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Cognition. Author manuscript; available in PMC 2013 January 1.

Published in final edited form as:

Cognition. 2012 January ; 122(1): 96–101. doi:10.1016/j.cognition.2011.08.018.

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Arrow-elicited cueing effects at short intervals: Rapid attentional orienting or cue-target stimulus conflict?

Jessica J. Green[a] and **Marty G. Woldorff**[a]

[a]Center for Cognitive Neuroscience, Duke University, Box 90999, Durham, NC, 27708, USA

Abstract

The observation of cueing effects (faster responses for cued than uncued targets) rapidly following centrally-presented arrows has led to the suggestion that arrows trigger rapid, automatic, shifts of spatial attention. However, these effects have primarily been observed during easy target-detection tasks when both cue and target remain on the screen until the behavioral response. We manipulated stimulus duration and task difficulty in an attention-cueing experiment to explore non-attentional explanations for rapid cueing effects. Contrary to attention-based predictions, short-interval cueing effects were observed only for long-duration cue and target stimuli, occurred even when the cue and target were presented simultaneously, and were driven by slowing of the uncued-target responses, rather than any facilitation for cued targets. We propose that, under these long-duration, short-interval conditions, the processing of the cue and target interact more extensively in the brain, and that when the cue and target convey incongruent spatial information (i.e., on invalidly cued trials) it leads to conflict-related slowing of responses

Keywords

Spatial cueing; Arrow cues; Attention; Automatic orienting; Conflict

Introduction

Focusing attention on a specific location in space can improve processing of information that occurs there. When a location cue is presented prior to the appearance of a task-relevant target, responses are typically faster and more accurate for target stimuli appearing at cued, relative to uncued, locations (e.g., Posner, 1980, Posner & Cohen, 1984). These response-time (RT) cueing effects can be elicited both by voluntary, goal-driven orienting and by involuntary, automatic orienting, although the time course of the RT effects differs. Voluntary effects elicited by centrally-presented instructional cues, such as arrows, that predict the target's likely location typically take a few hundred milliseconds from cue onset to develop. In contrast, involuntary effects elicited by peripheral cues, such as a sudden, task-irrelevant flash of light that automatically captures attention to its location, appear to develop rapidly but are often short-lived, lasting only a few hundred milliseconds after the cue (Egeth & Yantis, 1997; Müller & Rabbitt, 1989; Wright & Ward, 2008).

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Corresponding Author: Jessica Green, Center for Cognitive Neuroscience, Duke University, Box 90999, Durham, NC 27708, Phone: 1.919.668.1334, Fax: 1.919.681.0815, jessica.j.green@duke.edu.

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Reported enhancements of target detection performance at very short intervals following an arrow cue have led to the suggestion that arrows, being highly overlearned stimuli, can trigger rapid automatic shifts of spatial attention (within 100 ms) similar to peripheral cues (e.g., Ristic, Wright, & Kingstone, 2007; Tipples, 2002). In addition, Ristic and Kingstone (2006) reported that cueing effects were substantially larger for predictive arrows than for non-predictive arrows, even at cue-target intervals too short to show voluntary cueing effects. They concluded that predictive arrow cues induce an interaction between voluntary and automatic attention mechanisms and cannot be used to investigate purely voluntary attention. According to their interpretation, previous studies that used arrows to investigate the behavioural or neural correlates of voluntary orienting were inadvertently examining a combination of rapid involuntary (i.e., automatic) processes and slower voluntary ones.

Studies that report rapid effects in response to arrows, however, generally share two key paradigm characteristics that differ from typical voluntary orienting paradigms. First, both the 4 cue and target stimuli are of a long duration, often remaining on the screen until the participant responds to the target. Second, very easy detection tasks are used, which do not necessarily require a shift of attention to perform (Schneider & Shiffrin, 1977). In contrast, studies of voluntary orienting typically present both cue and target stimuli for short durations (~100 ms) and employ more difficult target detection or discrimination tasks likely to require a shift of attention to the cued location to successfully perform (e.g., Smith & Ratcliff, 2009).

