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Review

No single electrophysiological marker for facilitation and inhibition of return: A review

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HIGHLIGHTS

- Different electrophysiological components have been related to facilitation and inhibition of return.
- We suggest that there is no single neural marker for facilitation and inhibition of return.
- Many variables (task set, cue-target interval, etc.) determine the electrophysiological modulation of cueing effects.

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ABSTRACT

Different electrophysiological components have been associated with behavioural facilitation and inhibition of return (IOR), although there is no consensus about which of these components are essential to the mechanism/s underlying the cueing effects. Different spatial attention hypotheses propound different roles for these components. In this review, we try and describe these inconsistencies by first presenting the electrophysiological component modulations of exogenous spatial attention as predicted by different attentional hypotheses. We then review and quantitatively analyze data from the existing electrophysiological studies trying to accommodate their findings. Variables such as the task at hand, the temporal properties and interactions between cues and targets, the presence/absence of intervening events, or stimuli arrangement in the visual field, might critically explain the discrepancies between the theoretical predictions and the electrophysiological modulations that both facilitation and IOR produce. We conclude that there is no single neural marker for facilitation and IOR because the behavioural effect that is observed depends on the contribution of several components: perceptual (P1), late-perceptual (N1, Nd), spatial selection (N2pc), and decision processes (P3). Many variables determine the electrophysiological modulations of different attentional orienting mechanisms, which jointly define the observed spatial cueing effects.

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1. Introduction

Exogenous attentional mechanisms bias information processing in the brain, leading to a bottom-up selective response to salient or potentially relevant stimuli (see e.g., [28,31]). In the Posnerian cueing paradigm ([52]; see Ref. [8], for a review), spatially non-predictive peripheral cues, which trigger exogenous attentional capture [59], produce two distinct effects on target processing: (1) At short cue-target onset asynchronies (CTOAs; ~50–300 ms), reaction times (RTs) are usually faster for targets appearing at the same location as the peripheral cue (i.e., cued locations) than for targets presented at the opposite location (i.e., uncued locations), leading to a *facilitatory* effect. (2) At longer CTOAs (after ~300 ms), the opposite pattern of results emerges, with slower RTs for targets appearing at the cued location as compared to the uncued location. This latter effect, initially described by Posner and Cohen [53], is known as *Inhibition of Return* (IOR; [54]). Giving such an evocative name to the IOR effect has greatly contributed to the confusion between the *behavioural effect* that is measured (i.e., slower responses to targets appearing at cued locations as compared to uncued locations) and the *mechanism/s* underlying the effect (see Ref. [15]; for a review). Thus, the IOR terminology clearly reflects the theory initially proposed to explain the effect: IOR was theorized to be the consequence of an impaired ability to return attention to a previously attended location (see Ref. [34]; for a review). Although other explanations for the IOR effect have been currently considered, such as a *detection cost* [39] or *habituation* [14] of attentional capture to targets presented at a previously cued location (see also Refs. [2,21,41]), the mechanism/s underlying cueing effects still remains highly debated (see e.g. [40], for a review).

Several researchers have proposed that cueing effects reflect the modulation of multiples stages of processing (e.g. [2,29,32,39,64]), although no agreement has been reached about which of these stages of processing (and their associated electrophysiological components) is/are essential to the mechanism/s underlying both facilitation and IOR.

2. Electrophysiological component modulations predicted by different hypotheses

Many researchers have concentrated their efforts on finding the electrophysiological markers of facilitation and IOR, although results have been contradictory and no single electrophysiological marker can be unequivocally associated with behavioral facilitation or IOR. Table 1 presents the electrophysiological modulations hypothesized by the traditionally attentional reorienting hypothesis and two recent attentional–perceptual alternative hypotheses about facilitation and IOR. Note that according to Taylor and Klein [64], IOR can generate two mutually exclusive effects: (1) an attentional/perceptual effect, which occurs when saccadic eye movements are not permitted and the oculomotor system is suppressed; and (2) a motor effect, which occurs when saccadic responses are required and the oculomotor system is active (see also Refs. [25,35]; for reviews). Given that eye movements were strictly forbidden in most of the previous electrophysiological studies (although see Refs. [61–63]), we decided to focus this review on findings related to the attentional/perceptual effect, wherein the oculomotor system is actively suppressed. The interested reader is referred to Refs. [2,14,15,34,39,40], for different theoretical interpretations of the cueing effects, and to Luck et al. [37], for a review of the electrophysiological components of attention.

The traditional attentional reorienting hypothesis is assumed by most researchers in the field (see e.g. [34,55,57,62,63,65,68]), although not necessary by IOR experts, who greatly differ about their conception of IOR (see Ref. [15]). According to this hypothesis, three main processes occur during attentional orienting: (1) An initial attentional orienting to the cued location (most likely reflected in the P1 and/or N2pc component—posterior contralateral N2); (2) an attentional re-orienting to the fixation point, which occurs at long enough CTOAs (after ~300 ms). This attentional re-orienting might be enhanced or accelerated by the presence of intervening events between the cue and target[1] (see Ref. [44]; for a review of modulations produced by intervening events) and (3) an inhibited attentional orienting if the target is presented at the previously cued location as compared to the uncued location. This initial orienting and inhibited re-orienting to the target (proposed to produce both the facilitation and the IOR effect, respectively) might produce modulations at different stages of processing: perceptual (reflected in the P1 and N1 components), spatial selection (reflected in the N2pc component), and post-perceptual correlates of resource allocation and/or decisional processing (reflected in the Nd-negative difference, and P3 component, respectively; see e.g. [45]; see Section 3 for a discussion of these components).

Contrary to the traditional attentional reorienting hypothesis, the attentional–perceptual hypotheses only postulates two processes underlying the cueing effects (see e.g. [2,14,23,39]): (1) An attentional orienting to the cued location (most likely reflected in the P1 and/or N2pc component); and (2) a *habituated attentional capture* or *detection cost* (depending on the underlying hypothesis; see Table 1) when the target is presented at the cued location as compared to the uncued location (reflected in a reduced amplitude of the P1 and/or N1 component for cued as compared to uncued location trials). Importantly, both attentional–perceptual hypotheses do not consider attentional re-orienting as a necessary condition to observe the IOR effect (see e.g. [2] for a review; see also Refs. [6,14]). For example, Berlucchi [2] suggests an interpretation of the IOR effect in sensory terms, where the visual system response to the target would be reduced by the previous stimulation at the same spatial location, independently of attentional orienting. The *habituation hypothesis* ([14]; see also Ref. [2], for similar assumptions) postulates that the impaired early target perceptual processing (reflected in the P1 modulation) will only be measured when IOR is behaviourally observed (assuming an enhanced perceptual processing when facilitation is observed). Contrary, the *cue-target event integration-segregation hypothesis* ([39] for a review; see also Ref. [41]) postulates that perceptual processing should always be impaired by the very appearance of the cue when a long enough CTOA is used (after ~500 ms; [44]), no matter the behavioural result that is measured (facilitation

[1] The presence of intervening events favour the appearance of the IOR effect in some experimental situations in which no IOR would otherwise be observed (see e.g. [56,55,44,45]).