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BRIEF REPORTS

Irrelevant onsets cause inhibition of return regardless of attentional set

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It is disputed whether onsets capture spatial attention either in a purely stimulus-driven fashion or only when they are contingent on one's attentional set. According to the latter assumption, interference from irrelevant onsets may result from nonspatial filtering costs. In the present study, we used inhibition of return (IOR) as a marker for spatial attention. IOR occurs mainly for locations that attention has visited before. Participants searched for a red object among white objects. An attentional set for redness was demonstrated by a spatial validity effect of red cues on response times. However, a stronger validity effect was found for irrelevant white onsets, which slowed responses when the onset contained a distractor, but speeded them when the onset contained a target. Most importantly, this onset benefit for targets turned into a deficit at longer SOAs, indicating IOR. We conclude that onset distractors capture spatial attention regardless of the observer's attentional set.

There is ongoing debate about whether or not abrupt visual onsets automatically capture attention (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wu, 2009; Schreij, Owens, & Theeuwes, 2008; Yantis & Jonides, 1984). In a central study, Folk et al. (1992) provided evidence that capture by abrupt onsets is contingent on the observer's top-down attentional set. In their paradigm, participants responded to a target character appearing in one of four possible boxes positioned at equal distances from fixation. A spatial cue (four small dots surrounding a box) was presented 150 msec before the target display. This cue was uninformative, coinciding with the target location only at chance level. The target could consist of either a single white element (onset type) or a red element among white elements (color type). Despite the cue's irrelevance, Folk et al. (1992) found an effect of the cue, but only when it was of the same type as the target. When participants searched for onset targets, only onset cues drew attention, whereas color cues did not. Vice versa, when participants searched for color targets, color cues captured attention whereas onsets did not. Folk et al. (1992) concluded that in order for an object to capture attention, it must possess a feature that participants actively look for. In other words, attentional capture is under top-down control.

However, in an adaptation of the classic Folk et al. (1992) paradigm, Schreij et al. (2008) recently found evidence consistent with automatic, stimulus-driven capture by abrupt onsets. In their version, participants were always instructed to look for a red target, which was always preceded by a red cue. As in Folk et al. (1992), Schreij et al. (2008) found a spatial validity effect of the cue, demonstrating that participants had adopted an attentional set for color. The crucial manipulation was the presence of an abrupt onset distractor simultaneous with the target display. If capture by abrupt onsets depends entirely on the observer's attentional set, then no interference from this distractor should be expected. This turned out not to be the case: The presence of an abrupt onset caused search times to increase, indicating stimulus-driven attentional capture by abrupt onsets. To save the idea that capture by abrupt onsets is under top-down control, Folk et al. (2009) proposed an alternative explanation for Schreij et al.'s (2008) results. The onset-related costs could be due to nonspatial filtering operations (Folk & Remington, 1998; but cf. Schreij, Theeuwes, & Olivers, 2010). Nonspatial filtering is a mechanism that was first described by Kahneman, Treisman, and Burkell (1983), who found that a response to a target was delayed when other objects appeared concurrently with the target, even though the distinction between targets and distractors was clear. They reasoned that these simultaneously appearing distractors compete for attention and need to be filtered out. On this view, these objects do not attract spatial attention themselves (i.e., there is no capture) but nevertheless delay the moment at which attentional focus can be deployed to the target location.

A mechanism that could be used to determine more precisely whether or not irrelevant onsets capture spatial attention is *inhibition of return* (IOR). IOR is operationalized as the slowing of responses to previously attended locations (i.e., more than about 300 msec previously) in comparison with previously unattended locations (Posner & Cohen,

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1984). It is assumed that when attention is drawn to a location in space and is subsequently disengaged from that location, an inhibitory mechanism is implemented, slowing the return of attention (see Klein, 2000, for a review). Thus, an important aspect of IOR is that it is assumed to be spatial in nature (although it has also been shown that IOR can be object based; see Tipper, Weaver, Jerreat, & Burak, 1994). The purpose of the present study was therefore to determine whether the irrelevant onsets used by Schreij et al. (2008) indeed cause IOR while at the same time participants have an attentional set for the color red. If so, this would provide strong evidence that onsets capture attention in a spatially specific manner, despite an attentional set for a different property. On the other hand, if any of the previously found onset-related costs are due to nonspatial filtering, then no IOR would be expected. For this purpose, the colored search target could occasionally (at less than chance level) appear inside the irrelevant abrupt onset, after either a short or a long SOA. On the basis of the previous IOR literature (Posner & Cohen, 1984), we predicted that the abrupt onset would cause facilitation of target identification at the short SOA, relative to a no-onset condition, whereas at the long SOA it would cause inhibition. No such IOR is expected under a filtering account, since it assumes that attention has never visited the onset location in the first place.

METHOD

Participants

Twenty students 18 to 27 years of age (average, 20.3) participated. None reported color blindness or any other visual deficit.

Apparatus

The experiment was run on a PC with a 19-in., 120-Hz CRT at 1,024 × 768 pixel resolution, viewed from approximately 75 cm in a dimly lit, soundproof room. Stimulus presentation and response recording were done in E-Prime 1.2 (Psychology Software Tools, Sharpsburg, PA).

Stimuli

All backgrounds were black. First a bright white (CIE 0.286, 0.311; 59.50 cd/m^2) fixation cross at the center of the screen was surrounded by four light gray placeholder boxes (CIE 0.285, 0.306; luminance, 28.28 cd/m^2; dimensions, 3.4º of visual angle). These were positioned above, below, to the left, and to the right of the fixation cross, at a distance of 6.6º of visual angle. In the cue display, four sets of four dots (0.5º of visual angle) surrounded the boxes. Most sets were bright white (CIE 0.286, 0.311; 59.50 cd/m^2), except for the cued location, which was indicated by a red set (CIE 0.621, 0.345; 10.43 cd/m^2). Each box contained a bright white masking figure consisting of overlapping "X," "|," and "=" symbols (Myriad Roman). In the target display, the irrelevant line segments were removed, revealing an "X" or an "=." Simultaneously, the color of the target character turned from white to red. There were always two "X"s and two "="s present. In the onset condition, an extra light gray box was added to the display, containing a placeholder, distractor, or target character, depending on the trial condition.

Design and Procedure

Figure 1 shows the experimental procedure. The experiment took around 45 min. Oral instructions were given to familiarize participants with the task. Participants were instructed to look for a red "X" or "=" inside one of the placeholders and press "X" or "M" correspondingly. They were told to keep an index finger on each response button and to not move their eyes from fixation during a trial. Initially, the fixation display was presented for 500 msec, after which the fixation cross blinked for 100 msec to indicate the start

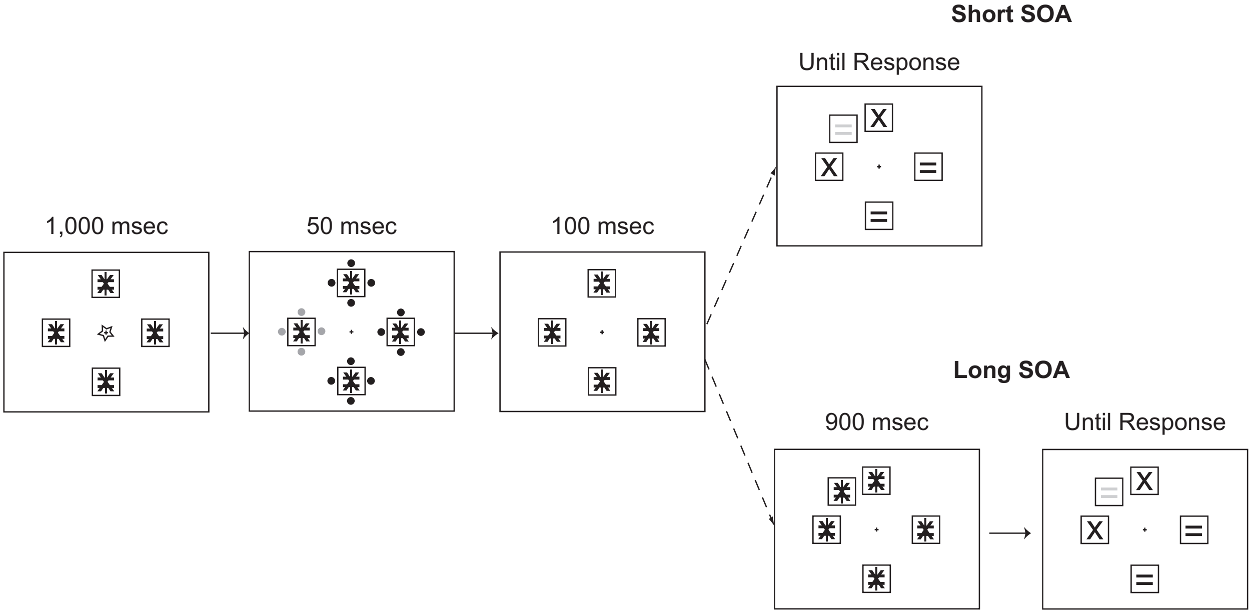

Figure 1. An illustration of a trial where the target appeared inside the onset. Note that this occurred at less than chance level, and the target appeared inside one of the four already present boxes in the majority of cases. First a fixation display was presented in which the fixation cross was flashed for 50 msec to alert participants about the start of the trial. Then a fixation display was presented again for 1,000 msec, followed by a color cue that was flashed for 50 msec. Then the fixation display was presented again for 100 msec. Depending on the block type, either the target directly appeared inside the onset element, or the onset appeared during the fixation display, after which the target was revealed inside the onset 900 msec later. The black lines in the illustration were in reality white against a black background, and the gray items were red.

of a trial. At 1,000 msec after this event, the red cue appeared for 50 msec. Following a variable stimulus onset asynchrony (SOA), the search display was presented until response (with a maximum of 2,000 msec). When the given response was incorrect, the experiment paused for 5 sec and a corresponding sound was played. The onset, when present, always appeared 150 msec after the cue display, but its contents were revealed only simultaneously with the target and remained masked until that moment. Between blocks, participants had to take a mandatory break of 30 sec.

There were three main factors, varied within subjects: onset type (no onset, onset distractor, onset target), cue validity (valid or invalid), and SOA (short or long). When short, the cue-to-target SOA was 150 msec and the onset-to-target SOA was 0 msec; in the long SOA condition, these were 1,050 msec and 900 msec, respectively (see Figure 1 for the full timeline). The red cue prior to the target was uninformative about the location of the upcoming target. When the cue was *valid*, its location corresponded with the target's (25% of the cases). The onset appeared in only 50% of the trials randomly at one of the four possible locations between two placeholders. In the *onset distractor* condition, the onset contained a distractor character, and in the *onset target* condition, it contained the target. Note that in the onset target condition, the cue could only be invalid, since the empty location in which the onset target appeared could not be cued. Cue validity and onset type were randomly mixed within 8 blocks of 80 trials each, preceded by 2 practice blocks. Only 6 of the 80 trials (7.5%) per block contained an onset target. The onset was a distractor on 34 trials, and there was no onset on the remaining 40 trials. SOA was counterbalanced across participants: Half performed the short SOA condition first and the long SOA in the second half of the experiment; for the other participants, this order was switched.

RESULTS

Incorrect responses (4.7% of the trials), as well as responses with response times (RTs) below and above 2.5 *SD*s from the mean (another 2.5%), were removed from the data set. The means of the remaining RTs and the error percentages are depicted in Figure 2.