We hypothesized that the automatic cueing effects purported to develop rapidly in response to arrow cues may actually reflect non-attentional processes, as it seems unlikely for long-duration stimuli and easy detection tasks to evoke stronger or more rapid attentional orienting than would short-duration stimuli and difficult detection tasks. Here, we investigated the influence of stimulus duration and task difficulty on cueing effects to directly address this possibility. Importantly, we also included a control condition wherein the cue and target were presented simultaneously, making it impossible for attention to be oriented, even automatically, prior to the target's appearance. Any RT effects in this condition would strongly support non-attentional explanations.

2. Experiment 1

2.1. Method

2.1.1. Participants—Fourteen volunteers (11 female; age: M=23.5 years, SD=5.54 years; all right-handed) participated after providing informed written consent. All procedures were approved by the Duke University Institutional Review Board.

2.1.2. Stimuli and procedure—Throughout each experimental block a grey fixation dot appeared in the center of the screen, along with two landmark square outlines (each 2.3° wide, located 3.45° below and 3.45° lateral to fixation). Each trial began with the presentation of an arrow cue (1.2° in length; 5 arrowhead: .53° tall × .3° long) that pointed toward one of the boxes and was 80% predictive of the target location (see Figure 1). The target (a small dot) followed at a stimulus-onset asynchrony (SOA) of 100, 200, 300, 400, or 600 ms, or at a 0-ms SOA (i.e., simultaneous cue and target). Participants were instructed to press a button (right index finger) as quickly as possible when they detected the target dot. On ~9% of trials no target was presented to ensure that participants were only responding when they actually detected the target stimulus. The fixation, landmark boxes, and cue stimuli were all medium grey in color (RGB=100,100,100).

Each participant took part in three task conditions: short-duration/easy-detection, short-duration/difficult-detection, and long-duration/easy-detection, in counterbalanced order

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within a single session. In the long-duration condition the cue and target remained on the screen until the participant responded or the trial ended (1500 ms after cue onset), whichever came first. In the short-duration conditions the cue and target were 50 ms and 100 ms in duration, respectively. In the easy-detection conditions the target dot was an easily visible light-grey (RGB=150,150,150). In the difficult-detection condition the target was initially dark grey (RGB=50,50,50) then adaptively varied across trials to maintain overall accuracy at 90%. Each participant performed a total of 1188 trials (396 in each task condition, including 288 valid, 72 invalid, and 36 catch trials).

2.1.3. Analysis—Cueing effects were assessed by comparing responses to targets preceded by a valid cue (pointing toward the target location) versus an invalid cue (i.e., pointing to the opposite location of the target). Median response times were entered into a repeated-measures analysis of variance (ANOVA) with factors for task condition (3 levels: long/easy, short/easy, and short/difficult), target location (2 levels: left and right), SOA (6 levels: 0, 100, 200, 300, 400, and 600 ms), and validity (2 levels: valid and invalid). Greenhouse-Geisser-adjusted p-values are reported where appropriate.

2.2. Results

Mean RTs and cueing effects are plotted in Figure 2a. We observed significant main effects of task condition [F(2,26)=3.31, p=.05, $\eta_p^2=.202$], target location [F(1,13)=5.40, p=.04, $\eta_p^2=.294$], validity [F(1,13)=68.37, p<.001, $\eta_p^2=.713$], and SOA [F(5,65)=20.97, p<.001, $\eta_p^2=.608$]. Although responses were ~6ms slower for left-sided than for the right-sided targets, the target location did not interact with any of the other factors (all p's > .18) indicating that the pattern of RTs across SOAs was not influenced by whether the location target was on the left or the right. Thus, for all plots and post-hoc t-tests the data were collapsed across left and right targets. The interactions between task condition and SOA [F(10,130)=4.94, p=.002, $\eta_p^2=.275$] and validity and SOA [F(5,65)=3.92, p=.012, $\eta_p^2=.232$] were also significant

Post-hoc t-tests were performed comparing RTs for validly and invalidly cued targets, separately for each SOA in each task condition. For short-duration stimuli, no cueing effect was observed for either the 0 or 100 ms SOA (all p's>.33) but was present for SOAs equal to or longer than 300 ms in both the short and long duration conditions (all t's>3.75, p's<.002). This pattern – i.e., cueing effects only at longer SOAs – is typical of voluntary deployments of attention. Cueing effects were observed at somewhat shorter SOAs in the short/difficult condition (at 200 ms, t=4.8, p=.001), although the effect neared significance in the short/easy condition as well (t=1.98, p=.07). Presumably, the increased difficulty of the task motivated faster and stronger shifts of attention to the cued location. Despite the rapid deployment of attention under these conditions, cueing effects were not observed until 200–300 ms following the cue, likely as a result of effortful, time-consuming voluntary orienting to the cued location.

In sharp contrast, in the long-duration/easy condition, cueing effects were observed not only at longer SOAs (≥300 ms, all t's>4.24, all p's<.001) but also at very short SOAs (0 and 100 ms, both t's>4.9. both p's<.001). These effects appeared to be bi-phasic across SOAs, with significant effects at both short and long SOAs but not for the mid-range 200 ms SOA (at 200 ms: t=.17, p=.39). The presence of a cueing effect at very short SOAs, including when the target was presented simultaneously with the cue, coupled with the apparent biphasic nature of the effect, strongly suggests that these rapid cueing effects were not the result of attentional orienting in response to an arrow cue.

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3. Experiment 2

The pattern of results in Experiment 1 suggest that the cueing effects at short and long SOAs reflect two distinct processes, with longer-SOA effects due to actual attentional orienting but those at short SOAs likely due to other, presumably non-attentional, processes. To better characterize these effects we performed a second experiment that included trials with a spatially non-predictive (neutral) cue. This allowed us to separate the overall cueing effect 9 (Invalid-minus-Valid RTs) into costs (Invalid-minus-Neutral RTs), reflecting a relative decrement in processing information at uncued locations, and benefits (Neutral-minus-Valid RTs), reflecting a relative enhancement of processing information at the cued location (Posner, Snyder, & Davidson, 1980). Differential patterns of costs and benefits for the short and long SOAs would provide further evidence that the short-SOA effects represent a distinct, potentially non-attentional, effect on responses.

3.1. Method

3.1.1. Participants—Twelve new volunteers (7 female; age: M=23.25 years, SD=3.91 years; 10 right-handed) participated after providing informed written consent.

3.1.2. Stimuli and procedure—All stimuli and procedures were identical to those used in Experiment 1, with the exception that a neutral cue was presented on 20% of trials. Neutral cues were double-ended arrows the same size and color as the predictive cues but pointing to both the left and right locations. Following neutral cues, targets were equally likely to occur in the left and right landmark boxes. Each participant performed a total of 1404 trials (468 in each task condition, including 288 valid, 72 invalid, 72 neutral, and 36 catch trials).

3.1.3. Analysis—Cueing effects were analyzed in an analogous fashion to Experiment 1, with the exception that the factor for cue validity included a third level for neutrally cued targets. Post-hoc comparisons using paired t-tests were then performed to assess the costs, benefits, and overall cueing effects for each SOA.

3.2. Results

In the overall ANOVA, we observed significant main effects of task condition [F(2,22)=18.75, p<.001, $\eta_p^2=.630$], left-vs.-right target location [F(1,11)=20.16, p=.001, $\eta_p^2=.647$], validity [F(2,22)=33.18, p<.001, $\eta_p^2=.751$], and SOA [F(5,55)=12.31, p<.001, $\eta_p^2=.528$], as well as an interaction between task condition and SOA [F(10,110)=6.95, p<.001, $\eta_p^2=.387$]. As in Exp. 1, for all post-hoc comparisons we collapsed across left and right targets since target location did not interact with any of the other factors (all p's > .16)despite RTs for left targets being ~8ms slower overall. The pattern of valid-versus-invalid cueing effects in the short-duration/easy and short-duration/difficult conditions replicated those in Experiment 1 (Figure 2b), but additionally yielded the cost/benefit profiles. These profiles were as expected, with approximately equal contributions from costs and benefits at longer SOAs. The bi-phasic pattern for the long-duration/easy condition also replicated, with significant effects for the short (0 and 100 ms) and long (>300 ms) SOAs (all t's>3.7, all p's<.004), but not for the intervening 200 ms SOA (t=1.7, p=.11). Moreover, at short SOAs there were only significant costs (t's>4.9, p's<.001), whereas at long SOAs both costs and benefits were significant (all t's>2.4, all p's<.03). These strikingly different cost-benefit profiles thus provide additional evidence that the short-SOA and longer-SOA effects derive from distinct processes.

