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BRIEF REPORT

Focal spatial attention can eliminate inhibition of return

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Abstract Inhibition of return (IOR) is an orienting phenomenon characterized by slower responses to spatially cued than to uncued targets. In Experiment 1, a physically small digit that required identification was presented immediately following a peripheral cue. The digit could appear in the cued peripheral box or in the central box, thus guaranteeing a saccadic response to the cue in one condition and maintenance of fixation in the other. An IOR effect was observed when a saccadic response to the cue was required, but IOR was not generated by the peripheral cue when fixation was maintained in order to process the central digit. In Experiment 2, IOR effects were observed when participants were instructed to ignore the digits, whether those digits were presented in the periphery or at fixation. These findings suggest that behaviorally manifested, cue-induced IOR effects can be eliminated by focal spatial attentional control settings.

Keywords Spatial attention · Inhibition of return · Attentional control setting

Inhibition of return (IOR) is an orienting phenomenon typically explored by scholars using the model task pioneered by Posner and Cohen (1984). In this paradigm, participants are asked to make a simple response to a peripheral target that is preceded by an uninformative peripheral cue. The time interval between the onset of the cue and the target (the cue–target onset asynchrony, or CTOA) is manipulated. Using such an experimental task, Posner and Cohen observed faster responses to spatially cued than to uncued targets (facilitation effect) at short CTOAs. When the CTOA was extended to over 200 ms, however, slower responses to cued targets was observed. Posner, Rafal, Choate, and Vaughan (1985) named this later effect *inhibition of return* (see Klein, 2000, for a review).

Many investigations suggest that the ability of a stimulus to elicit reflexive shifts of spatial attention may depend on attentional control settings induced by the task demands (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). Once an attentional control setting is established, only stimuli (e.g., cues) that match that setting will strongly capture attention. When investigated in the feature domain, the cue may or may not share a critical property (e.g., color, motion, or onset) with the target. For instance, Folk et al. (1992, Exp. 3) found that faster response times (RTs) for cued targets, as compared to uncued targets, were only observed when the cues and the targets shared the same task-relevant properties—that is, onset or color. Several recent studies have investigated how such *feature*-based attentional control settings influence IOR by simply increasing the CTOA. Gibson and Amelio (2000) and Pratt, Sekuler, and McAuliffe (2001) reported the following pattern: When participants were looking for an onset target, an onset cue generated capture followed by IOR, while a colored singleton cue generated neither. However, when the target was a colored singleton, colored cues generated capture but not IOR; onset cues generated neither. Later, Pratt and McAuliffe (2002) discovered that onset cues followed by color singleton targets could generate IOR. In addition to the feature domain, attentional control setting can also be explored

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in the spatial domain (e.g., Ishigami, Klein, & Christie, 2009; Theeuwes, 1991; Yantis & Jonides, 1990). In this case, cues presented at locations that never contain targets may fail to capture attention. Until the present study, how a *spatial* attentional control setting might interact with IOR was unknown. Here we report, for the first time, that IOR can be eliminated by focusing spatial attention strongly at fixation at around the time of the peripheral cue.

We did not set out to make this discovery. Rather, we were interested in eliciting the two flavors of IOR identified by Taylor and Klein (2000) without eye position monitoring.[1] Using a manual localization task to measure IOR, we expected to elicit the *attentional/perceptual* flavor when the cue was ignored and fixation was maintained, and the *motoric* flavor when an eye movement was made to the cue. We chose to attempt this using a dual task (see Fig. 1) in which two small digits were presented, one just after a peripheral cue that would presumably generate IOR, and the other after the return cue to fixation. In our first effort (Exp. 1a), participants reported the sum of these two digits after their speeded manual localization response to the target. The second digit was always presented at fixation, while the first digit was presented, in two blocked conditions, either at fixation (central–central) or at the peripherally cued location (peripheral–central). In both conditions, because the digits were small, they would be missed if not fixated. Hence, we expected that participants would maintain fixation in the central–central condition (attentional/perceptual flavor) and saccade to the cued location (and then back to fixation) in the peripheral–central condition (motoric flavor). We were surprised to find no IOR in the central–central condition. We conducted two follow-up experiments with minor variations in the displays and in our method of ensuring that the two digits were processed (Exps. 1b and 1c). The results were essentially the same in all three versions: IOR when the first digit was peripheral; no IOR when the first digit was central. We then demonstrated (Exp. 2) that the mere presence of the first digit at fixation that was not responsible for this absence of IOR: It was the participants' strong attentional focus on fixation at the time of the peripheral cue.

