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BRIEF REPORT

Out with the new, in with the old: Exogenous orienting to locations with physically constant stimulation

J. Eric T. Taylor[1] · Matthew D. Hilchey[2] · Jay Pratt[2]

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Abstract

Dominant methods of investigating exogenous orienting presume that attention is captured most effectively at locations containing new events. This is evidenced by the ubiquitous use of transient stimuli as cues in the literature on exogenous orienting. In the present study, we showed that attention can be oriented exogenously toward a location containing a completely unchanging stimulus by modifying Posner's landmark exogenous spatial-cueing paradigm. Observers searched a six-element array of placeholder stimuli for an onset target. The target was preceded by a decrement in luminance to five of the six placeholders, such that one location remained physically constant. This "nonset" stimulus (so named to distinguish it from a traditional onsetting transient) acted as an exogenous cue, eliciting patterns of facilitation and inhibition at the nonset location and demonstrating that exogenous orienting is not always evident at the location of a visual transient. This method eliminates the decades-long confounding of orienting to a location with the processing of new events at that location, permitting alternative considerations of the nature of attentional selection.

Keywords Attentional capture · Inhibition of return · Object-based attention

Insights on the orienting of attention are inferred from responses to target stimuli that follow the presentation of cues, which are typically new and distinct visual events. If target processing is affected by the mere occurrence of the cue or the location of the cue relative to the target, an involuntary shift of attention is often inferred (Maylor, 1985; Pratt, Hillis, & Gold, 2001a; Schreij, Theeuwes, & Olivers, 2010). Reading this literature, one could be forgiven for thinking that only new events capture attention (e.g., Hollingworth, Simons, & Franconeri, 2010; von Mühlenen & Conci, 2016; Yantis & Hillstrom, 1994). However, this prominent conclusion is the result of the paradigm's dominance, with researchers persistently cueing attention to locations containing new events. As has previously been argued (Hilchey, Taylor, & Pratt, 2016), this paradigmatic adherence leaves a blind spot in our understanding: Is it even possible to obtain evidence of an involuntary shift of attention to a location containing static stimulation? It appears possible to collect such evidence for attentional capture, as measured by the additional-singleton paradigm (Hilchey et al., 2016). But does this answer hold for the most archetypical of attentional tasks, Posner's landmark exogenous spatial-cueing paradigm (Posner & Cohen, 1984)? In this article we modify this paradigm to evaluate whether orienting can indeed occur to a location without a new event. This is especially important to discover in the context of the exogenous spatial-cueing paradigm, which historically has confounded orienting with the detection of a new event. As Posner noted in 1980, research on orienting "has confounded the alignment of attention to a source of input with the detection of a stimulus event" (p. 21), and usually it still does.

In Posner's exogenous spatial-cueing paradigm, the cue consists of the brightening of a placeholder stimulus in peripheral vision prior to the appearance of a target that appears randomly within the cued or an uncued stimulus. Generally speaking, when the interval between the cue and target is less than about 200 ms, responses are fastest to targets appearing at the cued location, an effect attributable to involuntary (or *exogenous*) attentional capture by the cue. At later intervals this pattern reverses, which is sometimes taken to suggest that

✉ J. Eric T. Taylor
j.eric.t.taylor@gmail.com

1 Brain and Mind Institute, University of Western Ontario, 1151 Richmond St. N, London, Ontario N6A 5B7, Canada

2 University of Toronto, Toronto, Ontario, Canada

attention is biased against locations or objects that have previously captured attention (Klein, 2000; Lupiáñez, Klein, & Bartolomeo, 2006). Following the advent of this cueing paradigm, researchers began intensively investigating the influence of new events on attention. For example, local changes in luminance can capture attention despite both instructions (Jonides, 1981; Theeuwes, 1991) and incentive to ignore the changes (Remington, Johnston, & Yantis, 1992). Other research has suggested that a new event, even if unaccompanied by a luminance transient, can capture attention (Yantis & Hillstrom, 1994). More recently, a long list of events have been found to attract attention to their location, including the onset of motion, looming projectiles, a spontaneous change in motion, and luminance-intransient S-cone stimuli (Abrams & Christ, 2003; Franconeri & Simons, 2003; Pratt, Radulescu, Guo, & Abrams, 2010; and Sumner, Adamjee, & Mollon, 2002, respectively). In all cases, the attention-grabbing stimulus is defined by a local change, even if this is unaccompanied by variation in local luminance (e.g., Guo, Abrams, Moscovitch, & Pratt, 2010). Indeed, the dominant approach to studying attentional capture is to present a (debatably) task-irrelevant new event and to examine the consequences thereof for target processing (Franconeri, Hollingworth, & Simons, 2005; Hollingworth et al., 2010). Even if the new-event paradigm is not explicitly endorsed by attention researchers, it is tacitly canon, as evidenced by its near-universal use in the Method sections of this literature. Simply, very few studies have examined whether the absence of an event, or a cue defined by "nothingness" (e.g., Kiss & Eimer, 2011), can capture attention to its location (Nakayama & Mackeben, 1989). We are trying to fill this gap.

The studies reviewed herein typify the intuitive approach to studying attentional capture, which we call the *new-event paradigm*. