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ORIGINAL ARTICLE

Inhibitory interaction: the effects of multiple non-predictive visual cues

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Abstract When the interval between a non-predictive cue and a target appearing at the same spatial location is longer than about 200 ms, target performance is typically poorer than when the cue and target appear at different locations. Recent studies have shown that this effect, known as inhibition of return (IOR), can occur at multiple cued locations, and is enhanced when multiple cues are presented at the same spatial location. However, little is known about how the magnitude of IOR at one spatial location is influenced by a subsequent or preceding cue presented at a different spatial location. We investigated this issue by presenting single or multiple cues at varying inter-cue intervals prior to target onset. Results suggest that the magnitude of IOR at a given location is influenced by the presentation of a preceding cue, but that once IOR occurs, it is unaffected by the presentation of a subsequent cue.

Introduction

Exogenous orienting of attention is a term used to describe how particularly salient sensory events, such as the onset of a stimulus, can quickly and efficiently recruit processing resources to their location. Such orienting is often studied within the context of a cue-target paradigm in which a salient non-predictive cue is presented at a potential target location prior to target onset. Interestingly, although participants are instructed to ignore this cue, when cue-target stimulus onset asynchrony (CTOA) is short, response times (RTs) to identify or detect targets are quicker at the cued location than at uncued locations (see Wright & Ward, 2008 for an extensive review). This improvement is believed to result from a reflexive shift of attention to the cued location which increases target processing efficiency. At longer CTOAs, this pattern reverses with response to targets at cued locations slower than responses to targets at uncued locations (Posner & Cohen, 1984). Posner, Rafal, Choate, and Vaughan (1985) labeled this later effect "inhibition of return" (IOR).

It has long been suggested that IOR serves to increase the efficiency of visual search by biasing the system towards novelty—that is, reducing the likelihood that locations without targets will be searched again (e.g. Posner et al., 1985). The biological basis for this is thought to lie in "forage facilitator" mechanisms that evolved as a means of helping our ancestors acquire food more efficiently (Klein, 1994, 2000; Klein & MacInnes, 1999). Evidence consistent with this viewpoint has emerged from a number of recent studies that have looked at the impact of multiple cues in different spatial locations. For example, Danziger, Kingstone, and Snyder (1998; see also Birmingham & Pratt, 2005; Dodd, Castel, & Pratt, 2003; Ogawa, Takeda, & Yagi, 2002; Paul & Tipper, 2003; Pratt & Chasteen, 2007; Snyder & Kingstone, 2000, 2001, 2007) presented observers with five peripheral placeholder boxes surrounding a central fixation. On each trial, zero to three non-predictive cues were presented, consisting of the brightening of a single placeholder box. Then, a target, consisting of an asterisk, was presented inside one of the boxes either 100 or 600 ms after the onset of the last cue (or the start of the trial when there was no cue). The results showed that IOR occurred at all three cued locations

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(Snyder & Kingstone, 2000 later showed up to five locations could be inhibited) in declining strength with an increase in CTOA. On the assumption that real-world searches usually require examination of multiple locations, this finding then provides strong evidence for a link between IOR and search efficiency.

Given the existence of multiple-location IOR, a logical question to ask is whether multiple cues presented at the same location would also yield greater IOR. That is, given that two cues in different locations separately yield IOR, would two cues presented in the same location result in more IOR than a single cue? This question was addressed by Visser and Barnes (2009; see also Dukewich & Boehnke, 2008 for a similar methodology using up to five consecutive cues) who compared IOR generated by a single cue with that generated by two successive cues, separated by a fixed temporal interval, presented at the same spatial location. The results suggested that more IOR occurred at locations cued twice than those cued only once. In turn, this implied that the impact of cues was not isolated, but rather that the magnitude of IOR at a given spatial location was impacted by each irrelevant cue presented there.

In the present work, we follow-up this result in order to more closely investigate spatio-temporal interactions between irrelevant cues. In particular, although it has been reliably demonstrated that multiple cues in different locations each yield IOR, and that multiple cues in a single location yield greater IOR, it is not yet known whether cues presented in different locations have interactive effects. For example, does the presentation of a second cue influence the magnitude of IOR at a previously cued location?

To examine this issue, we presented two cues at different spatial locations separated by a variable temporal interval. We reasoned that because the influence of a cue on target RTs varies significantly with CTOA (Samuel & Kat, 2003), interactions between the effects of cues should be reflected in changes to the magnitude of IOR across inter-cue onset asynchronies (ICOA). For example, at shorter ICOAs, facilitatory effects generated by the second cue might summate with inhibitory effects from the first cue to yield a net reduction in the magnitude of IOR at the location of the first cue. As ICOA increases, however, the second cue should now produce inhibitory effects that would summate with the inhibitory effects of the first cue, yielding a net increase in the magnitude of IOR at the location of the first cue. On this reasoning then, interactions between the inhibitory effects of cues would be indicated by variations in IOR across ICOA at one or both cued locations.

The pattern of effects obtained when ICOA is manipulated has significant implications for understanding how inhibitory processes arise from the occurrence of irrelevant visual events. If ICOA has no effect on IOR at either cued location, this implies that inhibitory processes initiated by an irrelevant visual event occur with little or no consideration of other similar stimuli presented at close spatio-temporal proximity. At the other extreme, if IOR is influenced by ICOA at both cue locations, this would imply that inhibitory processes are highly dynamic, and may modulate inhibition as a function of the nature of visual information presented both prior to and after an irrelevant visual event. In fact, as will be seen, the present results are consistent with a third alternative. It appears that although an initial cue modulates the impact of a subsequent irrelevant event, the effect is unidirectional. Subsequent cues do not influence inhibition at earlier cued locations.

Experiment 1

The goal of Experiment 1 was to determine whether varying the interval between the onset of multiple cues influenced the magnitude of IOR generated by either cue. To do this, we presented observers with a series of trials containing four placeholder boxes equidistant from a central fixation. On each trial, two cues were presented that consisted of the brightening of one of the placeholders. The onset of these cues was separated by intervals of 200, 500, or 800 ms. A detection target was then presented in the middle of a placeholder, 800 ms after the onset of the second cue. Response times (RTs) and accuracy were analyzed as a function of cue number (first or second) and inter-cue interval. An additional goal of this experiment was to replicate the findings of Visser and Barnes (2009). Because the location of cues and targets was completely counterbalanced, a number of trials consisted of two cues presented at the same location. This allowed use to compare the impact of cueing a location twice relative to presentation of a single cue.

