias theory. If IOR has both attention and motoric components, then this approach is not fully analytic. To determine whether IOR has a significant motoric component, it is necessary to directly test the response bias account of IOR rather than only provide evidence of an attentional account. To provide a direct test of the response bias account of IOR, we sought a motoric effect—most likely to be the result of response inhibition—that would operate at a stage of processing shared by IOR (if IOR had a motoric component). According to additive factors logic (Sternberg, 1969), if two variables affect the same processing stages, their effects should interact when they are combined orthogonally.

It is well known that the spatial position of a target does not influence simple RT to any significant extent. The difference between spatially corresponding (e.g., left response to left target) and spatially noncorresponding (e.g., left response to right target) stimulus–response (S–R) ensembles in a simple-RT task is about 3 msec (e.g., Poffenberger, 1912). However, when a second finger (that does not respond in a given block of trials) of the same hand is simply placed on a response key (without ever needing to respond in a given block of trials), the effect is increased from 4 to 16 msec (Hommel, 1996).

According to Hommel (1996), this S–R compatibility effect could arise because of competition that is resolved via inhibition between potential responses (Shallice, 1972), and this inhibition increases the readiness to respond to a spatially corresponding target. With only one effector on a response key, there is little or no response competition (Kornblum, 1965), whereas competition and response inhibition processes are summoned when a nonresponding effector is placed on a response key during a block of trials. It seems as though the compatibility effect that emerges because of the natural tendency to respond in the direction of targets (Simon & Rudell, 1967) only affects RT when the responses corresponding to the stimulus locations are "afforded" (Gibson, 1979), as would be the case with placement of the nonresponding effector on a response key. For this reason, we sought to determine whether the placement of a nonresponding effector would interact with, or affect, IOR. Thus, the purpose of the present investigation was twofold. First, we intended to replicate the nonresponding effector manipulation of Hommel (1996) to determine whether it would generate target–response (T–R) compatibility effects[2] in a simple-RT spatial cuing paradigm. We also used a "true" simple-RT task as a baseline to determine whether the effect of the nonresponding effector genuinely increased T–R compatibility, because none of Hommel's experiments specifically determined whether the nonresponding effector actually increased S–R compatibility effects in simple-RT tasks. Second, given that the nonresponding effector induces a motoric (i.e., S–R compatibility) effect, we sought to determine its influence on IOR. If IOR does not have a motoric component, the placement of a nonresponding effector should not change its magnitude.

METHOD

Subjects

Nineteen subjects from an introductory psychology course at Dalhousie University participated in the experiment. All subjects had normal or corrected-to-normal vision. The subjects received partial course credit for their participation.

Apparatus and Stimuli

VSCOPE (Rensink & Enns, 1992) software was used to present stimuli and collect responses on a Macintosh 636 computer. The subjects were seated 55 cm away from the screen. Stimuli were presented in black on a white background. The midpoint of the screen was placed approximately at eye level. An array of three square placeholders (black outline with white fill) was present for the duration of the trial except during the intertrial interval (ITI). Each placeholder measured 1.5° (vertical) × 1.5° (horizontal). The center of the middle placeholder was approximately placed along the subjects' midline. The distance between the lateral side of the middle placeholder to the inner lateral side of the lateral placeholders was 6.2°. The fixation point, a small filled dot that measured 0.3° in diameter, was centered in the middle placeholder. The cue was a "+" or an "x" encapsulated within a circle, but the form of the cue was irrelevant to the task.[3] The diameter of the circle was 1.5°. The target was a filled black square placed over one of the placeholders. A checkerboard-like square (10 × 10 small boxes that alternated between black and white fill) placed within the placeholder signaled no-go trials.

Procedure

See Figure 1 for the sequence of trial events. The ITI lasted 750 msec. During this interval, the screen was blank. The place-

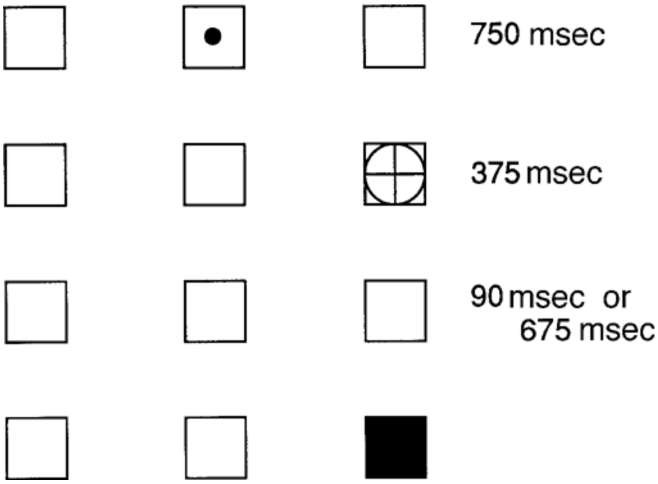

Figure 1. An example of trial events. See text for details.