First, an ANOVA was performed with SOA (short, long), onset type (no onset, onset distractor), and cue validity (valid, invalid) as factors. Note that the onset target level was omitted in this particular analysis, because it could not be fully crossed with cue validity (onset targets could only be combined with invalid cues; see the Method section). This analysis revealed that onset type interacted with SOA [$F(1,19) = 10.57, p < .05$]. Onset interference was larger in the short SOA than in the long SOA condition. There was also an interaction between cue validity and SOA [$F(1,19) = 20.767, p < .001$], indicating that the effect of the red cue diminished with a longer SOA. There was no three-way interaction of these factors ($p > .2$). A separate ANOVA for each SOA condition with cue validity (valid, invalid) and onset presence (no onset, onset distractor) as factors revealed a significant main effect of cue validity in the short SOA condition [$F(1,19) = 35.44$, $p < .001$]; participants were slower after an invalid cue than after a valid cue. The presence of an onset distrac-

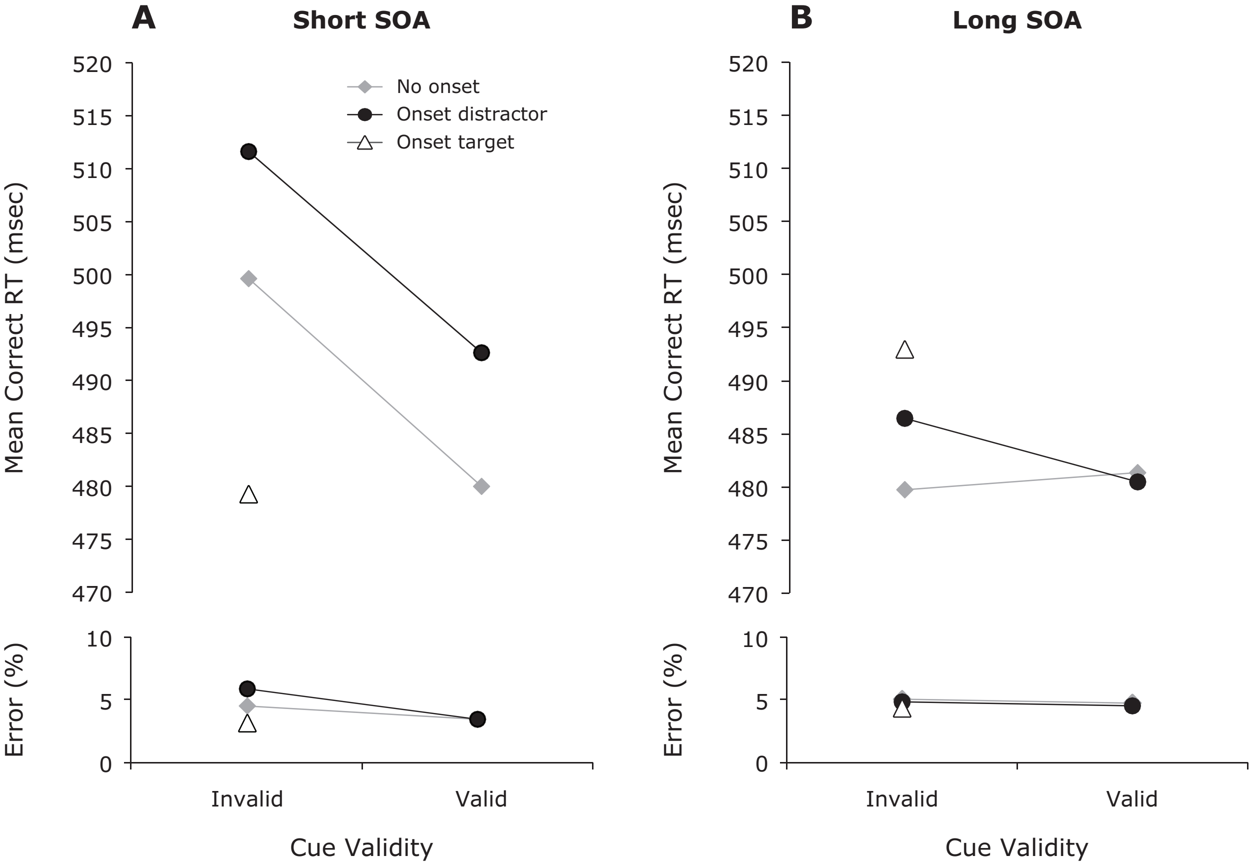

Figure 2. Response times (RTs) and error rates (percentages) for the different onset distractor conditions with an invalidly or validly cued target. (A) Data for the short SOA (150 msec) between cue and target onset. (B) Data for the long SOA (1,050 msec).