Participants

Twenty-eight participants (20 female) between the ages of 18 and 33 (mean = 22.3 years; SD = 4.3 years) were recruited through advertisements on university notice boards. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received a small honorarium of $10 to compensate them for their time and effort. All participants reported normal or corrected-to-normal vision, and were naïve to the purpose of the experiment.

Apparatus and stimuli

All stimuli were presented on a 19-in. (viewing size: 17.75 in.) Viewsonic monitor (Model G190T) running at a

refresh rate of 100 Hz, and slaved to a Pentium-IV computer running Presentation software (Version 9.20; Neurobehavioral Systems, 2005). The software was also responsible for recording response times and accuracy from a computer keyboard.

Testing was conducted in a quiet, dark laboratory with only dim illumination of the keyboard provided by a small light. The viewing distance from the monitor was approximately 60 cm. For the duration of each trial, observers viewed a display consisting of four outline gray squares (2° × 2°; luminance = 27 cd/m^2). These squares formed an imaginary cross centered upon a fixation cross (0.3° × 0.3°; luminance = 27 cd/m^2), with each square equidistant from fixation and from each other. The centre of each placeholder was 6° from fixation. Cues consisted of the brightening of a square to 114 cd/m^2 and increase in square thickness from four to six pixels. Targets consisted of a solid luminous square (1.2° × 1.2°; luminance = 114 cd/m^2) presented at the center of an outline square. All stimuli were presented against a black background.

Procedure

Trials were divided evenly between ICOAs of 200, 500, or 800 ms. In addition, stimulus presentation was constrained such that an equal number of first cues, second cues, and targets appeared at each of the four possible locations. This complete counter-balancing yielded a block of 192 trials. The entire experiment comprised five blocks of 192 trials, totaling 960 trials.

Prior to beginning the experiment, observers were given written and oral instructions which stressed two points. First, that observers should keep their eyes centered at fixation, and second, that cues would not predict target location and thus should be ignored. Each trial began with the presentation of a fixation cross flanked by four outline squares that served as placeholders. These placeholders remained on the display for the duration of the trial. Observers were instructed to press the space bar to start the sequence of stimuli, at which point the fixation cross disappeared. Following a 500 ms pause during which the display was blank, the first cue was presented for 100 ms. Next, the cue disappeared, and a second pause occurred for 100, 400, or 700 ms. This yielded a 200, 500, or 800 ms ICOA. Then, the second cue was presented for 100 ms.

Finally, after a 700 ms pause, the target was presented for 1000 ms or until a response was made by pressing the spacebar. This yielded an 800 ms CTOA between the second cue and target, and CTOAs of 1000, 1300, or 1600 ms between the first cue and the target, depending on ICOA. On 12.5% of trials (divided equally between blocks), no target was presented. These "catch trials" were designed to discourage participants from anticipating target onset. To aid in this, observers received feedback at the end of each block which informed them about their accuracy on catch trials. If they found themselves making many errors, they were instructed to slow down and be more careful.

Results

Error rates on catch trials ranged from 1.34 to 2.52% and did not vary reliably as a function of ICOA ($p > 0.07$, $\eta^2 < 0.10$). Errors on all other trials were defined as failures to respond to a target, or responses made less than 200 ms or more than 1000 ms after target onset. Mean RTs were calculated on non-error trials separately as a function of cue validity, and ICOA. Below, results are considered separately for trials on which targets appeared at the location of the first cue (two-back trials), at the location of the second cue (one-back trials), and at a location cued twice (double-cue trials).

One-back trials

Mean RTs were submitted to a 2 (Cue Validity: Valid, Invalid) × 3 (ICOA: 200, 500, 800 ms) within-subjects analysis of variance (ANOVA). As suggested by inspection of Table 1, there was a significant main effect of Cue Validity, F (1, 27) = 144.56, $p < 0.001$, $\eta^2 = 0.84$, confirming that RTs were slower for validly-cued targets than invalidly-cued targets. This is the empirical signature of IOR. There was also a main effect of ICOA, F (2, 54) = 36.32, $p < 0.001$, $\eta^2 = 0.57$. Inspection of the data suggests this was due to a decline in overall RTs as ICOA increased. Finally, there was a significant interaction between Cue Validity and ICOA, F (2, 54) = 12.96, $p < 0.001$, $\eta^2 = 0.32$. Inspection of the data shows that this interaction stemmed from an increase in IOR as ICOA increased. Note that this effect cannot be due to differences in the temporal interval between the second cue and the target: this interval was always 800 ms. Rather, the effect must be due to variation in the temporal interval between cues.

Error rates on one-back trials were extremely low, ranging from 0.80% to 1.17%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.24, η^2's < 0.05).

Two-back trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. As with one-back trials, this analysis revealed significant main effects of Cue Validity, F (1, 27) = 144.43, $p < 0.001$,

Table 1 Response time (RT) and percentage error (% Err) data for each cueing condition in Experiments 1–4

Experiment	Two-back			One-back			Double-cue			Invalid			Single-cue			Single-cue Invalid		
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L
1																		
RT	450	418	419	451	431	440	476	449	459	432	402	401						
	12	*12*	*13*	*11*	*11*	*11*	*12*	*13*	*14*	*12*	*12*	*12*						
%	1.15	0.98	0.96	0.80	0.91	0.94	0.82	0.61	1.21	1.07	1.17	1.10						
Err	*0.34*	*0.31*	*0.32*	*0.31*	*0.26*	0.35	0.39	0.34	0.45	0.22	*0.27*	*0.26*						
2																		
RT	460	440	438	464	453	454	486	475	472	442	421	420	481	453	452	460	442	440
	10	9	9	*9*	9	*8*	*10*	*12*	*9*	*9*	*9*	*9*	*9*	*9*	*10*	*9*	*10*	*10*
%	0.92	1.17	1.69	0.95	0.94	0.90	2.47	0.76	0.40	1.37	1.10	0.98	0.91	1.46	0.80	0.99	0.82	1.06
Err	*0.34*	*0.47*	*0.46*	*0.40*	*0.34*	*0.30*	*0.99*	*0.44*	*0.40*	*0.32*	*0.28*	*0.27*	*0.29*	*0.37*	*0.36*	*0.22*	*0.21*	*0.21*
3																		
RT	421	405	410	435	430	434	449	436	442	409	395	399						
	9	*9*	*10*	*9*	*10*	*10*	*11*	*9*	*10*	*8*	*9*	*9*						
%	0.99	0.86	1.36	1.38	1.51	0.73	0.85	1.40	1.90	1.04	1.30	0.93						
Err	*0.38*	*0.37*	*0.30*	*0.33*	*0.43*	*0.31*	*0.50*	*0.61*	*0.77*	*0.22*	*0.34*	*0.26*						
4																		
RT	415	390	397	425	416	420	444	437	438	400	374	385						
	11	*12*	*13*	*12*	*12*	*11*	*14*	*15*	*14*	*12*	*13*	*14*						
%	1.65	3.82	4.17	2.17	2.26	3.12	2.08	3.12	4.17	1.71	2.95	3.47						
Err	*0.43*	*1.23*	*1.81*	*0.60*	*0.61*	*1.57*	*0.61*	*1.13*	*1.94*	*0.29*	*0.66*	*0.77*						

Numbers in italics refer to SEM

S short ICOA, *M* medium ICOA, *L* long ICOA (except in single-cue and single-cue invalid where these refer to CTOA)

$\eta^2 = 0.84$, confirming the presence of IOR, and ICOA, F (2, 54) = 74.19, MSe = 244.73, $p < 0.001$, indicating a decline in overall RTs as ICOA increased. However, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 54) = 0.18, $p > 0.83$, $\eta^2 = 0.01$. Error rates on two-back trials were also extremely low, ranging from 0.98 to 1.17%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) ANOVA that revealed no significant effects (all p's > 0.63, η^2's < 0.01).

Double-cue trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 27) = 164.16, $p < 0.001$, $\eta^2 = 0.86$, confirming the presence of IOR, and ICOA, F (2, 54) = 22.69, $p < 0.001$, $\eta^2 = 0.46$, indicating a decline in overall RTs between the two shortest ICOAs, followed by a slight increase in overall RTs between the two longest ICOAs. However, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 54) = 1.77, $p > 0.17$, $\eta^2 = 0.06$.

Error rates on double-cue trials were also extremely low, ranging from 0.89 to 1.15%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) ANOVA that revealed no significant effects (all p's > 0.21, η^2's < 0.06).

Comparisons across trial types

To determine whether the magnitude of IOR was greater at locations cued twice than those cued only once, we calculated difference scores between RTs on valid and invalid trials as a function of trial type (two-back, one-back, double-cue) and ICOA. These scores can be seen in Fig. 1a, and were submitted to a 3 (Trial type) × 3 (ICOA) within-subjects ANOVA. The results revealed main effects of Trial type, F (2, 54) = 52.01, $p < 0.001$, $\eta^2 = 0.66$, and ICOA, F (2, 54) = 5.33, $p < 0.01$, $\eta^2 = 0.17$, but no interaction between these factors, F (4, 108) = 1.82, $p < 0.14$, $\eta^2 = 0.06$. Replicating Visser and Barnes (2009), follow-up comparisons confirmed that double-cued trials yielded more IOR than one-back trials ($p < 0.001$; all other comparisons between trial types were also significant at $p < 0.001$). Follow-up analyses also indicated that IOR was significantly larger at the longest ICOA than the

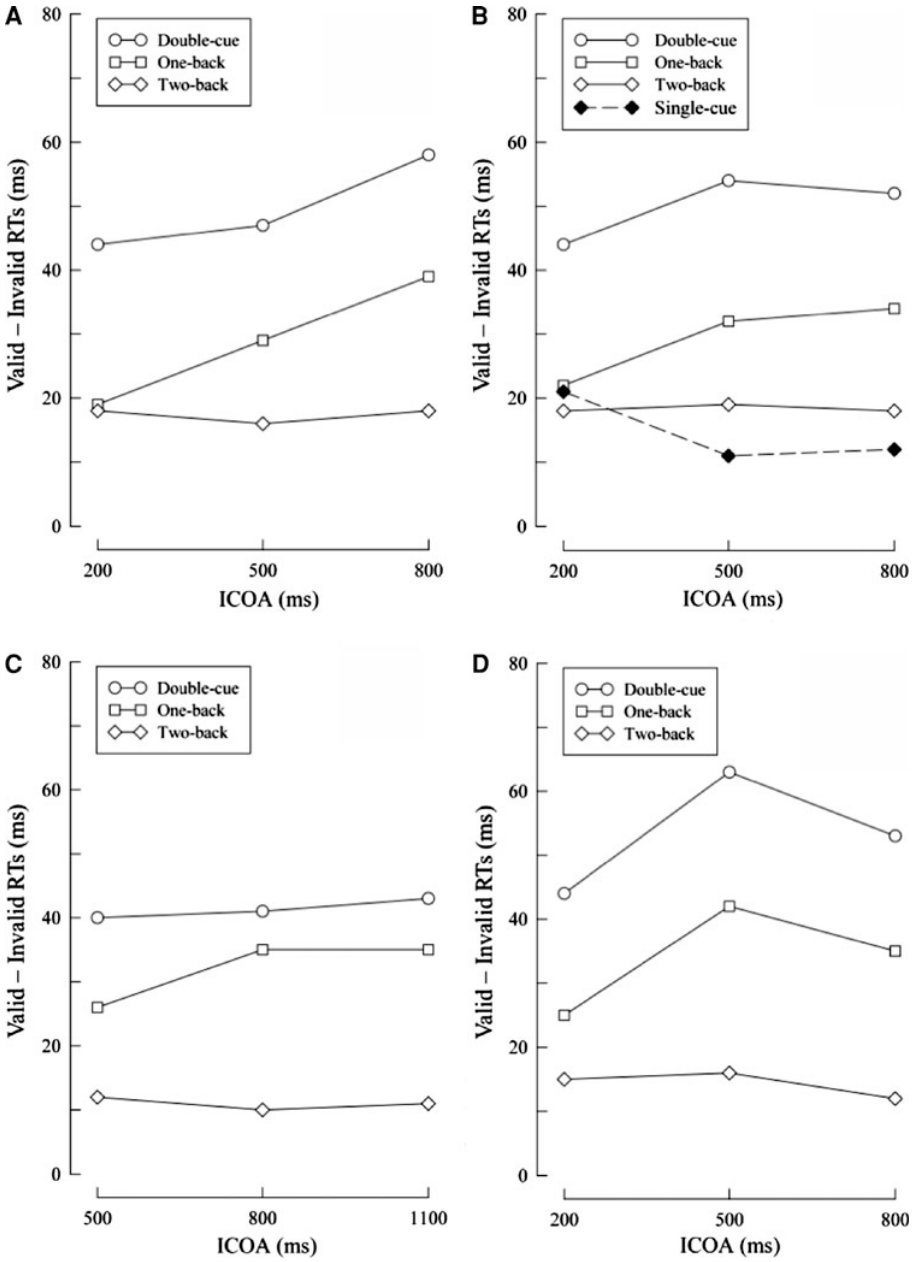

Fig. 1 Mean RT difference between valid and invalid trials (i.e., IOR) as a function of cueing condition. Panels **a–d** depict results from Experiments 1–4 respectively. Note that in the "single-cue" condition in Experiment 2, the second cue was omitted. However, to facilitate comparison between performance here and in the two-back condition, which have identical CTOAs, results are presented in the same figure. The CTOA in both the two-back and single-cue conditions may be obtained by adding 800 ms to the appropriate value on the *X*-axis

shortest ICOA ($p < 0.01$; no other comparisons were significant, $p > 0.07$).

