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Time course of inhibition of return in a spatial cueing paradigm with distractors

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ABSTRACT

Studies of endogenous and exogenous attentional orienting in spatial cueing paradigms have been used to investigate inhibition of return, a behavioral phenomenon characterized by delayed reaction time in response to recently attended locations. When eye movements are suppressed, attention is covertly oriented to central or peripheral stimuli. Overt orienting, on the other hand, requires explicit eye movements to the stimuli. The present study examined the time course of slowed reaction times to previously attended locations when distractors are introduced into overt and covert orienting tasks. In a series of experiments, manual responses were required to targets following central and peripheral cues at three different cue-target intervals, with and without activated oculomotor systems. The results demonstrate that, when eye movements are suppressed, behavioral inhibition is reduced or delayed in magnitude by the presence of a distractor relative to conditions without distractors. However, the time course of behavioral inhibition when eye movements are required remains similar with or without distractors.

1. Introduction

1.1. Inhibition of return

In spatial cueing paradigms (Posner, 1980), participants are generally asked to indicate as quickly and accurately as possible whether a target stimulus has appeared on the left or right side of an array. Prior to the appearance of the target, participants are presented with a cue. These cues are uninformative in regards to the target response task in most studies – there is as much chance that the target will appear at the cued location as the other location. When the interval between cue and target presentation (cue-target onset asynchrony; CTOA) is short, facilitation occurs – responses to targets appearing at cued locations have faster reaction times (RTs) than responses to targets appearing at uncued locations (e.g., Maylor, 1985; Posner & Cohen, 1984). However, when the CTOA is around 300 ms or longer, RTs to targets that appear at cued locations tend to be slower than those to targets that appear at uncued locations, an effect termed inhibition of return (IOR) by Posner, Rafal, Choate, and Vaughan (1985).

The proposed functional significance of IOR is novelty seeking (Posner & Cohen, 1984), or foraging facilitation (Klein, 1988). To accommodate this function, IOR must therefore be relatively long lasting, coded in spatiotopic coordinates, and present during the execution of eye movements (Hilchey, Klein, & Satel, 2014). Later work suggested that there were two distinct forms of inhibition: i) an input-based form of IOR that primarily affects early sensory processes, and ii) an output-based form of IOR that primarily affects later motor processes (Taylor & Klein, 2000). Sensory IOR is thought to be generated exclusively when the oculomotor system is actively inhibited, whereas motor IOR occurs when the eyes are free to move in response to either cues or targets, regardless of whether the cues and targets are endogenous or exogenous in nature in the form of central or peripheral stimuli (e.g., Hilchey et al., 2014; Rafal, Calabresi, Brennan, & Sciolto, 1989; Taylor & Klein, 2000). However, because the input-based form of inhibition is likely coded in retinotopic (rather than spatiotopic) coordinates and occurs only when the eye movement system is actively inhibited, it does not align with the original definition of IOR and so we will from here on refer to it simply as an inhibitory cueing effect (ICE) rather than sensory IOR, as suggested by Hilchey et al. (2014).

Some studies have proposed that oculomotor activation is the primary criterion in determining whether an input-based ICE or output-based IOR is generated (Taylor & Klein, 2000; see Klein & Hilchey, 2011, for a review), in large part because an equivalent amount of inhibition was observed whether central arrow or peripheral stimuli were used when eye movements were allowed to either cues or targets but not when eye movements were forbidden. However, Taylor and Klein

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(2000) only investigated a static CTOA of 1500 ms. A similar pattern was observed in a subsequent time course design (Hilchey et al., 2014), where equivalent inhibition was observed behaviorally regardless of target type at a CTOA of 1050 ms, but no inhibition was observed for central targets at CTOAs of 450 ms or less, suggesting that IOR arises at some point between 450 and 1050 ms post-cue when a saccadic localization task is used in the spatial cueing paradigm.

1.2. Distractors

Regardless of oculomotor activation state, it is also clear that the type of task can influence the time at which behavioral inhibition is observed, especially when task demands are different between task sets (Berger, Henik, & Rafal, 2005; Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997; Lupiáñez & Milliken, 1999; Terry, Valdes, & Neill, 1994). Simple detection tasks are the most straightforward, involving just a simple manual key press upon detection of the target. Discrimination or two-alternative force choice (2-AFC) tasks can be either feature-based (e.g., press X if the target is red, press O if the target is blue) or location-based (e.g., press the left button if the target appears on the left, press the right button if the target appears on the right). In addition, these discrimination tasks can be presented either with single targets, or with a target and a non-target (hereafter referred to as a distractor) at the opposite location.

Early work comparing detection and discrimination responses showed that inhibition did not occur when a discrimination response was required. Terry et al. (1994, Exp. 1), using a target-target paradigm, asked participants to respond to targets appearing to the left or right of fixation with a simple manual key press (i.e., feature discrimination without localization). They further presented a paradigm in which participants completed a single target localization task or a discrimination task with a distractor at the location opposite of the target (Exp. 2). In both the detection task and the localization task, there was a slowed response to repeated targets but facilitation occurred in the discrimination task. However, although Terry et al. (1994) found no inhibition with their discrimination task, it was later discovered that inhibition can indeed be elicited in discrimination tasks despite the presence of distractors along with target stimuli given a long enough CTOA (Lupiáñez, Milliken, Solano, Weaver, & Tipper, 2001; Pratt, 1995; Pratt & Abrams, 1999; Pratt, Kingstone, & Khoe, 1997).