tor slowed responses too [onset type: $F(1,19) = 29.65$, $p < .001$]. There was no interaction between onset type and cue validity [$F(1,19) < 1.0$, $p > .5$], suggesting additive effects. In the long SOA condition, the validity effect of the cue disappeared completely [$F(1,19) = 0.62$, $p = .44$]. The cost associated with the onset distractor was also reduced, to the extent that it was no longer significant [$F(1,19) = 2.635$, $p = .146$]. There was no interaction between these factors, either [$F(1,19) = 2.293$, $p = .17$]. An analysis on the error rates revealed no significant effects.

Second, we assessed the effects of onset targets for invalidly cued trials. An ANOVA with onset type (no onset, onset distractor, onset target) and SOA (short, long) as factors revealed a significant interaction [$F(2,38) = 25.40$, $p < .001$], reflecting the fact that, in comparison with the no-onset condition, onset targets led to *faster* responses at the short SOA, but to *slower* responses at the long SOA. This was confirmed by separate analyses. At the short SOA, there was a significant benefit for onset target trials relative to no-onset trials and onset distractor trials [$t(19) = 4.75$, $p < .001$, and $t(19) = 5.69$, $p < .001$, respectively]. RTs were significantly slower on onset distractor trials than on no-onset trials [$t(19) = 4.55$, $p < .001$]. In the long SOA condition, RTs were significantly slower for onset targets than for no-onset trials [$t(19) = -2.61$, $p < .05$]. There was no significant difference between RTs in onset target and distractor conditions [$t(19) = 1.339$, $p = .20$]. There was a significant difference between the onset distractor and no-onset conditions [$t(19) = -1.34$, $p < .05$]. Analyses on the error pattern revealed no significant effects or speed/accuracy trade-offs.

DISCUSSION

The results of this experiment replicate Schreij et al. (2008) in that onset distractors presented together with color targets led to interference, even though participants were looking for color. The experiment also showed that when the onset happens to coincide with the target location, detection is speeded. This in itself suggests that an abrupt onset is preferentially processed, rather than filtered out. The filtering operation's main goal is to prevent an irrelevant onset from acquiring attention, and therefore one would not expect an irrelevant onset to receive priority in processing (see also Schreij et al., 2010). More importantly, this RT benefit turns into a cost when the interval between the onset and the target at the same location is prolonged, thus revealing the typical characteristics of IOR. Our data also show that the color cue loses its capacity to drive attention with a long SOA. This was to be expected, because participants had ample time in this condition to disengage their attention from the cue, which is known to be uninformative. In addition, all responses in the long SOA condition were as fast as for a validly cued target in the short SOA condition. This pattern of overall decreasing RTs with increasing SOA has been found in most IOR studies (Klein, 2000).

Finding IOR at the onset location is important for two reasons. First, the occurrence of IOR is a strong indicator that spatial attention was directed to the onset location—something that cannot be explained by a mere filtering operation. Second, IOR is thought to mainly follow reflexive shifts of attention (Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989), and thus the present results support the idea that onsets drive attention automatically, in a stimulus-driven fashion. Even though it is generally assumed that IOR occurs only when attention is captured reflexively (for an overview, see Klein, 2000), recently a few exceptions have been reported. For example, Weger, Abrams, Law, and Pratt (2008), as well as Berlucchi, Chelazzi, and Tassinari (2000), have shown that it is possible to obtain IOR-like effects under certain conditions of endogenous orienting (see also Berlucchi, 2006).