The results of Experiment 1 are consistent with earlier multiple cueing studies (e.g. Danziger et al., 1998) in showing that robust IOR can occur at multiple spatial locations simultaneously. They also replicate earlier findings by Visser and Barnes (2009) and Dukewich and Boehnke (2008) showing that increasing the number of cues presented at a spatial location yields greater IOR. What is new here is that we show that the magnitude of IOR at the most recently cued spatial location is influenced by the temporal interval between cues. Importantly, this suggests that, at least with respect to IOR, the effects of an irrelevant visual event (i.e., a non-predictive spatial cue) do not occur independently from the effects of previous similar events at other spatial locations.

That said, the results of Experiment 1 also suggest that the influence of an irrelevant visual event on processing is unidirectional. Specifically, although IOR magnitude is modulated by prior visual events, once it has occurred in response to a cue, its magnitude is unaffected by subsequent visual events. Evidence for this comes from the

fact that while one-back trials were significantly modulated by ICOA, this modulation was absent on two-back trials. Before drawing this conclusion, however, it is important to consider an alternative explanation: namely, that the second cue did influence inhibition generated by the first cue, but that this effect was not reflected in variations in IOR across ICOA.

This possibility is suggested by examination of Fig. 1a which reveals that IOR in the two-back condition was relatively steady at CTOAs from 1000 to 1600 ms (ICOAs of 200–800 ms). This result is inconsistent with previous studies that have used a single cue and target, which have generally found a decline in IOR across these CTOAs (e.g., Klein, 2000; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Samuel & Kat, 2003). This difference raises the possibility that the second cue used here may actually have enhanced the magnitude of IOR at longer CTOAs in the two-back condition, relative to what would have occurred with only a single cue.[1] Thus, in this case, the absence of an interaction might still be consistent with the idea that the second cue impacted IOR generated at the location of the first cue.

Experiment 2

The results of Experiment 1 suggested a clear influence of an initial cue on the magnitude of IOR generated at the location of a subsequent cue. However, it is unclear whether the second cue influenced the magnitude of IOR at the location of the first cue. Specifically, the fact that IOR in the two-back condition did not decline at longer ICOAs (and hence CTOAs) may imply that the second cue actually enhances IOR at the location of the first cue. To evaluate this possibility, in Experiment 2, we replicated Experiment 1 but omitted the second cue on half of trials. This provided a single-cue baseline against which to evaluate the possible effects of a subsequent cue, and afforded an important opportunity to replicate the results obtained in Experiment 1 under different experimental conditions.

Participants

Thirty-six participants (5 male) between the ages of 17 and 40 (mean = 20.6 years; SD = 3.4 years) were recruited through web-based experimental signup software. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received one bonus point towards their final grade in one of the Psychology courses that they were enrolled in, reported normal or corrected-to-normal vision, and were naïve to the purpose of the experiment.

Apparatus and stimuli

All stimuli were presented on a 19-in. (viewing size: 17.75 in.) NEC monitor (MultiSync FE992) running at a refresh rate of 100 Hz, and slaved to a Pentium-IV computer running Presentation software (Version 9.85; Neurobehavioral Systems, 2006).

Procedure

The testing procedure was identical to Experiment 1, except that on one-half of trials, the second cue was omitted. On these trials, the CTOA between the only cue and the target was either 1000, 1300, or 1600 ms—identical to the CTOAs between the first cue and targets on trials where two cues were presented.

Results

Error rates on catch trials ranged from 0.86 to 1.76% and did not vary as a function of ICOA ($p > 0.06$, $\eta^2 < 0.08$). Errors on other trials were defined as in Experiment 1. Mean RTs were calculated on non-error trials separately as a function of cue validity, ICOA and number of cues. Below, results are considered separately for trials on which targets appeared at the location of the first cue (two-back trials) on two-cue trials, at the location of the second cue (one-back trials) on two-cue trials, at a location cued twice (double-cue trials), and at the location of the only cue (single-cue trials) on single-cue trials.

One-back trials

Mean RTs were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. As suggested by inspection of Table 1, there was a significant main effect of Cue Validity, $F\ (1,\ 35) = 75.31$, $p < 0.001$, $\eta^2 = 0.68$, confirming the presence of IOR. There was also a main effect of ICOA, such that overall RTs declined as ICOA increased, $F\ (2,\ 70) = 16.98$, $p < 0.001$, $\eta^2 = 0.33$. Finally, there was a significant interaction between Cue Validity and ICOA, $F\ (2, 70) = 3.18$, $p < 0.05$, $\eta^2 = 0.08$. Inspection of the data shows that this interaction stemmed from an increase in IOR as ICOA increased.

Error rates on one-back trials were low, ranging from 0.91 to 1.36%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.31, η^2's < 0.04).

[1] We thank Raymond Klein and Kristie Dukewich for pointing out this possibility.

Two-back trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. As with one-back trials, this analysis revealed significant main effects of Cue Validity, F (1, 35) = 73.54, $p < 0.001$, $\eta^2 = 0.68$, confirming the presence of IOR, and ICOA, F (2, 70) = 30.69, $p < 0.001$, $\eta^2 = 0.47$, indicating a decline in overall RTs as ICOA increased. However, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 70) = 0.03, $p > 0.96$, $\eta^2 = 0.01$.

Error rates on two-back trials were also low, ranging from 0.92 to 1.69%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.07, η^2's < 0.08).

Double-cue trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 35) = 90.58, $p < 0.001$, $\eta^2 = 0.72$, confirming the presence of IOR, and ICOA, F (2, 70) = 7.50, $p < 0.01$, $\eta^2 = 0.18$, indicating a large decline in overall RTs between the two shortest ICOAs, followed by a much smaller decrease in overall RTs between the two longest ICOAs. However, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 70) = 0.63, $p > 0.53$, $\eta^2 = 0.02$. Error rates on two-back trials were low, ranging from 0.40 to 2.47%.