holders and the fixation point were displayed for 750 msec, after which one of the two cues was presented for 375 msec in one of the three placeholders. The subjects were instructed that the identity and the location of the cue were completely irrelevant to the task. Following the cue, an interval with only the placeholders was presented for 90 or 675 msec. The target or the no-go signal was then presented, in any one of the three placeholders, until a response was made. The subjects were instructed to withhold responses when a no-go signal was displayed. The subjects participated in two 1-h sessions.

Simple-RT task (SRT). The subjects were instructed to respond quickly to, but not to anticipate, the presence of the target with a simple detection response. In separate blocks, the subjects responded with either the left or the right index finger, using the "z" key for the left index finger blocks and the "/" key for right index finger blocks. The subjects were instructed to keep their nonresponding hand off the keyboard and in their lap.

Simple-RT task with the nonresponding effector (SRT+NRE). The procedure followed the SRT with one exception. The subjects were instructed to place the nonresponding effector on top of the alternate key. For example, for a block of left-key presses (on the "z" key), the subjects placed the right index finger on the "/" key. The subjects were instructed not to press the key with the nonresponding effector.

Design

In all, there were eight blocks of trials. Half of these blocks were the SRT+NRE condition, and half were the SRT condition. The subjects were given practice trials before the start of a new condition. Half were performed with the left hand, and half were performed with the right. The subjects performed the task in two sessions, on 2 consecutive days, at approximately the same time of day for 1 h. SRT and SRT+NRE sessions were performed on different days, and order was roughly counterbalanced between subjects. Responses with the left and the right hands were made within the same session, and order was roughly counterbalanced between subjects. In each block, the spatial position of cues (left, center, or right) and targets (left, center, or right) was random and equiprobable. Cue identity and cue location were uninformative concerning the location of the target signals. The ratio of go trials to no-go trials was 2:1 (16:8 in each cell of the design).[4] In total, there were 1,728 trials per subject.

RESULTS

RTs less than 200 msec and greater than 1,000 msec were removed from the analysis. This criterion excluded approximately 0.12% of trials. False alarm (FA) rate was defined as the percentage of responses on no-go trials.

Mean RTs and FAs were each entered into two separate repeated measures analyses of variance (ANOVAs). The first analysis (central targets), directed at the possibility of central inhibition, considered trials where targets appeared in the center placeholder. Three variables were entered in this analysis: (1) task (SRT or SRT+NRE), (2) cuing (cued or uncued targets),[5] and (3) cue–target onset asynchrony (CTOA; 465 or 1,050 msec). The second analysis (peripheral targets), specifically directed at examining T–R compatibility and IOR, considered trials where targets appeared in one of the peripheral placeholders. Four variables were entered in this analysis: (1) task (SRT or SRT+NRE), (2) cuing (cued, uncued, or center cue), (3) T–R compatibility (correspondence or noncorrespondence), and (4) CTOA (465 or 1,050 msec).

Central Targets

The analysis of RTs showed that responses were faster in the 1,050-msec CTOA conditions (M = 360 msec) than in the 465-msec CTOA condition (M = 371 msec) [$F(1,18) = 7.72$, $MS_e = 549.62$, $p < .05$]. Responses to uncued targets (M = 356 msec) were faster than responses to cued targets (M = 375 msec) [$F(1,18) = 31.65$, $MS_e = 406.84$, $p < .001$]. The cuing × task interaction [$F(1,18) = 0.51$, $MS_e = 216.94$, $p = .487$, power = .101] and the cuing × CTOA interaction [$F(1,18) = 2.33$, $MS_e = 138.03$, $p = .145$, power = .290] were not significant. The analysis of FAs showed that there was a significant cuing effect [$F(1,18) = 7.89$, $MS_e = 18.77$, $p < .05$] and an interaction between cuing and CTOA [$F(1,18) = 4.68$, $MS_e = 5.49$, $p < .05$]. At the 465-msec CTOA, more FAs were made to uncued targets (M = 4.1%) than to cued targets (M = 1.3%) [$t(18) = 3.39$, $p < .005$]. The cuing effect at the 1,050-msec CTOA was not significant.