General method

Participants were tested in a dimly lit lab. Visual stimuli were presented on a 17-in. CRT computer monitor at a viewing distance of about 56 cm. Events were controlled and data collected by a Windows PC running custom software written in Python.

The sequence of stimulus displays in all the experiments is illustrated in Fig. 1. The common features were as follows. The initial display contained three vertically arranged empty gray boxes (5° of visual angle apart) constructed with vertical and horizontal lines that measured 1-pixel thick and 1° long. After presenting this fixation frame for 1,000 ms, the border of one of the two peripheral boxes was brightened for 50 ms (uninformative peripheral cue). Immediately following the offset of the cue, the first digit was presented, either at the location of the peripheral cue or at fixation, for 600 ms. Then, 100 ms later, a 50-ms "cue back" was presented at fixation that was immediately followed by the second digit, presented at fixation for 500 ms. After a 100-ms interval, the target (a bright plus symbol subtending 0.8° × 0.8°) was presented in one of the peripheral boxes, and the participants made a speeded localization response. The target was presented for 2 s or until a response was made. Whether the first digit was presented at fixation (central–central condition) or in the periphery (peripheral–central condition) was manipulated within subject but between blocks. The order of these two conditions was counterbalanced across participants. Features unique to each experiment are presented below. All participants reported normal or corrected-to-normal visual acuity.

Experiments 1a, 1b, and 1c: Attend the digits

The key feature of these experiments is that one or another measure was taken to ensure that the participants would have to process both digits.

Method

In total, 23 participants (17 female, 6 male) with an average age of 21 years were tested in Experiment 1a;[2] 26 participants (21 female, 5 male) with an average age of 20 years were tested in Experiment 1b; and 20 participants (16 female, 4 male) with an average age of 20 years were tested in Experiment 1c.

The sequences of events in Experiments 1a and 1b are illustrated in Fig. 1A (the last frame was not presented in Exp. 1b). The sequences of events in Experiment 1c are illustrated in Fig. 1B and C. To equate the physical displays

[1] Taylor and Klein (2000) discovered two kinds of IOR that depended on the activation of the oculomotor system. *Attentional/perceptual IOR* was produced when the participant was forbidden eye movements to either the cue or the target; *motoric IOR* was produced when the participant saccaded to either the cue or the target.

[2] One of the participants was excluded from the analysis because she missed 50% of the targets.