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Upon closer examination, it appeared that in the long-duration/easy condition of both experiments, the RT-SOA function sharply declined over the first few SOAs and then plateaued, particularly for invalidly cued targets. Coupled with the predominantly cost-driven effect at these same short SOAs, we speculated that these cueing effects may have resulted from an additional process specific to invalidly cued targets. To test this hypothesis, we directly compared RTs in the short-duration/easy and long-duration/easy conditions separately for validly and invalidly cued targets. Data from both experiments were combined to increase power after confirming that they were not significantly different ($p>.2$ for all interactions with experiment as a factor). Post-hoc t-tests for each SOA revealed that for validly cued targets the RTs were very similar across the short- and long-duration conditions (Figure 3a), with only a small difference when the cue and target onset simultaneously ($t=2.3$, $p=.035$). For invalidly cued targets (Figure 3b), however, RTs were dramatically slower in the long-duration/easy condition for both the 0-ms and 100-ms SOAs (both t’s>4.16, both p’s<.001). This pattern thus supports our hypothesis that the short-SOA effects in the long-duration/easy condition were driven primarily by RT slowing on invalid trials. Additionally, for both valid and invalid trials, RTs did not differ between the short- and long-duration conditions at longer SOAs, consistent with the hypothesis that the long-SOA effect is the result of voluntary attention-orienting processes that are not influenced by stimulus duration.

4. Discussion

Several recent studies using short cue-target SOAs have suggested that arrow cues, because they are so well learned, elicit very rapid (within 100 ms) and automatic attentional orienting (e.g., Ristic, Wright, & Kingstone, 2007; Tipples, 2002). The existence of such a rapid, automatized, attentional-orienting mechanism for well-learned cues would have important neuro-cognitive implications. Here, we investigated the role of task difficulty and stimulus duration on arrow-elicited cueing effects to determine whether these short-SOA effects truly reflect rapid attentional orienting. By using a higher-density sampling of cue-target SOAs, along 12 with a neutral cue condition to differentiate between cost- and benefit-based effects, we were able to disentangle the cueing effects that occur at short and long SOAs. Moreover, our inclusion of a simultaneous onset condition (i.e., 0-ms SOA) allowed us to rule out automatic attention orienting as an explanation.

Regardless of stimulus duration or task difficulty, at longer SOAs (i.e., ≥ 300 ms) responses to validly cued targets were faster than responses to invalidly cued targets. This pattern is consistent with voluntary shifts of attention to a cued location, which should take time to develop (Egeth & Yantis, 1997). The observation of short-SOA effects only for long-duration stimuli, however, is not consistent with automatic attention-orienting explanations. If arrow cues induce very rapid, automatic attention shifts, then short-SOA effects should have been observed in all conditions, regardless of the duration of the arrows. In addition, the observation of cueing effects even when the cue and target were presented simultaneously rules out attention-shifting explanations, as even rapid automatic attention shifts are based on the cue information and would require time to emerge after the presentation of the cue.

The current pattern of results suggests that these effects may instead derive from the presence of conflicting stimulus input. More specifically, at short SOAs and long cue and target durations, RTs were particularly slow for invalidly cued targets, and the cost/benefit analyses revealed that the cueing effects were almost exclusively driven by RT costs for invalidly cued targets. Together, these results suggest that responses were slowed down at short SOAs when the cue and target contained conflicting spatial information. Accordingly, a likely explanation is that when the cue and target are presented simultaneously, or nearly

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so, and remain on the screen together, their processing interact more extensively (Funes, Lupianez, & Milliken, 2005). When the cue and target convey incongruent spatial information (i.e., on invalidly cued trials), this conflicting information slows responses to the target, consistent with numerous studies of the processing of conflicting stimulus input (e.g., Diedrichsen, Ivry, Cohen, & Danziger, 2000; Miller, 1991). Although delineating the processing level at which such interference occurs (e.g., at early perceptual stages or at later response-processing stages) will require additional future studies, the present data strongly support the view that these short-SOA cueing effects with long-duration cues and targets are caused by such interference mechanisms. In contrast, when the cue and target are each presented only briefly, their temporal separation enables the processing of them as separate items whose spatial information does not interact, even at short SOAs.