Peripheral Targets

Figure 2 shows the effects of T–R compatibility, cuing, and CTOA on RTs and FAs to peripheral targets. The

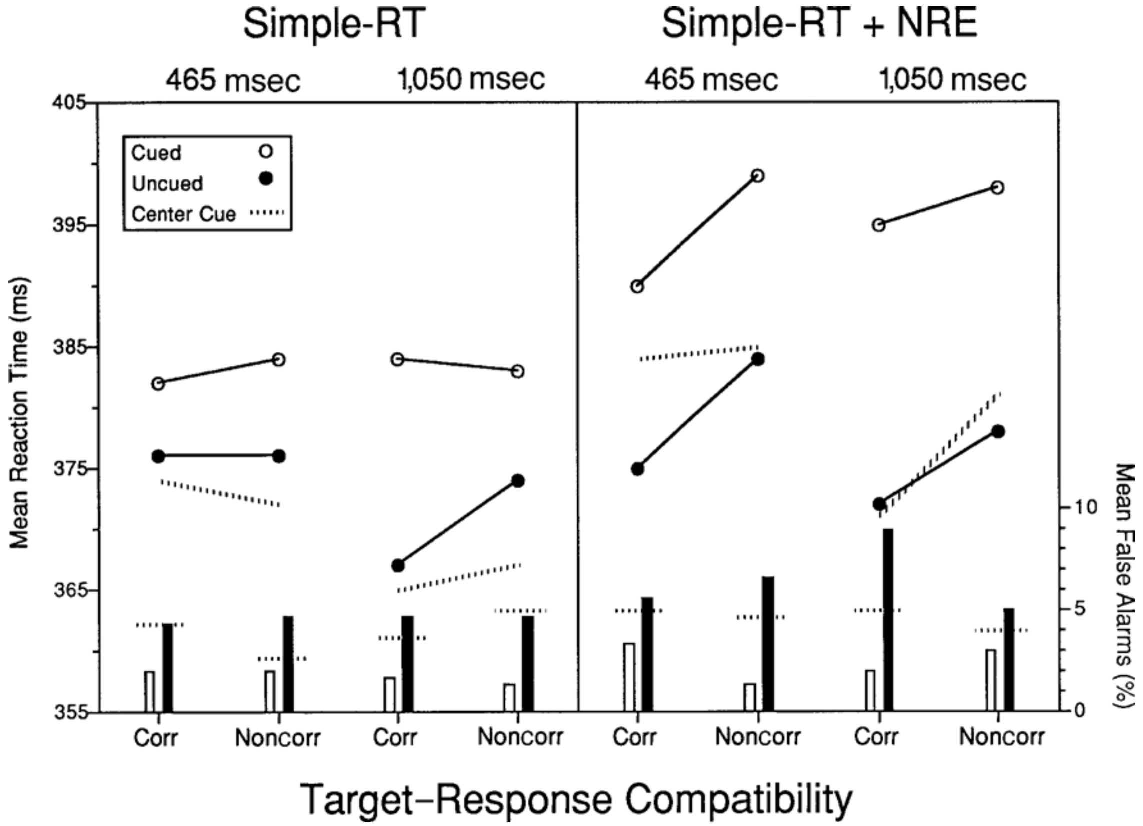

Figure 2. Effects of spatial cuing, placement of the nonresponding effector, and target–response compatibility on reaction times and false alarm rates for peripheral targets. Corr = correspondence; Noncorr = noncorrespondence.

analysis of RTs showed that there was an effect of T–R compatibility [$F(1,18) = 11.41, MS_e = 157.77, p < .005$] and an interaction between task and T–R compatibility [$F(1,18) = 5.87, MS_e = 113.92, p < .05$]. Although T–R compatibility was not significant with the SRT task, responses to T–R corresponding trials ($M = 381$ msec) were faster than responses to T–R noncorresponding trials (M = 388 msec) with the SRT+NRE task [$t(18) = 5.40, p < .001$]. Furthermore, with T–R correspondence, RTs in the SRT and SRT+NRE tasks were not significantly different. However, with T–R noncorrespondence, the RTs in the SRT+NRE task were slower than the RTs in the SRT task ($M = 376$ msec) [$t(18) = 2.14, p < .05$].