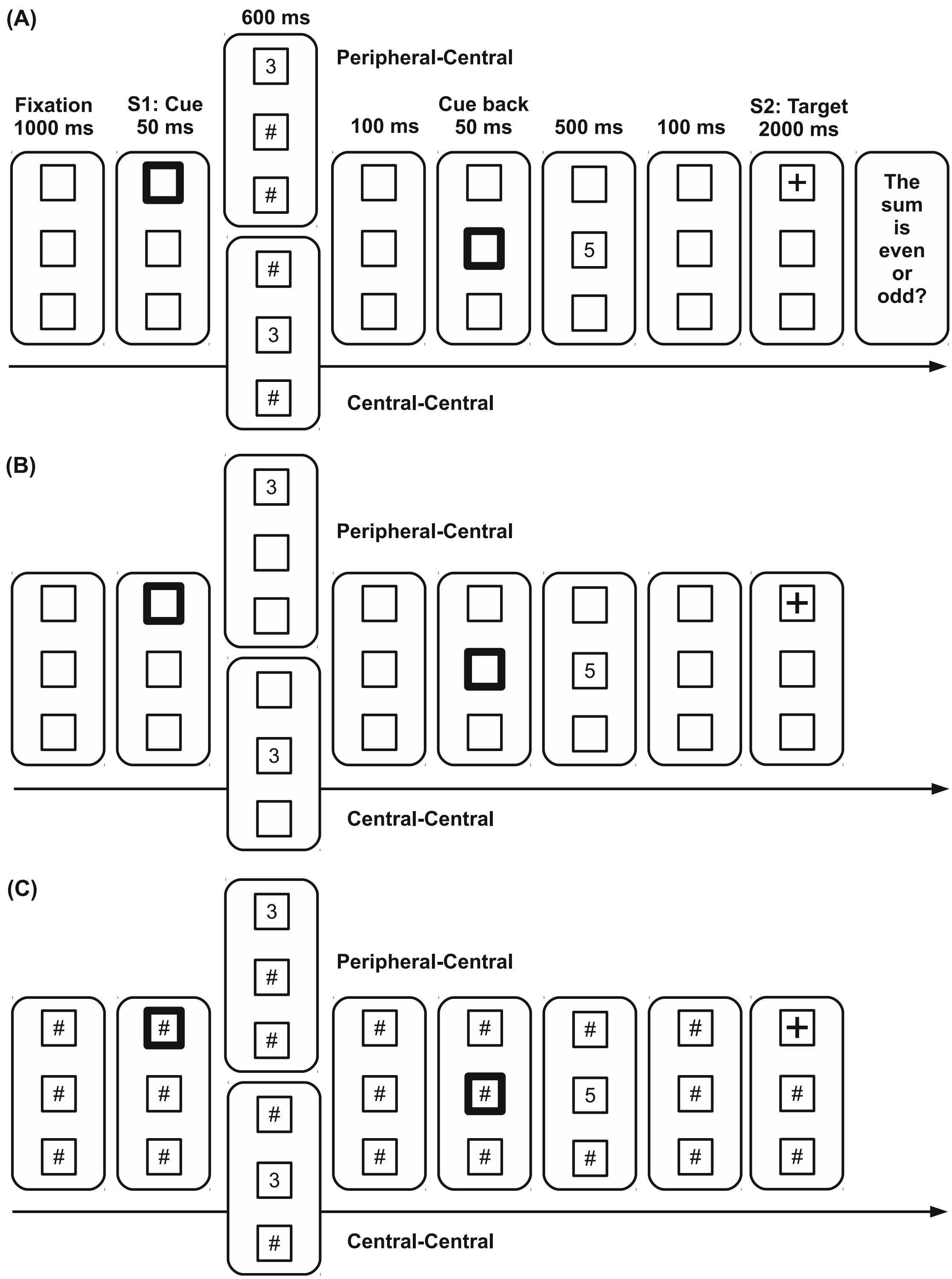

Fig. 1 (**A**) Sequence of events in Experiments 1a and 1b; the last frame was not presented in Experiment 1b. In Experiment 1c, the number sign was either not presented (**B**) or was presented in a box not occupied by a digit or the target (**C**)

of the central–central and peripheral–central conditions, in Experiments 1a and 1b, number signs ("#") were presented in boxes that were not occupied by the first digit (Fig. 1A). In addition, in the peripheral–central condition, the presence of peripheral number signs ensured that participants would use the cue to direct their gaze to the location where the digit would appear. As is shown in Fig. 1A, number signs also appeared in the uncued boxes, so it was unclear whether the onset of the irrelevant number signs might have affected the results of Experiments 1a and 1b. In Experiment 1c, either no number signs were presented (Fig. 1B) or number signs were presented in all boxes that were not occupied by a digit or the target. The latter manipulation ensured that neither number signs nor digits would appear as onsets.

In Experiment 1a, after a speeded response to the target (using the "F" or the "V" key for targets appearing in the upper or the lower box, respectively), participants were required to report whether the sum of the two sequentially presented digits was an even or an odd number by pressing the left or the right arrow key. To reduce the mental and physical task demands exerted by this mathematics task, in Experiments 1b and 1c, digit processing was ensured by making the localization task "go/no go"; depending on whether or not the two digits were the same, participants responded to upper and lower targets with the "Z" and "/" keys, respectively. The digits matched on 75% of the trials.

In Experiment 1a, each experimental block of 80 trials (one for each condition) was preceded by a 60-trial practice block. In Experiment 1b, each experimental block of 224 trials was preceded by a 32-trial practice block. In Experiment 1c, participants experienced four experimental blocks generated from the orthogonal combination of condition (central–central vs. peripheral–central) and the absence versus presence of number signs (Fig. 1B and C), and each experimental block of 112 trials was preceded by 32 practice trials. The order of the experimental blocks was counterbalanced across participants in all experiments.

Results

Errors In Experiment 1a, error trials were those on which the participant reported an incorrect sum (digit error) or responded to the target with a wrong key (target error). In Experiments 1b and 1c, error trials were those on which the participant missed the target or responded when no target was presented (false alarm). Error rates for each condition of Experiments 1a, 1b, and 1c are presented in Table 1. ANOVAs performed on these error rates revealed no main effects or interactions involving cueing (cued vs. uncued).

RTs to targets An ANOVA on the RT data from Experiment 1c revealed that the presence of number signs did not significantly affect RTs [$F(1, 19) = 3.16$, n.s.] and, importantly, did not interact with any other factors [all Fs < 1.56, n.s.]. Thus, this manipulation was ignored in further analyses.