Regardless, the present results provide strong evidence that these short-SOA cueing effects are not the result of very rapid automatic attention shifts toward the cued location. The short-SOA cueing effects were highly dependent on the duration of the stimuli, were largest when the target occurred before a shift of attention could have possibly taken place (i.e., when the cue and target onset simultaneously), and were driven almost completely by slowing for the invalidly cued targets. Our results thus suggest that a fundamental reinterpretation of the RT differences elicited by spatial cueing stimuli such as arrows is needed, one that accounts for the temporal overlap of the cue and target stimuli and the conflicting spatial information that they may contain.

Highlights for “Arrow-elicited cueing effects at short intervals: Rapid attentional orienting or cue-target stimulus conflict?”

- Rapid arrow cueing effects previously attributed to rapid attentional orienting
- We observed rapid effects only for long-duration cue and target stimuli
- Largest effect when target simultaneous with cue, before attention can shift
- Effects reflect slowing for invalidly cued targets, not speeding for valid targets
- Effects attributable to cue-target spatial conflict rather than attention orienting

Acknowledgments

This work was supported by NIH grants R01-NS051048 and R01-MW 60415 to M.G.W.

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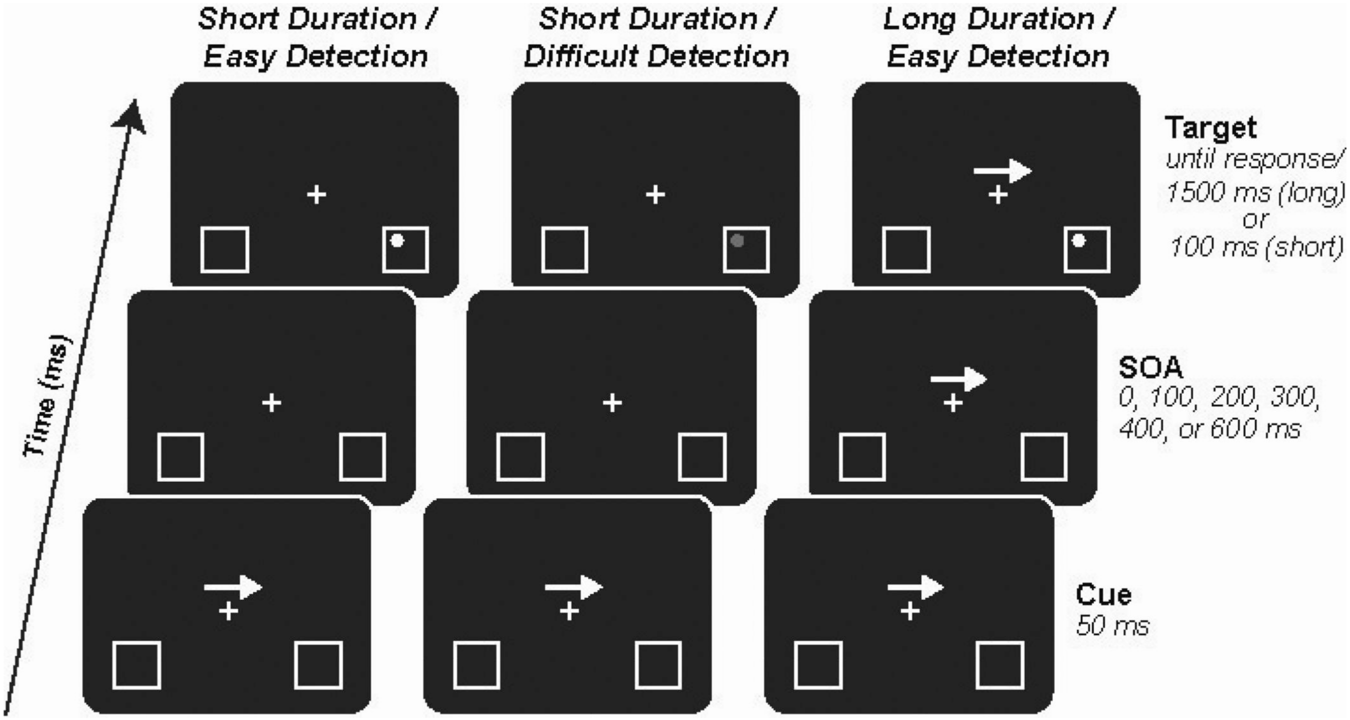