The analysis of RTs also showed that the cuing effect was significant [$F(2,36) = 23.76$, $MS_e = 432.49$, $p < .001$], as was the interaction between task and cuing [$F(2,36) = 3.87, MS_e = 176.47, p < .05$]. In the SRT and SRT+NRE tasks, the RTs following central cues were not statistically different from the uncued RTs. However, RTs were slower for cued targets than for uncued targets in the SRT task [cued, $M = 383$ msec; uncued, $M = 373$ msec; $t(18) = 2.84, p < .05$] and in the SRT+NRE task [cued, $M = 395$ msec; uncued, $M = 377$ msec; $t(18) = 6.38, p < .001$]. To determine whether the presence of the NRE affected cuing (i.e., IOR), IOR scores were calculated by subtracting RTs to uncued targets from RTs to cued targets. IOR in the SRT task ($M = 10$ msec) was indeed smaller than IOR in the SRT+NRE task ($M = 18$ msec) [$t(18) = 2.42, p < .05$]. Further analysis revealed an interaction between cuing and CTOA [$F(2,36) = 4.07, MS_e = 213.19, p < .05$]. The difference between RTs to cued targets and RTs to noncued targets (i.e., RTs to uncued targets and targets that followed central cues) was significantly larger [$t(18) = 2.33, p < .05$] at the 1,050-msec CTOA ($M = 18$ msec) than at the 465-msec CTOA ($M = 10$ msec).

Finally, there was an interaction between cuing, T–R compatibility, and CTOA [$F(2,36) = 3.58, MS_e = 88.82$, $p < .05$]. Separate analyses for each CTOA did not yield any differences that were informative about the source of this interaction. However, the three-way interaction was no longer present [$F(1,18) = 1.88$, $MS_e = 62.94$, $p = .188$, power $= .242$] when we reanalyzed the data after removing the central cue condition, thus localizing the source of this three-way interaction to the central cue condition. A separate analysis of RTs to targets following a central cue revealed several effects—notably, a significant effect of CTOA [$F(1,18) = 71.15, MS_e = 98.82$, $p < .001$] and a just significant interaction between CTOA and T–R compatibility [$F(1,18) = 4.42$, $MS_e = 31.56, p = .050$] that were not present with a peripheral cue. At the 465-msec CTOA, there was a significant T–R compatibility effect [T–R correspondence, $M = 368$; T–R noncorrespondence, $M = 374$; $t(18) = 2.81$, $p < .05$]; however, at the 1,050-msec CTOA, the T–R compatibility effect was nonsignificant.

In the analysis of FAs, cuing was the only significant effect [$F(1,18) = 8.63$, $MS_e = 53.72$, $p < .001$]. FAs to trials with uncued targets ($M = 5.5\%$) did not differ significantly from trials with center cues ($M = 4.2\%$). However, FAs to cued targets ($M = 2.1\%$) were significantly lower than FAs to uncued targets [$t(18) = 3.38$, $p < .005$] and FAs to targets with center cues [$t(18) = 4.47$, $p < .001$].

DISCUSSION

The present experiment demonstrated four novel results. First, the placement of the nonresponding effector (the index finger of the other hand) on an irrelevant response key generated T–R compatibility effects, whereas the absence of the nonresponding effector did not. Second, the presence of the nonresponding effector also increased peripheral IOR, but not central inhibition. Third, the FA rates were lower for targets at the cued location than at the uncued location, demonstrating for the first time that some, if not all, of the RT disadvantage on cued trials was due to a more conservative criterion for initiating a response to signals at this location. Fourth, peripheral inhibition appears to differ from central inhibition, although they share some similarities. These findings will be discussed with respect to T–R compatibility and IOR.

Target–Response Compatibility

The present investigation replicated and extended a previous observation by Hommel (1996) that compatibility effects normally absent in simple RT can be observed when a nonresponding effector is passively placed on a response key. Hommel did not systematically compare the magnitude of his S–R compatibility effects in SRT and SRT+NRE tasks. In this investigation, we did, and we found that T–R compatibility effects are larger when a nonresponding effector is placed passively on the keyboard. That T–R noncorresponding RTs were slower with placement of the nonresponding effector and T–R corresponding RTs remained unchanged supports the idea that response inhibition was probably responsible for the effect. Further support for the involvement of response inhibition comes from Hommel's study: He found larger compatibility effects when the nonresponding effector was another finger within the hand of the responding effector (i.e., index and middle fingers served as responding and nonresponding effectors) relative to when the nonresponding effector was a finger from the other hand (i.e., left and right index fingers served as responding and nonresponding effectors).