Table 1 Mean response times (RTs) and error rates for each condition of Experiments 1a, 1b, and 1c and Experiments 2a and 2b

	Central–Central			Peripheral–Central		
	Cued Target	Uncued Target	IOR	Cued Target	Uncued Target	IOR
Experiment 1a (Attend the Digits)						
RT (ms)	433	427	6	522	498	24**
Digit error (%)	5.68	5.80		11.59	10.45	
Target error (%)	1.59	1.47		3.07	2.73	
Experiment 1b (Attend the Digits)						
RT (ms)	380	382	–2	453	437	16$^{\&}$
Miss (%)	1.55	1.61		3.71	3.23	
FA (%)	0.55	0.38		1.58	1.27	
Experiment 1c (Attend the Digits)						
RT (ms)	358	358	0	420	401	19*
Miss (%)	3.30	1.92		1.68	1.58	
FA (%)	3.03	3.57		2.68	1.07	
Experiment 2a (Ignore the Digits)						
RT (ms)	383	364	19**	386	363	23**
Target error (%)	0.42	1.26	0.74	1.26		
Experiment 2b (Ignore the Digits, Eye Position Monitored)						
RT (ms)	376	366	10$^{\&}$	377	368	9*
Target error (%)	1.38	0.98	1.93	1.30		
Eye movement (%)	8.33	7.37	11.65	10.78		

FA, false alarms. $^{*}p<.05$, $^{**}p<.01$, $^{\&}p=.06$

The mean RTs for each condition in Experiments 1a, 1b, and 1c are also presented in Table 1. An ANOVA of the RTs, with the variables experiment (1a, 1b, or 1c), condition (central–central or peripheral–central), and cueing (cued or uncued), revealed significant main effects of experiment [$F(2, 65) = 3.99$, $p < .05$], condition [$F(1, 65) = 47.42$, $p < .001$], and cueing [$F(1, 65) = 10.62$, $p < .01$]. The main effect of experiment probably reflects the higher dual-task demands of the mathematical computation in Experiment 1a. The main effect of cueing reflects IOR; that is, RTs to cued targets were longer than those to uncued targets (Table 1). A significant interaction between cueing and condition was observed [$F(1, 65) = 6.39$, $p < .05$], signaling that IOR magnitudes were different for the central–central and peripheral–central conditions. Importantly, this pattern of results was consistent across experiments (see Fig. 2), as suggested by the nonsignificant three-way interaction between cueing, condition, and experiment [$F(2, 65) = 0.01$, n.s.]. Planned comparisons revealed significant or marginally significant IOR effects for the peripheral–central condition in Experiments 1a [$t(21) = 2.66$, $p < .01$], 1b [$t(25) = 1.57$, $p = .06$], and 1c [$t(19) = 1.89$, $p < .05$]. The IOR effect for the central–central condition did not reach significance in any experiment [all ts < 0.8, n.s.].

Discussion

In Experiment 1, IOR was observed when participants made eye movements to the cue, but was not observed when participants focused attention on fixation at around the time of the cue. This finding was a surprise to us, because the cue (no response)–target paradigm with manual responses to targets is probably the most frequently utilized in the IOR literature, and IOR is relatively ubiquitous when this paradigm is used (for a review, see Samuel & Kat, 2003). The consistent elimination of IOR in the central–central condition raised the question: Why did peripheral cues that our participants did not fixate fail to generate IOR? A unique methodological feature of our central–central condition, namely the requirement to attentively process information presented at fixation at around the time of the peripheral cue, could be the causal factor. If so, the theoretical mechanism might be attentionally mediated filtering of the cue. This hypothesis was tested in Experiment 2 by eliminating the digit task while maintaining the presentation of the digits.

Experiment 2: Ignore the digits

If the requirement to actively process the centrally presented digits was disrupting IOR in the central–central conditions in Experiment 1—say, through a narrowing of the attentional beam to fixation at around the time of the cue—we would expect to observe IOR regardless of the location of the first digit if there was no requirement to process it.

Method

A group of 20 undergraduates (10 female, 10 male) with an average age of 23 years participated in Experiment 2a.[3] They were paid 20 *yuan* for participation. A further 20 undergraduates (10 female, 10 male) with an average age of 22 years were tested in Experiment 2b. They participated for course credit or monetary compensation (30 *yuan*).