Figure 1.

Sequence of events on a typical trial in each of the task conditions.

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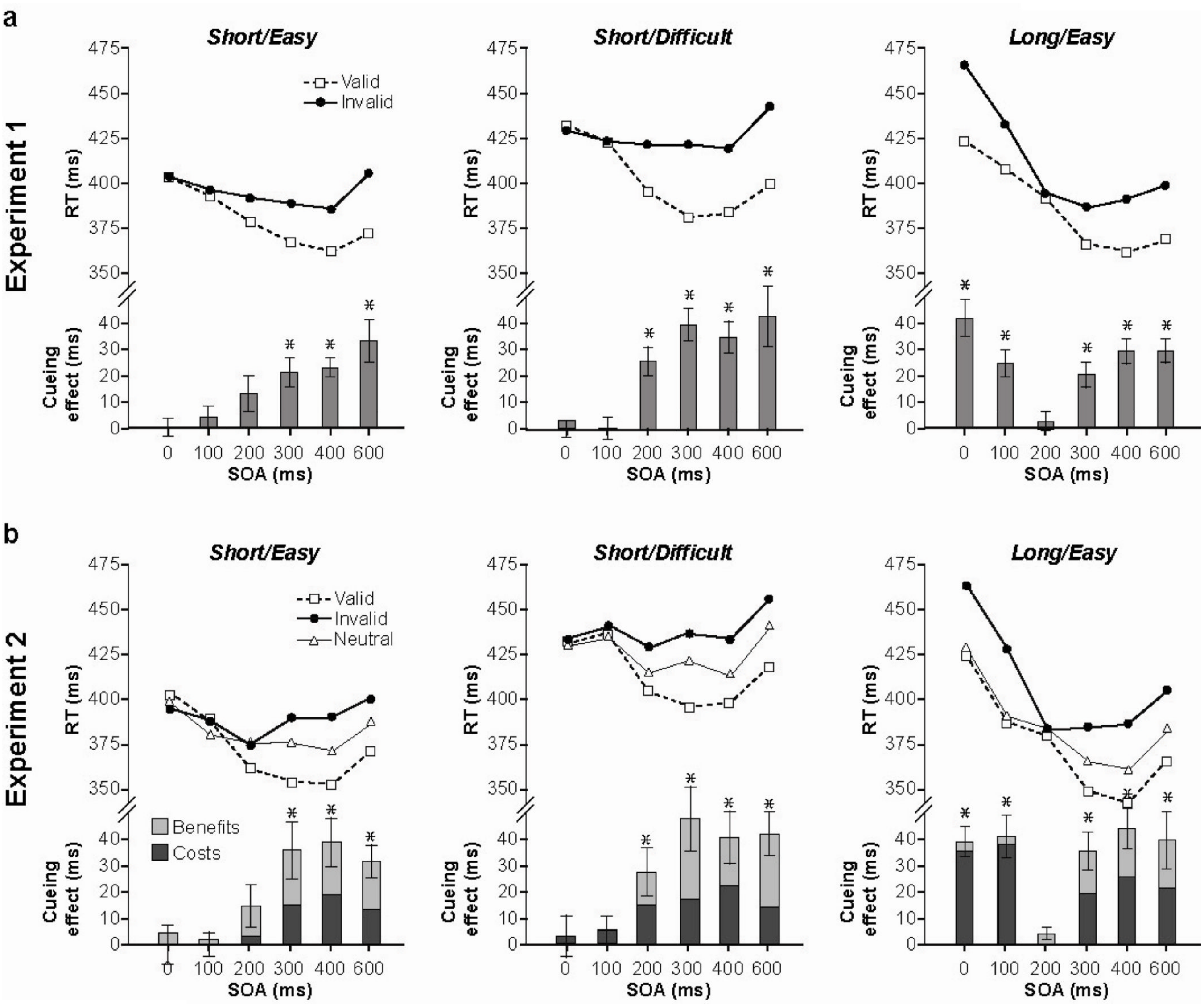

Figure 2.

