



Motor inhibition of return can affect prepared reaching movements

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HIGHLIGHTS

- ▶ Previous work suggests IOR results from sensory/attentional or motor programming processes.
- ▶ We show that motor IOR affecting *reaching* can arise from response *execution* processes.
- ▶ Our result confirms that motor IOR can be observed outside of the oculomotor system.

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ABSTRACT

Inhibition of return (IOR) is a widely studied phenomenon that is thought to affect attention, eye movements, or reaching movements, in order to promote orienting responses toward novel stimuli. Previous research in our laboratory demonstrated that the motor form of *saccadic* IOR can arise from late-stage response execution processes. In the present study, we were interested in whether the same is true of *reaching* responses. If IOR can emerge from processes operating at or around the time of response execution, then IOR should be observed even when participants have fully prepared their responses in advance of the movement initiation signal. Similar to the saccadic system, our results reveal that IOR can be implemented as a late-stage execution bias in the reaching control system.

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1. Introduction

Inhibition of return (IOR) refers to a delay in responding to visual targets appearing in a location previously occupied by a cue or another target, and is typically observed when the time between the onset of the two stimulus events is greater than approximately 300 ms. Early accounts of the phenomenon ascribed IOR to the presence of an inhibitory mechanism that discourages the return of eye movements, spatial attention, or both to recently attended locations, perhaps to increase the efficiency of visual search behavior [8,10,21].

Further research indicated that a motor form of IOR can be observed [4,7,14,19,21], for example, when consecutive responses are signaled by central stimuli, an observation that cannot easily be explained by sensory or attentional mechanisms [6,18,19,21]. Using central stimuli, the motor form of IOR has been reported for saccadic eye movements and more recently, reaching movements [e.g., 3, 14, 19, 20]. While evidence for IOR is usually based on

reaction time (RT), this measure alone cannot reveal the stage at which IOR arises in the stimulus-response sequence.

In a recent experiment with saccadic eye movements [4], we demonstrated that the motor form of IOR can arise from processes operating at or around the time of response execution; even when participants could prepare a saccadic movement in advance, the execution of that response was delayed when it was preceded by a saccade in the same direction compared to a saccade in the opposite direction. Although the motor form of IOR can arise from late-stage execution processes within the saccadic control system, it remains unclear whether IOR can be similarly implemented at this late stage within the reaching control system. This question is important for gaining a clearer understanding of the mechanism(s) underlying IOR. For example, if IOR operates as a late-stage execution bias only within the oculomotor system, it would suggest the presence of a relatively specialized or unique mechanism designed to influence eye movements; alternatively, if IOR can operate as a late-stage execution bias in multiple effector systems, it would suggest the presence of a more generalized mechanism. In the present investigation, we therefore examined whether motor IOR can be observed in late-stage response execution processes when reaching, rather than saccadic responses are required. If IOR was present, we expected to observe the defining pattern of IOR, where

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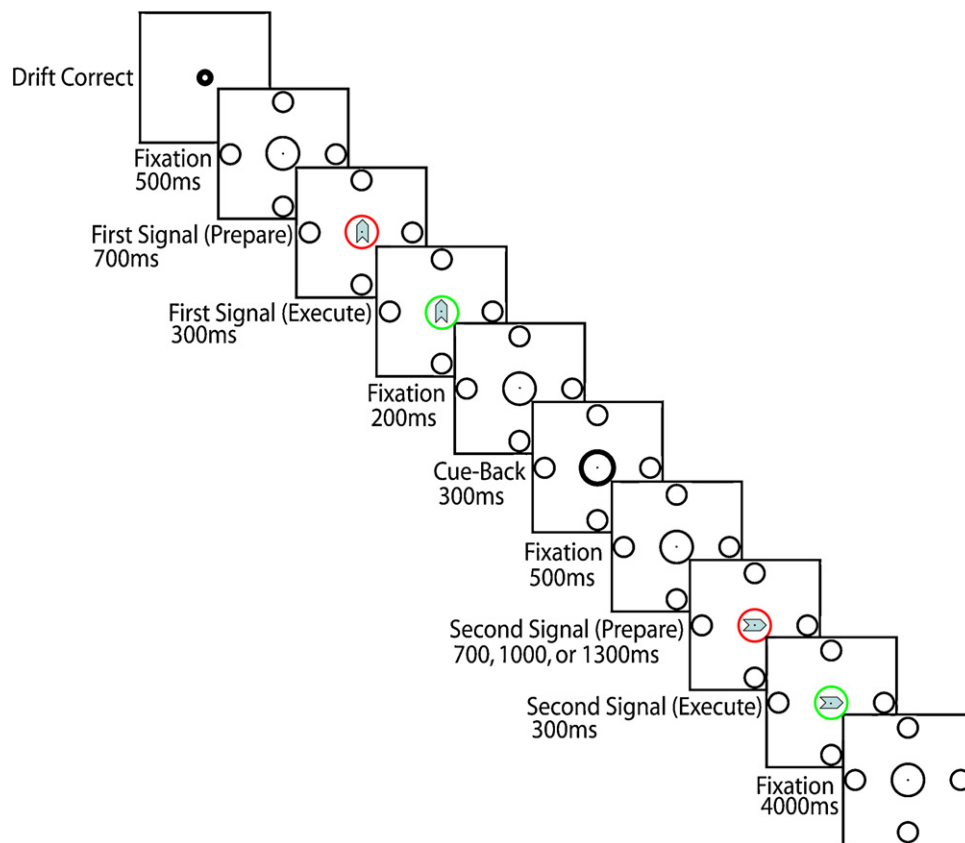