The stimuli and procedures used in Experiment 2a were the same as those in Experiments 1a and 1b (see Fig. 1a), except that the last frame in each trial was removed and, in both conditions, participants were asked to fixate the central box and to ignore the digits. As in Experiment 1, the first digit was presented in the central box in the central–central condition and in a peripheral box in the peripheral–central condition. Each condition had 100 trials and was preceded by 20 practice trials. The two conditions were blocked, with their order counterbalanced across participants. Experiment 2b was identical to Experiment 2a, except that the participants were cautioned to maintain their gaze on the fixation stimulus, eye position was monitored by a EyeLink video-based eyetracker,[4] and all trials on which an eye movement was detected were excluded from the analysis.

Results

Errors Target error rates were very low in Experiment 2, with insufficient variance to permit analysis (see Table 1). More eye movements were detected in the peripheral–central condition (see Table 1) in Experiment 2b [$F(1, 18) = 4.43$, $p = .05$].

RTs to targets An ANOVA of the RTs of Experiment 2a revealed a significant main effect of cueing [$F(1, 18) = 18.28$, $p < .001$] that did not interact with condition [$F(1, 18) = 0.03$, n.s.]. Planned comparisons revealed significant IOR for both

[3] One of the participants was removed from the analysis because, for unknown reasons, his mean RT was below 50 ms.

[4] This experiment had two versions: Auditory feedback was given when a saccade was detected in one version, while no such feedback was given in the other version. Of the 20 participants, 11 (6 female, 5 male) were tested with feedback, and 9 (5 female, 4 male) were tested without feedback. One of the participants in the second group was excluded from the analysis because excessive saccades were detected (56% trials in the central–central condition). The two versions are combined here because an ANOVA revealed a significant effect of cueing [$F(1,17) = 9.15$, $p < .01$] that did not interact significantly with any other factors [all Fs < 1, n.s.].

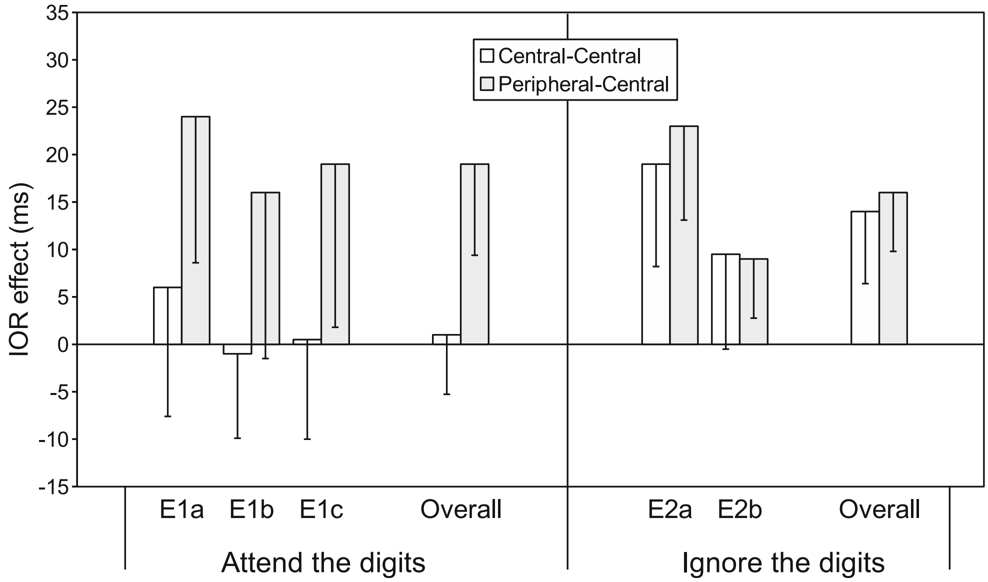

Fig. 2 Summary of the main findings of the present study. Error bars denote 95% confidence intervals

the central–central [$t(18) = 2.93, p < .01$] and peripheral–central [$t(18) = 3.55, p < .01$] conditions (see Table 1 and Fig. 2).

An ANOVA of the RTs of Experiment 2b also revealed a significant main effect of cueing [$F(1, 18) = 8.65, p < .01$] which did not interact with condition [$F(1, 18) = 0.01$, n.s.]. Planned comparisons revealed marginally significant IOR for the central–central condition [$t(18) = 1.64, p = .06$] and significant IOR for the peripheral–central condition [$t(18) = 2.42, p < .05$] (see Table 1 and Fig. 2).