As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed a significant main effect of ICOA, F (2, 70) = 3.33, $p < 0.05$, $\eta^2 = 0.09$, indicating a steady increase in error rate as ICOA increased. No other main effects or interactions were significant (all p's > 0.16, η^2's < 0.06).

Single-cue trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (CTOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 35) = 48.76, $p < 0.001$, $\eta^2 = 0.58$, confirming the presence of IOR, and CTOA, F (2, 70) = 38.05, $p < 0.001$, $\eta^2 = 0.52$, indicating a decline in overall RTs as CTOA increased. Unlike the analogous analysis of two-back trials, there was also a significant interaction between Cue Validity and CTOA, F (2, 70) = 3.73, $p < 0.03$, $\eta^2 = 0.10$. Inspection of Table 1 shows that this interaction primarily stemmed from a steep decline in IOR between the two shortest CTOAs.

Error rates on single-cue trials were low, ranging from 0.93 to 1.14%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (CTOA) analysis. This analysis revealed no significant effects (all p's > 0.07, η^2's < 0.08).

Comparisons across trial types

Two different comparisons were conducted across trial types. The first was between the magnitude of IOR on double-cue, two-back, and one-back trials. This comparison was made in order to determine whether locations cued twice yielded more IOR than those cued only once as in Visser and Barnes (2009) and Experiment 1. The second comparison was between the magnitude of IOR on single-cue and two-back trials. The purpose of this comparison was to test whether the second cue inflated IOR at the location of the initial cue as suggested by the lack of an interaction between ICOA and cue validity in the two-back trials found both here and in Experiment 1. To this end, we calculated difference scores between RTs on valid and invalid trials as a function of trial type (two-back, one-back, double-cue, single-cue) and ICOA. These scores can be seen in Fig. 1b, and were submitted to a 3 (Trial type) × 3 (ICOA) within-subjects ANOVA. The results revealed a main effect of Trial type, F (2, 70) = 29.19, $p < 0.001$, $\eta^2 = 0.46$, but no other main effect or interaction (p's > 0.28, η^2's < 0.04). Replicating Visser and Barnes (2009) and Experiment 1, follow-up comparisons confirmed that double-cue trials yielded more IOR than one-back trials ($p < 0.001$; all other comparisons between trial types were also significant at $p < 0.01$).

Next, difference scores in the two-back and single-cue trials were submitted to a 2 (Trial type) × 3 (ICOA/CTOA) within-subjects ANOVA. The results revealed no main effects (p's > 0.13, η^2's < 0.06), and critically, no interaction between Trial type and ICOA/CTOA, F (2, 70) = 1.03, $p > 0.36$, $\eta^2 = 0.03$. This suggests that there was no difference in the magnitude of IOR between the two-back and single-cue condition, nor was there a difference in the pattern of IOR across ICOA/CTOA in the two conditions. Given that there was a significant interaction between CTOA and cue validity in the single-cue condition, but not in the analogous analysis of the two-back condition, one might wonder whether the failure to find a statistically significant interaction between ICOA/CTOA and Trial type in this analysis is a Type II error. Although this possibility cannot be ruled out, a power analysis suggests that 3062 participants would be required to find a statistically significant interaction between ICOA/CTOA

and cue validity given the current effect size (Faul, Erdfelder, Lang, & Buchner, 2007). Thus, it would seem that the second cue has, at most, a very minor influence on the magnitude of IOR at the location of a prior cue.

The results of Experiment 2 confirmed four findings from Experiment 1. First, robust IOR occurred at more than one cued location (e.g. Danziger et al., 1998). Second, more IOR occurred when a location was cued twice than only once (Visser & Barnes, 2009; Dukewich & Boehnke, 2008). Third, replicating Experiment 1, the magnitude of IOR at the location of the second cue varied with the interval between the first and second cues. Fourth, the results here also suggest that the magnitude of IOR arising from the first cue is unaffected by the presentation of a subsequent cue. Specifically, presentation of the second cue did not bolster the magnitude of IOR at the location of the first cue over what was obtained at this location with just the initial cue.

Experiment 3

Although Experiment 2 provided important converging evidence for the results of Experiment 1, in Experiment 3 we wished to address two further issues. First, in Experiments 1 and 2, the fixation marker disappeared before the onset of the cues and target. This may have increased the likelihood that participants made eye movements to the locations of cues and targets, thereby influencing our results. To reduce the likelihood of eye movements in Experiment 3, the fixation marker remained onscreen throughout the trial. Second, in Experiments 1 and 2, we used identical ICOAs. Thus, an additional goal of Experiment 3 was to determine whether our findings generalized across different ICOAs than those used in the previous experiments.

Participants

Twenty-six participants (10 male) between the ages of 18 and 25 (mean = 20.1 years; SD = 1.8 years) were recruited through web-based experimental signup software. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received one bonus point towards their final grade in one of the Psychology courses that they were enrolled in, reported normal or corrected-to-normal vision, and were naïve to the purpose of the experiment.

Apparatus and stimuli

Apparatus and stimuli were identical to those used in Experiment 2

Procedure

The testing procedure was identical to Experiment 1, with three exceptions. First, the fixation cross remained on the screen throughout the duration of the trial. Second, rather than pressing the spacebar to initiate a trial, each trial in a block ran automatically, with the beginning of each new trial signaled by the fixation cross changing color from gray to red for 200 ms, and then returning to gray. Finally, the ICOAs were changed to 500, 800, or 1100 ms.

Results

Error rates on catch trials ranged from 0.72 to 1.60% and did not vary as a function of inter-cue interval ($p > 0.19$; $\eta^2 < 0.07$). Errors on other trials were defined as in Experiments 1 and 2. Mean RTs were calculated on non-error trials separately as a function of cue validity, ICOA and number of cues. Below, results are considered separately for trials on which targets appeared at the location of the first cue (two-back trials), at the location of the second cue (one-back trials), and at locations cued twice (double-cue trials).

One-back trials

Mean RTs were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. As suggested by inspection of Table 1, there was a significant main effect of Cue Validity, F (1, 25) = 151.57, $p < 0.001$, $\eta^2 = 0.86$, confirming the presence of IOR. There was also a main effect of ICOA, F (2, 50) = 5.39, $p < 0.01$, $\eta^2 = 0.18$, such that overall RTs initially declined with an increase in ICOA, and then increased again at the longest ICOA. Finally, there was a significant interaction between Cue Validity and ICOA, F (2, 50) = 3.42, $p < 0.05$, $\eta^2 = 0.18$. Inspection of the data shows that this interaction arose from an increase in IOR from the 500 ms to the 800 ms ICOAs, with little change in IOR between the 800 and 1100 ms ICOAs.