Although we claim that the nonresponding effector is an action-based (or intentional) variable, one might argue that it acts (on attention) as a perceptual distractor. It is possible that the bilateral proprioceptive, tactile, or visual stimulation may be responsible for the generation of T–R compatibility effects with the nonresponding effector. However, findings reported in Pratt et al. (1997) suggest that IOR was smaller when an irrelevant visual stimulus was always presented at the location opposite to the target. Given that we found that IOR was increased in the presence of the nonresponding effector (providing irrelevant stimulation), Pratt et al.'s finding loosely suggests that the nonresponding effector was unlikely to have distracted attention. Thus, it seems likely that the presence of the nonresponding effector generates response inhibition.^{6}

The Effects of Inhibition of Return

Almost all single-response IOR experiments have used target-absent trials as catch trials (Donder's a-task, used by Maylor & Hockey, 1985; Posner & Cohen, 1984; Possamaï, 1986, 1991; Reuter-Lorenz et al., 1996; Riggio, Bello, & Umiltà, 1998). A disadvantage of this task (Sperling & Dosher, 1986) is that FAs cannot be attributed to a cued trial or an uncued trial. Consequently, it is impossible to determine whether there is a criterion difference for responding to targets in these locations. The task we chose to use (a Donder's c-task) is a methodological advance, because it allows direct measurement and comparison of the response criterion at the cued and uncued locations.

Recall that Klein and Taylor (1994) proposed that the cued–uncued RT differences (IOR) reflected a criterion shift that favors responding toward the uncued location and that perceptual processing was unaffected by the inhibition. The faster responding in the presence of higher FA rates at the uncued location is precisely the pattern of results predicted by this proposal. Slower responses at the cued location (relative to the uncued location) mean that there will be more response-execution information from the identity of the target. More response-execution information regarding the identity of the target means fewer FAs to the sudden onset of the no-go signal. Although there are studies suggesting that IOR may have a motor component (e.g., Abrams & Dobkin, 1994; see Taylor & Klein, 1998, for a review), this is the first demonstration that such a component is implemented as a response bias.

In a recent signal detection study, Handy et al. (1999) found that RTs were shorter and d' was higher at the uncued location than at the cued location. Subjects were required to press a key only when the target (a line) was of a particular orientation; otherwise, they were to withhold responding. In this regard, the method is similar to the one used here. Handy et al. quite naturally interpreted their d' difference to mean that IOR resulted in a relative decrease in the quality of perceptual information accumulating at the cued location. Their finding appears to be in contrast with what we have reported here. However, a major methodological difference between our study and Handy et al.'s might have contributed to this discrepancy. Handy et al. used a unilateral posttarget mask to reduce the discriminability of the target. On presentation of a mask, however, the accumulation of information in the visual system about the orientation of the target is terminated, and the information already extracted will begin to decay (Posner, 1975; Posner, Klein, Summers, & Buggie, 1973). As noted by Taylor and Klein (1998, note 6) if responses are based on the quality of information accessed during this decay period (i.e., after deletion of target information), faster responses may be more accurate than slower ones even when responses are based on the same encoding function. Thus, the d' difference observed by Handy et al. may not have been a consequence of improved perceptual encoding but instead may have been due to a combination of decaying information and a response-delaying effect of IOR. In other words, the lower d' Handy et al. observed at the cued location could have been the result of a reluctance to make a response (in this case, "consult the information at the masked location") toward the cued location. This interpretation predicts that, with unmasked stimuli that remain present until the response, faster RTs to uncued go stimuli will be associated with higher FAs to uncued no-go stimuli. Because this is precisely what was found in the present experiment (whose methodology resembled Handy et al.'s, but without the mask), our (nonperceptual) interpretation of Handy et al.'s d' difference gains credence.

Central IOR (?)