As in Experiment 1, an ANOVA was performed with experiment (2a vs. 2b) as a factor. This analysis revealed a significant main effect of cueing [$F(1, 36) = 26.19, p < .001$] and a marginal interaction between experiment and cueing [$F(1, 36) = 3.89, p = .06$]. No other main effects or interactions were significant [all Fs < 0.3, n.s.]. The interaction between cueing and experiment suggests that, although it did not eliminate IOR, maintaining fixation did reduce the magnitude of IOR in Experiment 2b.

Discussion

The results of Experiment 2 are very clear: IOR was robust in the central–central condition and equal in magnitude to IOR in the peripheral–central condition. Since the displays were identical to those used in Experiment 1 (1a and 1b), we can confidently conclude that when participants were performing a dual task that required them to attend the tiny digits, the failure to obtain IOR in the central–central condition of Experiment 1 was caused by the requirement to actively process them; that is, a *spatial* attentional control setting that focused attention at fixation diminished the ability of the peripheral cues to cause IOR. Because IOR was significant and did not interact with condition (central–central vs. peripheral–central) when eye movements were monitored (Exp. 2b), we can be sure (in agreement with previous studies; e.g., Taylor & Klein, 2000, Exp. 1) that IOR in all of the conditions of Experiment 2 was not caused by eye movements. IOR was reduced in both the central–central and peripheral–central conditions by about the same amount when the participants were encouraged (by eye position monitoring) to maintain their gaze at fixation. We believe that this effort itself may have weakly activated the same focused attentional control setting we have hypothesized to be responsible for the elimination of IOR in the central–central condition of Experiment 1.

General discussion

Our main findings are graphically summarized in Fig. 2. In Experiment 1, we utilized a secondary digit identification task to elicit a saccadic response to the cue in one condition (peripheral–central) and to maintain fixation in the other condition (central–central). IOR effects were observed in the peripheral–central but not the central–central condition. This is a remarkable finding for several reasons. First, as already noted, IOR has been most frequently studied using a cue–target paradigm with no response to the cue and has been ubiquitously observed in this paradigm. Second, consider studies in which IOR has been caused by ignored or foveated peripheral stimuli. From conditions that parallel our stimulus–response sequence, Taylor and Klein (2000) found at least as much, if not more, IOR following peripheral cues and targets in their no-response–manual condition (21 ms) as in their saccade–manual condition (14 ms). Godijn and Theeuwes (2002) explored the role of fixating an irrelevant onset in an oculomotor capture task, concluding “Whether or not a saccade to the onset was executed had no effect on the size of the inhibition" (p. 244).

The absence of IOR is not due to the load on working memory

It might be suggested that the absence of IOR in the central–central condition in Experiment 1 was caused by the high working memory load exerted by the digit task. This is unlikely for a variety of reasons. First, when the load is imposed after the cue, as in our study, previous research has demonstrated that a spatial working memory load interferes with IOR, while a verbal working memory load does not (e.g., Castel, Pratt, & Craik, 2003; Theeuwes, Van der Stigchel, & Olivers, 2006). Our digit task was more akin to a verbal than to a spatial load. Second, because participants were also required to process the two digits in the peripheral–central condition, the working memory load in this condition would have been comparable to that for the central–central condition. Since robust IOR was observed in this condition, memory load cannot have been the critical factor.

A spatial attentional control setting can eliminate IOR

We attribute the unusual disappearance of IOR in the central–central condition of Experiment 1 to strongly focused attention at fixation. This explanation is supported by Experiment 2, in which IOR effects were restored in the central–central condition when such a strongly focused attention at fixation was not required. The nonautomaticity of IOR that is implied by our finding was also demonstrated by Snyder and Kingstone (2001), who found (using a sequence of cues) that multiple-location IOR, but not IOR from the last cue before a target, was eliminated for cues that occurred at times when participants were certain that a target could not be presented. Although their conclusion concerned temporal (un)certainty about the time of the target, it is possible that their participants eliminated IOR from all but the last cue through the adoption of a spatial attentional control setting that was focused on fixation *until* the participants were signaled that the target was imminent. Given that the generation of IOR can be modulated by a spatial attentional control setting, we are left with the question, "Why doesn't a feature-based attentional control setting eliminate IOR?" We cannot answer this question with confidence, but we suspect that the solution may lie in the special relationship that IOR in this cue–target paradigm has with space. Hilchey, Ivanoff, Taylor, and Klein (2011) found that IOR delayed the accumulation of spatial information about the target more than it delayed the accumulation of identity information. If the effect of IOR is about space, then perhaps its generation is only affected by the observer's *spatial* attentional control settings.

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