Error rates on one-back trials were low, ranging from 0.73 to 1.50%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.12, η^2's < 0.09).

Two-back trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. As with one-back trials, this analysis revealed significant main effects of Cue Validity, F (1, 25) = 30.40, $p < 0.001$,

$\eta^2 = 0.55$, confirming the presence of IOR, and ICOA, F (2, 50) = 15.03, $p < 0.001$, $\eta^2 = 0.38$, indicating a decline in overall RTs as ICOA increased. However, replicating earlier experiments, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 50) = 0.03, $p > 0.96$, $\eta^2 = 0.01$.

Error rates on two-back trials were minimal, ranging from 0.86 to 1.36%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.17, η^2's < 0.07).

Double-cue trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 25) = 177.62, $p < 0.001$, $\eta^2 = 0.88$, confirming the presence of IOR, and ICOA, F (2, 50) = 11.53, $p < 0.001$, $\eta^2 = 0.32$, indicating a decline in overall RTs between the two shortest ICOAs, followed by an increase in overall RTs between the two longest ICOAs. However, the magnitude of IOR was unaffected by ICOA as indicated by a non-significant interaction between Cue Validity and ICOA, F (2, 50) = 0.13, $p > 0.88$, $\eta^2 = 0.01$.

Error rates on double-cue trials were also low, ranging from 0.85 to 1.90%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) ANOVA that revealed no significant effects (all p's > 0.26, η^2's < 0.05).

Comparisons across trial types

As in previous experiments, to determine whether the magnitude of IOR was greater at locations cued twice than those cued only once, we calculated difference scores between RTs on valid and invalid trials as a function of trial type (two-back, one-back, double-cue) and ICOA. The resulting scores can be seen in Fig. 1c, and were submitted to a 3 (Trial type) × 3 (ICOA) within-subjects ANOVA. The results revealed a main effect of Trial type, F (2, 50) = 80.30, $p < 0.001$, $\eta^2 = 0.76$, but no other main effect or interaction (p's > 0.39, η^2's < 0.04). Follow-up comparisons confirmed that double-cue trials yielded more IOR than one-back trials ($p = 0.001$; all other comparisons between trial types were also significant at $p < 0.001$).

The present results replicate the key findings of Experiments 1 and 2. In particular, while one-back trials were influenced by ICOA, this effect was entirely absent in the two-back condition. This suggests that the initial cue influences the impact of a subsequent cue, but not vice versa. The findings also replicated earlier results showing that cueing a location twice leads to substantially more IOR than cueing a location only once (Visser & Barnes, 2009; Dukewich & Boehnke, 2008). This suggests that the patterns of results seen in earlier experiments were not unique to the ICOAs employed, the need to press the space bar to start the trial, or the increased possibility of eye movements resulting from offsetting the fixation cross when each trial was initiated.

Experiment 4

A key question that has yet to be addressed here is the mechanism that underlies the impact of the first cue on the magnitude of IOR arising at the location of the second cue. One possibility is that IOR reflects summation of "spreading inhibition" from the location of the first cue with IOR resulting from presentation of the second cue. On this account, inhibition is maximal at the location of a non-predictive cue and then steadily declines in strength as distance from the cue increases (Birmingham, Visser, Snyder, & Kingstone, 2007; Bennett & Pratt 2001; Pratt, Adams, & McAuliffe, 1998). This suggests that inhibitory effects of cues presented at different locations should summate as long as the location of a second cue is within the inhibitory spread arising from the first cue. Further, it should be the case that cued locations that are physically closer should show more inhibition than those more distant from one another.

To examine this possibility, we compared cued target RTs when they occurred at a location directly adjacent to a prior cue (near) and directly opposite a prior cue (far). Further, to increase statistical power, we collapsed across identical ICOAs (i.e., 500 and 800 ms) in the three experiments. Although the resulting analysis showed that RTs were slightly longer in the near condition (442 vs. 440 ms), this 2 ms difference failed to reach significance ($p > 0.24$, $\eta^2 = 0.02$).

Another possible explanation for the unidirectional direction of the cue interactions obtained here involves the notion of temporal predictability. Although the first cue does not predict the location of a subsequent cue, it does predict the time of its appearance: namely, as time passes from the appearance of the first cue, it becomes increasingly likely that the second cue will be presented. This, in turn, may influence processing of the second cue and the resulting magnitude of IOR at its location. Consistent with this possibility, Tipper and Kingstone (2005) showed that varying the percentage of catch trials between experimental blocks, and hence temporal expectancy of targets, significantly modulated IOR. Also suggestive is the fact that in the experiments reported here so far, overall RTs varied reliably with ICOA, implying that as time passed from the

presentation of the cue, some aspect of second cue and/or target processing changed.

To investigate whether the temporal information given by first cue modulates the between-cue interactions found in the first three experiments, we used a non-aging distribution of ICOAs similar to that employed by Gabay and Henik (2008). Here, the proportion of short-, medium- and long-duration ICOAs was varied in order to eliminate the temporal predictability of the first cue. In all other respects, the experimental design was identical to that of Experiment 1.

Participants

Twenty-eight participants (13 female) between the ages of 17 and 37 (mean = 19.8 years; SD = 3.9 years) were recruited through web-based software. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received course credit towards an Introductory Psychology class, reported normal or corrected-to-normal vision, and were naïve to the purpose of the experiment.

Apparatus and stimuli

All stimuli were presented on a 19-in. (viewing size: 17.75 in.) Acer monitor (AC716) running at a refresh rate of 100 Hz, and slaved to a Pentium-IV computer running Presentation software (Version 12.20; Neurobehavioral Systems, 2008).

Procedure

The testing procedure was identical to Experiment 1, except that the proportion of 200, 500, and 800 ms ICOA trials was systematically varied to eliminate the temporal predictiveness of the cue. This yielded a total of 256 trials at the shortest ICOA, 128 trials at the middle ICOA, and 64 trials at the longest ICOA. There were also 64 catch trials. The resulting 512 trials were presented in random order in a single block of self-paced trials.

Results

Four participants were omitted from the data analysis. One participant failed to respond on 75% of trials that contained a target. Three others had catch trial error rates of greater than 40%.