The present investigation replicated the observation of central inhibition (Maylor & Hockey, 1985; Possamaï, 1986) that has been reported in some previous studies. The presence of central inhibition is inconsistent with the view that IOR is the result of a voluntary suppression of saccades to the location of the cue (Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987) because eye movements do not need to be suppressed with central cues.[7] In addition, Maylor and Hockey (1985) argued that the existence of central inhibition disputes the view that attention must leave the cued area for inhibition to begin (Posner & Cohen, 1984). However, these inferences can be avoided if there is reason to believe that the two inhibitions are produced by different underlying mechanisms, with IOR elicited by peripheral cues. Several findings in the present study clearly point to important differences, though there are similarities as well. The difference between cued and uncued targets is increased significantly in the presence of the nonresponding effector for peripheral cues and targets, whereas it is not for central inhibition. This suggests that peripheral inhibition, but not central inhibition, may have a motor component process that is specifically delayed by the presence of a lateral nonresponding effector. Visual inspection of the pattern of results in Figure 3 reveals a second dissociation, wherein peripheral inhibition tends to increase with increasing cue–target onset asynchrony, whereas central inhibition tends to decline. This dissociation was confirmed by a 2 (target location: center or peripheral) × 2 (CTOA) × 2 (task) ANOVA on IOR scores, which revealed a significant interaction between target location and CTOA [$F(1,18)$ =

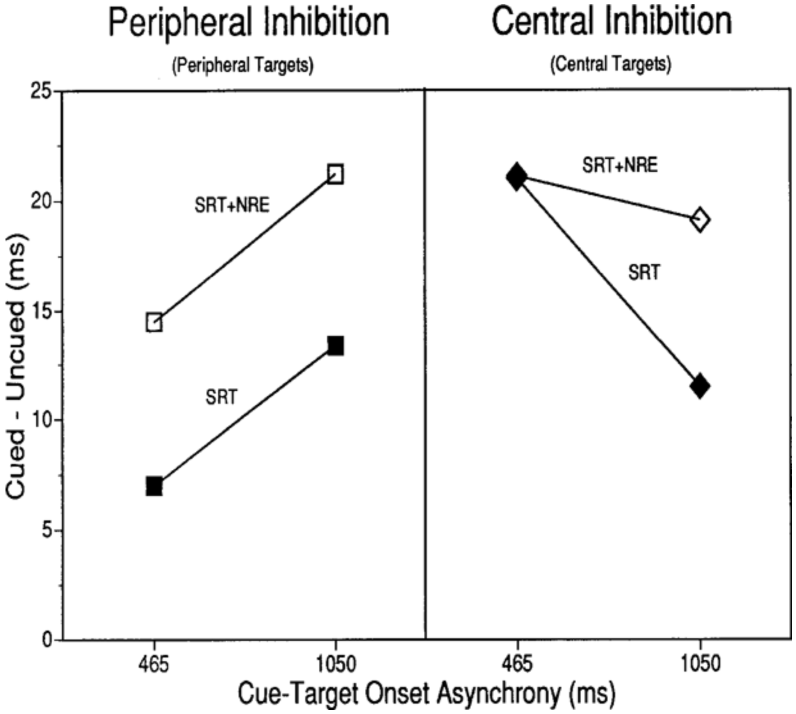

Figure 3. Summary results showing the effects of the nonresponding effector and cue–target asynchrony on peripheral and central inhibition (cued–uncued difference).

5.10, $MS_e = 285.10$, $p < .05$]. Despite these differences, the pattern of FAs suggests that both types of inhibition are implemented by a bias not to respond to targets at the cued location. In all, these findings tentatively suggest that although the motoric mechanisms responsible for central inhibition may not be entirely the same as those responsible for peripheral inhibition, the inhibition may be implemented similarly.

Conclusion

The results provide strong evidence in favor of an action-based account of IOR. Yet, one must take note that this evidence in favor of a motoric component to IOR in this study does not directly challenge the possibility of perceptual and/or attentional components to IOR. In the presence of the nonresponding effector, spatial T–R compatibility and IOR effects increased in magnitude, suggesting that response inhibition or competition seems to be a shared component process to these effects. The nonresponding effector affords a particular (task-irrelevant) response and generally increases its potential readiness to respond when a target appears. The presence of the nonresponding effector does not change the simple-RT task into a choice-RT task (Donder's b). In the simple-RT task with the nonresponding effector, we observed IOR at a relatively early CTOA (465 msec). The choice-RT task used by Lupiáñez et al. (1997), however, showed facilitation at CTOAs less than 700 msec. Thus, the time course of IOR with the nonresponding effector may be similar to that without the nonresponding effector.