Fig. 1. Example stimuli and sequence timing from a single trial. Each trial began with an EyeLink drift correction procedure that required the participant to press the space bar with their left hand while maintaining fixation within the fixation circle that was always present throughout the trial. After completing the drift correction, participants were instructed to place the index finger of their right hand within the central fixation circle. After 500 ms, S1 (an arrow pointing at one of the four peripheral placeholders) was presented while the fixation circle was red (preparation signal) for 700 ms, then green (execution signal) for 300 ms. Following the offset of S1, the fixation circle turned black (for 200 ms), and a cue-back stimulus (change of the fixation circle outline from 4px to 8px weight), reminding participants to return their finger to center, was then displayed for 300 ms. After another 500 ms (during which fixation was displayed in black at 4px weight), S2 was presented (i.e., another arrow was displayed, pointing at one of the four peripheral placeholders) within the fixation circle that was first red (preparation signal) for 700–1300 ms (depending on the stimulus onset asynchrony [SOA]), then green (execution signal) for 300 ms, followed by S2 disappearance. As a consequence of the variable presentation time of the red S2 signal (700, 1000, or 1300 ms), three different SOA times were possible: 2000, 2300, or 2600 ms. The inter-trial interval was 4 s. For both S1 and S2, participants were instructed to prepare their reaching movement while the fixation circle was red, and to execute the corresponding reaching response when the fixation circle turned green. Between trials, participants were instructed to rest their right arm on the desk. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

responses are slowest in a previously signaled location (0° offset), but relatively faster when offset by 90° or 180° [2]. Such an observation would show, for the first time, that motor IOR can arise at or during late-stage execution processes within the reaching control system. Our experimental paradigm replicated that of Cowper-Smith et al. [4], with the only exception that reaching rather than saccadic responses were required.

2. Material and method

Seventeen undergraduate students (13 female, 4 male) were recruited at Dalhousie University. Participants were right handed, had normal vision and reported no history of visual, motor, or neurological abnormalities.

The methods for the experimental paradigm were presented by Cowper-Smith et al. [4]. The present study replicated these methods exactly, except that consecutive reaching responses, rather than saccadic responses, were required. The sequence of stimuli and task are presented in Fig. 1.

With the exception of 44 catch trials, two central arrowhead signals (S1 and S2) were presented on each trial that pointed toward one of the four possible target locations with equal probability (0.25). These pairings signaled consecutive reaching responses offset from each other by 0° , 90° , or 180° . Each S1/S2 pairing was

presented 12 times and all pairings were randomized on a trial-by-trial basis. For both S1 and S2, participants were instructed to prepare their reaching movement while the fixation circle was red, and to execute the corresponding reaching response when the fixation circle turned green. At response execution, participants were instructed to reach and touch the signaled targets as quickly and accurately as possible, and to return their finger to center upon display of the cue-back as well as after completing their S2 response. Participants were informed that the preparation signal (i.e., when fixation was red) was 100% informative. On catch trials, the S1 signal was displayed within a red fixation circle for 1300 ms that did not change to green; after 1300 ms, the inter-trial interval commenced. Stimuli were presented, and reaching responses were recorded using a 30-inch ELO touch screen LCD monitor (Elo TouchSystems, Menlo Park, California, USA). Reaction times were defined by the moment participants lifted their finger off the screen relative to the onset of the execution signal, and the accuracy of reaching movement endpoints was monitored to ensure participants responses landed (i.e., touched) within the boundary of the indicated target location.

An error message was displayed, the trial was aborted and was randomly inserted (recycled) later in the experiment if participants: (1) moved their eyes outside of central fixation; (2) did not respond within 1.5 s to the green execution signal (with a

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