Error rates on catch trials were higher than in previous experiments, ranging from 6.57 to 8.16%, but did not vary as a function of inter-cue interval ($p > 0.56$; $\eta^2 < 0.03$). Errors on other trials were defined as in Experiments 1–3. Mean RTs were calculated on non-error trials separately as a function of cue validity, and ICOA. Below, results are considered separately for trials on which targets appeared at the location of the first cue (two-back trials), at the location of the second cue (one-back trials), and at a location cued twice (double-cue trials).

One-back trials

Mean RTs were submitted to a 2 (Cue Validity: Valid, Invalid) × 3 (ICOA: 200, 500, 800 ms) within-subjects ANOVA. As suggested by inspection of Table 1, there was a significant main effect of Cue Validity, F (1, 23) = 68.88, $p < 0.001$, $\eta^2 = 0.75$, confirming the presence of IOR. There was also a significant main effect of ICOA, F (2, 46) = 6.68, $p < 0.01$, $\eta^2 = 0.23$, which reflects an initial decline in overall RTs between the 200 and 500 ICOA, followed by an increase in RTs between the 500 and 800 ms ICOA. Notably, unlike previous experiments, there was no significant interaction between Cue Validity and ICOA, F (2, 46) = 2.12, $p > 0.13$, $\eta^2 = 0.08$, suggesting that inter-cue interval did not affect IOR magnitude. However, because inspection of Table 1 seemed to indicate that IOR did increase substantially between the 200 and 500 ms ICOAs, we conducted a follow-up analysis limited to these two ICOAs. This revealed significant main effects of Cue Validity, F (1, 23) = 99.75, $p < 0.001$, $\eta^2 = 0.81$, and ICOA, F (1, 23) = 22.25, $p < 0.001$, $\eta^2 = 0.49$ and a highly significant interaction between Cue Validity and ICOA, F (1, 23) = 9.45, $p < 0.01$, $\eta^2 = 0.29$.

Error rates on one-back trials were modest, though higher than previous experiments, ranging from 1.71 to 3.48%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) analysis. This analysis revealed no significant effects (all p's > 0.23, η^2's < 0.07).

Two-back trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 23) = 14.77, $p < 0.01$, $\eta^2 = 0.39$, confirming the presence of IOR, and ICOA, F (2, 46) = 19.22, $p < 0.001$, $\eta^2 = 0.46$, indicating that overall RTs initially declined and then increased at the longest ICOA. As in previous studies, there was no significant interaction between Cue Validity and ICOA, F (2, 46) = 0.18, $p > 0.83$, $\eta^2 = 0.01$, indicating IOR on at the two-back location was unaffected by ICOA.

Error rates on two-back trials were low, although again higher than previous experiments, ranging from 1.65 to 3.82%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) ANOVA. This revealed a

main effect of ICOA, F (2, 46) = 3.26, $p < 0.05$, $\eta^2 = 0.12$, indicating a significant increase in errors between the 200 and 500 ms ICOAs. This, in turn, implies that some of the decrease in RTs at these ICOAs may be attributable to a speed-accuracy trade-off. Neither the main effect of Cue Validity nor the interaction between Cue Validity and ICOA were significant (all p's > 0.50, η^2's < 0.03).

Double-cue trials

Mean RTs (see Table 1) were submitted to a 2 (Cue Validity) × 3 (ICOA) within-subjects ANOVA. This analysis revealed significant main effects of Cue Validity, F (1, 23) = 65.11, $p < 0.001$, $\eta^2 = 0.74$, confirming the presence of IOR. Neither the main effect of ICOA nor the interaction between Cue Validity and ICOA were significant (all p's > 0.05, η^2's < 0.12).

As on the one-back and two-back trials, error rates were higher than previous experiments, ranging from 1.71 to 4.17%. As with the RT data, error data were submitted to a 2 (Cue Validity) × 3 (ICOA) ANOVA that revealed no significant effects (all p's > 0.18, η^2's < 0.08).

Comparisons across trial types

To determine whether the magnitude of IOR was greater at locations cued twice than those cued only once, we calculated difference scores between RTs on valid and invalid trials as a function of trial type (two-back, one-back, double-cue) and ICOA. The resulting scores can be seen in Fig. 1d, and were submitted to a 3 (Trial type) × 3 (ICOA) within-subjects ANOVA. The results revealed a main effect of Trial type, F (2, 46) = 20.77, $p < 0.001$, $\eta^2 = 0.48$, but no other main effect or interaction (all p's > 0.20, η^2's < 0.07). As in earlier experiments, follow-up comparisons showed that double-cued trials yielded more IOR than one-back trials ($p < 0.001$; all other comparisons between trial types were also significant at $p < 0.02$).

The goal of Experiment 4 was to determine whether the unidirectional effect of an initial cue on IOR at the location of a second cue depends on the temporal information provided by the first cue about the appearance of the second. To this end, we varied the proportion of trials at each ICOA using a non-aging distribution like that of Gabay and Henik (2008). The results suggested that this manipulation did affect performance. Error rates were noticeably higher on both catch and target-present trials. Also, unlike previous experiments, between the 500 and 800 ms ICOAS, overall RTs increased, while overall IOR declined on the one-back and double-cue trials. Likely reflecting this difference, the interaction between Cue Validity and ICOA found in all previous experiments on one-back trials was not significant in Experiment 4 when all ICOAs were included in the analysis. However, when only the two shortest ICOAs were analyzed, a highly significant interaction between Cue Validity and ICOA re-emerged, consistent with the substantial increase in IOR between the 200 and 500 ms ICOAs clearly visible in Fig. 1d. On the basis of this result then, it seems reasonable to conclude that temporal information provided by the first cue may contribute to increases in IOR at the location of the second cue at longer ICOAs. However, elimination of temporal predictiveness between the first and second cue does not eliminate the increase in IOR across ICOA at the location of the second cue, suggesting other mechanisms underlie this effect.

A final point for discussion here relates to the finding that while temporal predictiveness did not influence IOR in the initial work of Gabay and Henik (2008), predictiveness between the first and second cues did modulate IOR at the location of the second cue in the present experiment. This finding is similar to a more recent paper, in which Gabay and Henik (2010) found that temporal predictiveness modulated IOR in a target discrimination task. To explain this result, Gabay and Henik (2010) suggested that predictiveness influences the speed of cue processing or exogenous orienting in the face of increased task complexity. The same may be true here, given that our multiple-cueing paradigm is also likely more complex than a simple detection task in a standard single-cue study (e.g., greater need for cognitive control). However, this explanation can only be offered tentatively, and it is clear that more studies are needed before a comprehensive explanation for the impact of predictiveness on IOR can be made.