Mean response times (RTs) and cueing effects plotted as a function of SOA for (a) Experiment 1 and (b) Experiment 2. Line graphs in the top of each panel display mean RTs for validly and invalidly cued targets (and neutrally cued targets in Experiment 2), for the short-duration/easy (left graph), short-duration/difficult (middle graph), and long-duration/easy (right graph) conditions. Bar graphs in the bottom of each panel depict the cueing effect (invalid-minus-valid RTs). For Experiment 2, the overall cueing effect is separated into costs (invalid-minus-neutral RTs; dark shading) and benefits (neutral-minus-valid RTs; light shading).

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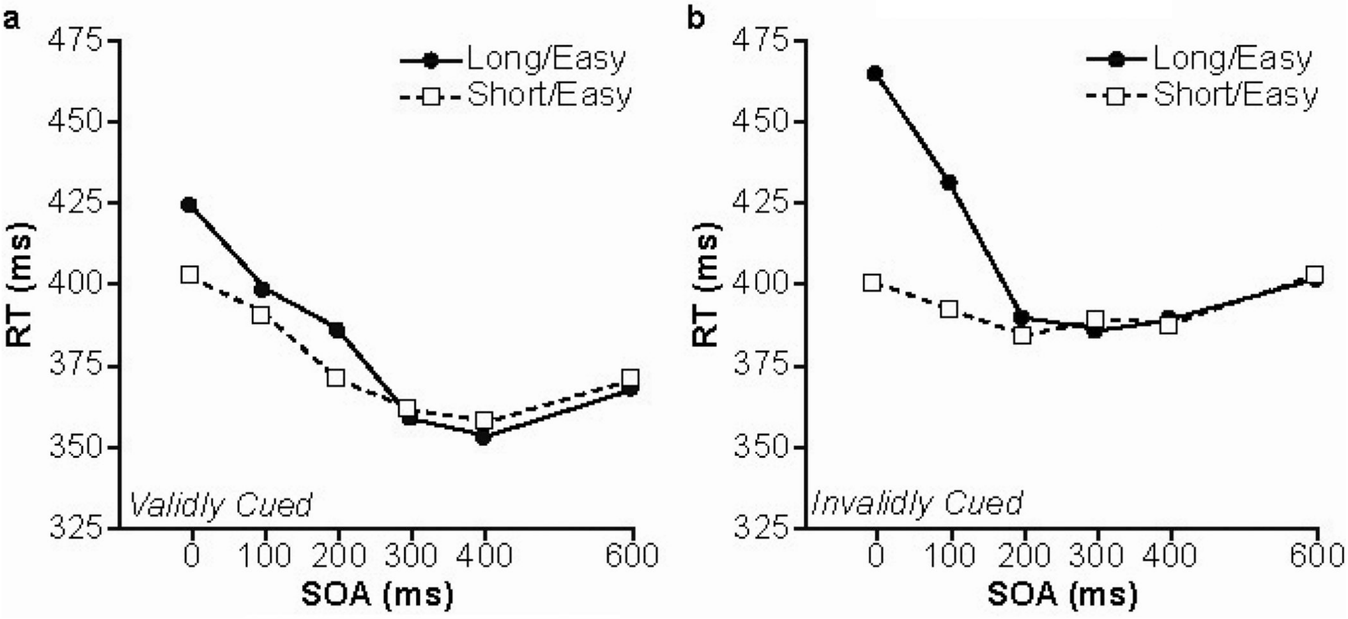

Figure 3.

Comparison of mean RTs for the long-duration/easy and short-duration/easy conditions for validly (a) and invalidly (b) cued targets. Data shown are collapsed across Experiments 1 and 2.