Note that at the long SOA, the onset distractor still inflicted RT costs when the cue was invalid. Thus, although we found evidence for onset targets to be inhibited, the onset distractor still caused an RT cost. One might explain these remaining costs as the result of a filtering operation still working at the long SOA. However, in their original conception of filtering, Kahneman et al. (1983) argued that filtering costs are tied to perceptual events such as the sudden appearance of an object, rather than to the mere presence of an object. They showed that filtering costs disappeared when objects had been present for while, as was the case here in the long SOA condition. Another possibility is that onset distractors are suppressed, and that this suppression is accompanied by a surrounding gradient of inhibition. Bennett and Pratt (2001) demonstrated that IOR is indeed not constrained to the inhibited location, but that it spreads out to the surrounding area. This inhibitory annulus then suppresses no-onset targets appearing nearby. This would lead to slowed target-related responses, especially when attention is not cued toward the target.

The occurrence of IOR in the Folk et al. (1992) contingent cuing paradigm has been demonstrated before by Gibson and Amelio (2000) and Pratt, Sekuler, and McAuliffe (2001). In contrast to the present study, these studies looked at IOR toward the cue, rather than toward an additional distractor, by prolonging the usual SOA of around 150 msec between the presentation of the cue and the target displays to an SOA that would permit IOR. Both studies showed that an onset cue could evoke IOR, but only when participants were also looking for an onset target, not a color target, thus providing support for contingent capture rather than stimulus-driven capture. However, a later study by Pratt and McAuliffe (2002) demonstrated that the onset cue can elicit IOR even when the target is defined by color. Pratt and McAuliffe argued that the absence of IOR in their earlier study was due to outliers in the data set, and that the absence of IOR in the Gibson and Amelio study may have been due to the peculiarities of their displays. For example, Gibson and Amelio used a short brightening of the placeholder box as an onset cue instead of the usual four surrounding dots. In the presence of an attentional control setting for a color-defining target, perhaps such a brightening of an existing object may not be a sufficiently strong stimulus to capture attention. There is substantial evidence that the effectiveness of luminance transients largely depends on whether a new perceptual object is being created (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001).

In the present study, the abrupt onset stimulus was always a new object, and, together with the Pratt and McAuliffe study, our results now unequivocally show that IOR—and thus involuntary attentional orienting—toward an onset is possible even when observers look for color. Our findings further extend those of Pratt and McAuliffe by demonstrating capture by onsets simultaneously with (i.e., occurring on the very same trials as) the presumed capture by the color cues, as is demonstrated through the cue validity effect. This indicates that contingent and stimulus-driven capture do not need to be mutually exclusive. Thus, unlike what Folk et al. (2009) have argued, it is not necessary to assume an attentional orienting mechanism for the one effect and a completely different filtering mechanism for the other. The present results cannot be explained by filtering, since filtering would not predict IOR.

This is not to say that contingent capture and stimulus-driven capture reflect one and the same mechanism. Note that in the Gibson and Amelio (2000) and the Pratt and McAuliffe (2002) studies, as well as in the present study, a color cue never elicited IOR, even when participants had adopted an attentional set for color. This raises strong doubts whether contingent capture really is a form of *capture*, often receiving the additional labels of being *automatic* and *exogenous* in nature (Folk & Remington, 1998). Instead, one could argue that when observers are instructed to look for the red object that will appear shortly, they will do exactly that and will take the occasional selection of the near simultaneous cue for granted (see also Belopolsky, Schreij, & Theeuwes, 2010; Pratt et al., 2001). In other words, attention would be endogenously driven. The fact that there was no IOR for the cued locations fits with a more endogenous source of attention (Klein, 2000; Posner & Cohen, 1984). This is not to say that colors cannot capture attention in an exogenous, stimulus-driven fashion. Theeuwes and Godijn (2002) and Folk and Remington (2006) found IOR to a color singleton when this color singleton was *not* relevant to the observer.

In conclusion, we have shown that even when observers have an attentional set for color, irrelevant onsets cause IOR. Since IOR can be taken as a measure of stimulus-driven allocation of spatial attention, we conclude that onsets capture spatial attention in an automatic fashion regardless of attentional set.

AUTHOR NOTE

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