General discussion

It is well established that multiple non-predictive cues each result in inhibitory effects on subsequent targets (e.g. Danziger et al., 1998). However, little is known about whether these effects are independent, or whether inhibition at each cue location is modulated by spatiotemporally adjacent cues. To examine this issue we varied the temporal interval between two consecutive non-predictive cues on the assumption that inhibitory interactions would be reflected in variations in the magnitude of IOR at each cued location as ICOA was varied. The results suggested that interactions between cues do occur. However, these interactions are not equivalent: while the presentation of an initial cue increases IOR resulting from a second cue, presentation of a second cue does not influence IOR arising from a prior cue. This follows from repeated interactions obtained between ICOA and cue validity on one-back

trials, the absence of such interactions on two-back trails, and evidence that IOR did not differ reliably between two-back trials and single-cue trials in Experiment 2.

An additional finding from the present studies was that IOR obtained on double-cue trials was reliably greater than that obtained on two-back trials. Replicating Visser and Barnes (2009; see also Dukewich & Boehnke, 2008), this finding shows that cueing a single location twice produces substantially more IOR than cueing a location only once. This is consistent with the notion that the inhibitory effects arising from non-predictive cues roughly summate, suggesting that multiple irrelevant events serve to increase the impetus to disregard information at a given spatial location.

Interestingly, although one-back trials showed reliable modulations in IOR magnitude as a function of ICOA, double-cued trials did not. This result was found consistently across all four experiments. Although this seems somewhat puzzling at first glance, it is likely that variations in IOR across ICOA on double-cued trials can be roughly estimated by the sum of IOR obtained at the one-back and two-back locations. This means that IOR on double-cue trials is the sum of one-back trials, which showed a robust variation across ICOA, and two-back trials, which show practically no variation across ICOA. The end product then is the trend towards variations in IOR across ICOA seen in all four panels of Fig. 1, but no statistically significant differences.

By far the biggest puzzle presented by these results concerns the mechanism by which an initial cue impacts inhibition at the location of a trailing cue. Two options have already been evaluated. One is that the initial cue increases IOR at the location of the second cue via spreading inhibition (Birmingham et al., 2007; Bennett & Pratt, 2001; Pratt et al., 1998). However, this can account for, at best, only a small proportion of the effect as the magnitude of IOR at the location of the second cue did not vary significantly with distance from the location of the first cue. A second option, examined in Experiment 4, was whether the temporal information provided by the first cue about when the second cue was likely to appear influenced IOR magnitude. Again, there was scant evidence for this hypothesis. While eliminating temporal predictiveness did influence overall RTs and accuracy, it did little to modulate the interaction between ICOA and Cue Validity on one-back trials.

Another possible mechanism to explain variations in IOR across ICOA is suggested by recent work from Dukewich (2009) who argued that IOR is a particular instantiation of the more general phenomenon of habituation (Thompson & Spencer, 1966). To whit, faced with multiple visual inputs at a given location, at least some of which are irrelevant, the brain's response to stimuli at that location gradually decreases. This is reflected in slowed responses to targets presented at the location of a prior irrelevant cue (i.e., IOR). The notion of habituation is highly consistent with the increase in IOR seen when the same location is cued multiple times (Dukewich & Boehnke, 2008; Visser & Barnes, 2009). Moreover, with respect to the present results, habituation can also explain why an initial cue leads to more IOR at the location of the second cue, but not vice versa. Namely, habituation grows in strength as the number of cues increases, thereby slowing responses—a unidirectional effect.

For this explanation to be correct, however, it must be assumed that habituation occurs not only along the dimension of location, as is traditionally conceptualized, but also along the dimension of stimulus identity. This allows for an explanation of the unidirectional nature of cueing, and also potentially explains why this effect did not vary significantly with distance from the cue, since slowing is no longer be tied to a spatial location. More generally, this modification provides the foundation for a habituation-based account of multiple location IOR. As Dukewich (2009) notes, multiple-location IOR is difficult to explain if it is assumed that habituation is entirely spatially localized because presenting a cue in a new location should lead to dis-habituation at other spatial locations, rather than prolonged evidence for IOR. However, if it is assumed that similar stimuli can be grouped for the purposes of habituation, then a new cue should not lead to dis-habituation as long as the cues are similar. Indeed, just such conditions are found here and in all previous multiple-location cueing studies (Danziger et al., 1998; Snyder & Kingstone, 2000, 2001, 2007). This modified account also makes a clear prediction for future testing. Presenting different types of cues (e.g., different shapes) at each spatial location should eliminate multiple-location IOR.

Another potentially fruitful observation is that the largest increase in IOR on one-back trials was consistently found between the shortest and middle ICOAs, regardless of the actual duration of those ICOAs. That is, in Experiments 1, 2, and 4, when the shortest ICOA was 200 ms, IOR increased sharply between the 200 and 500 ms ICOAs, and was relatively unchanged between 500 and 800 ms ICOAs. Similarly, in Experiment 3, when the shortest ICOA was 500 ms, IOR increased sharply between the 500 and 800 ms ICOAs, and was relatively unchanged between the 800 and 1100 ms ICOAs. This pattern suggests that the interaction between the first and second cues depends not on the absolute temporal interval between them, but rather on their relative temporal interval. Put differently, the increase in IOR seems to be tied to the onset of the second cue, rather than unfolding subsequent to the onset of the first cue (in which case, the relationship between ICOA and IOR magnitude should look similar across experiments). Although it is unclear how this can

precisely be used to explain the results here, the fact that the change in IOR depends on the presentation of the second cue, is broadly consistent with the habituation explanation advanced above. Another option is that this pattern reflects a change in response preparedness (Ivanoff & Klein, 2001, 2004) that may mediate the IOR effects. Clearly, this is an area that remains for future investigation.

Ultimately, although a definitive explanation for the effects reported here is still uncertain, the fact remains that an initial cue substantially impacted responses to a subsequent cue, but not vice versa. This imbalance suggests fundamental differences in the way inhibition occurs at cued locations in response to spatiotemporally adjacent events. On the one hand, when inhibition is initially allocated to a spatial location, it is done without regard for prior inhibition allocated to other spatial locations. On the other hand, it seems that once inhibition has been established, it is insensitive to changes resulting from later environmental events. To the extent that IOR reflects processes designed to improve search, such differences seem sensible. One would expect that inhibition would be most helpful to search if it were sensitive to processing of prior environmental events. Similarly, once inhibition has been allocated in response to an irrelevant visual event at a given location, it seems that boosting inhibition in response to an event a different location might be counter-productive to search efficiency.

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