In accordance with previous investigations (Lupiáñez et al., 1997; Pratt et al., 1997), we did not find a significant interaction between the T–R compatibility effect and IOR. According to additive factors logic (Sternberg, 1969), additivity suggests that T–R compatibility and IOR arise from different processing stages; consequently, Lupiáñez et al. (1997) have argued that their "pattern of data suggests that the IOR effect is not related to response biases" (p. 1252). This apparent additivity seems to qualify the linkage we are asserting between the nonresponding effector's influence on T–R compatibility and IOR. However, a meta-analytic reevaluation of the evidence on this issue suggests that T–R compatibility (i.e., Simon effect) and IOR do interact but that the effect is small, and most studies have had insufficient power to detect it (Ivanoff, Klein, & Lupiáñez, 2000).

Prior to our experiment, two important studies in the IOR literature led scholars to consider motoric contributions to the cause and effect of IOR. First, Rafal, Calabresi, Brennan, and Sciolto (1989) convincingly demonstrated that oculomotor programming played an important role in generating IOR. According to this view, the peripheral cues used in our study cause IOR via activation of an oculomotor program to foveate the cue. Second, Abrams and Dobkin (1994) showed (among other things) that eye movements, made in a direction indicated by a centrally presented arrow, were faster away from a cued location than toward it. Since there was no peripheral target event in this condition, it was inferred that one component of IOR was to delay responding in the direction of the initial cue – a motor effect of IOR. Our study extends this observation by providing evidence for a motor component when manual responses are made and by showing that this component is implemented via response bias.

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NOTES

1. ILM occurs when a brief probe precedes a line at one of its ends in close temporal succession. Subjects typically report motion away from the probe along the line. If IOR is related to perceptual-attentional processing, then at long cue–target onset asynchronies (CTOAs), subjects should report seeing motion toward the cue. Schmidt (1996) failed to observe IOR with ILM reports.

2. In this experiment, spatial S–R compatibility effects are taken with respect to the location of the responding effector and the relative spatial location of the target. Therefore, we replace the generic term *S–R compatibility* with the term *T–R compatibility* when we discuss S–R compatibility effects in a cuing experiment.

3. Cues alternated in form to keep the stimuli in this experiment visually similar to another investigation of IOR and spatial compatibility effects in choice-RT tasks from the laboratory (Ivanoff & Klein, 1999). Trials with "x" and "+" cues were mixed together, and target form was not considered in the analysis.

4. One subject performed the task with a slightly higher real-to-catch trial ratio (20:8). His results were included in the analyses, since they did not seem to differ from the other subjects.

5. In the context of central inhibition, a cued target is one where both the cue and the target appeared in the center placeholder. An uncued target, on the other hand, is one where the cue appeared in either of the peripheral placeholders and the target appeared in the center placeholder. Before we assessed central inhibition, we sought to determine the influence of the spatial position of cues on responses (when the target appeared at center). Cue–response (C–R) corresponding trials were those where the spatial location of the cue matched the relative location of the response. Conversely, C–R noncorresponding trials were those where the spatial location of the cue did not match the relative spatial location of the target. Four 2 (C–R compatibility) × 2 (CTOA: 465 and 1,050 msec) ANOVAs were performed on the RTs and FAs from the SRT and SRT+NRE tasks. The effect of C–R compatibility was nonsignificant for the condition with the nonresponding effector present on [RT, $F(1,18) = 0.04$, $MS_e = 130.58$, $p = .892$, power = .054; FA, $F(1,18) = 1.51$, $MS_e = 34.04$, $p = .235$, power = .203] and absent from [RT, $F(1,18) = 0.65$, $MS_e = 236.45$, $p = .410$, power = .115; FA, $F(1,18) = 0.15$, $MS_e = 13.99$, $p = .706$, power = .065] the response key. Consequently, C–R corresponding and noncorresponding trials were averaged in the following analysis to give the uncued condition.

6. In Hommel's (1996) fifth experiment, he discovered that placing a cap over the response key (so that there was no way to make a response) did not significantly alter his S–R compatibility effect. This finding suggests that the response inhibition is not due to the volitional suppression of an afforded (and task-irrelevant) response. Rather, the response inhibition could owe to the confusability between responding and nonresponding effectors when both effectors receive similar proprioceptive and tactile input. Further research is needed to examine the nature of this response inhibition in greater detail than that which is presented here.

7. We thank Robert Rafal for suggesting this point.

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