Using saccadic instead of manual responses, Pratt (1995) observed behavioral inhibition when participants made an eye movement localization response to the target upon simultaneous presentation of both a target and a distractor. With a CTOA of 960 ms following the onset of a non-informative peripheral cue, Pratt (1995) presented either a single target (detection) or a target and a distractor (discrimination) on either side of the central fixation – the target and distractor being a diamond and a square which were counterbalanced across participants. Results showed that both conditions elicited equivalent amounts of inhibition upon localization of the target with saccades. When fixation was maintained during target onset with the presence of a distractor, however, inhibition persisted but was reduced (Kingstone & Pratt, 1999). Pratt and Abrams (1999) later replicated their experiments with manual responses, finding similar evidence for an ICE that is, however, inconsistent with the output form of IOR.

Using peripheral cues followed by peripheral targets (“X”s and “O”s) at CTOAs ranging from 100 to 1000 ms, Lupiáñez et al. (2001, Exp. 2) introduced a distractor at the location directly opposite to the target, which led to an ICE emerging at an earlier CTOA (400 ms) compared to when there were no distractors present. However, increasing task difficulty by requiring participants to discriminate between “M” and “N” rather than “X” and “O” (Lupiáñez et al., 2001, Exp. 3) revealed no ICE when distractors were absent. Inhibition appeared only with the presence of distractors at later CTOAs of 700 ms and 1000 ms. Taken together, Lupiáñez et al. (2001) made the distinction between target discrimination and target selection (with the presence of a distractor), concluding that the former delays while the latter hastens the emergence of behavioral inhibition.

1.3. Visual search

It is important to further investigate IOR in a cue-target paradigm involving distractors, because allocating attention while conducting a visual search rarely ever involves only simple detection-like tasks. That is, humans are unlikely to be looking and searching for a target stimulus that is at the same time devoid of distractors. A much more common task in the real world would be akin to finding an eraser in a pencil box where one would need to discriminate between a target (e.g., an eraser) and distractor stimuli (e.g., pencils). Although a spatially non-predictive cue-target paradigm (Posner, 1980) is simpler than that of visual search in which one performs a succession of saccades in a more complex visual array in search of a target, the mechanisms underlying such processes are thought to be similar (Klein, 1988) when eye movements are allowed.

Outside of experiments using Posner's (1980) spatial cueing paradigm, distractors and IOR have been more commonly explored in studies of visual search. For example, Klein (1988) used a serial search task to induce the inhibitory tagging mechanism, as well as a parallel search task as a baseline to account for potential non-IOR explanations. A probe was placed at a location where an item was previously displayed (referred to as an on-probe, much like a cued target in Posnerian paradigms), which was detected more slowly than off-probes. This observation of reduced RTs to on-probes, only apparent in the serial but not parallel search paradigm, is reminiscent of IOR where RTs to cued trials are slower compared to uncued trials. It thus follows that IOR has been observed when distractors were present in visual search paradigms when observers executed saccades to targets that were either presented alone or along with a distractor (e.g., Müller & Von Mühlenen, 2000; Theeuwes & Godijn, 2004).

Müller and Von Mühlenen (2000) extended upon Klein's (1988) serial search task in search of IOR by performing a series of experiments requiring saccades during serial visual search prior to presenting probes at either potentially inhibited search distractor locations or at previously empty location (again, akin to cued and uncued trials). They reported evidence of object-based IOR as long as the search array remained on screen, which further supports the idea that IOR operates on recently attended locations to increase efficiency in conducting a visual search.

Evidence of IOR with distractors is further supported by electrophysiological studies of visual search (Eimer, 1996; Hickey, Di Lollo, & McDonald, 2008) but rarely examined together, because traditional IOR paradigms do not include distractors whilst traditional visual search paradigms always include distractors. This gap in the literature occurs in spite of IOR having been found in visual search paradigms (Müller & Von Mühlenen, 2000; Takeda & Yagi, 2000) as well as its role in facilitating visual search (Danziger, Kingstone, & Snyder, 1998; Klein, 1988; Klein & MacInnes, 1999; Wang & Klein, 2010).

2. Study 1

The main goal of the first study was to establish how IOR and input-based ICEs are affected over time by the interference from distractors, with or without oculomotor activation and with endogenous (central) or exogenous (peripheral) cues. We therefore examined behavioral inhibition in four experiments where the target was always accompanied by a distractor. To dissociate oculomotor IOR from other ICEs, we required participants to either remain fixated at a central point throughout the entire trial (Exps. 1 & 2) or to engage the oculomotor system and make eye movements in response to the cues (Exps. 3 & 4). We also manipulated the cue type (peripheral vs. central cues) to separate shifting of attention that is exogenous in nature (Exps. 1 & 3) to attention that is endogenous in nature (Exps. 2 & 4).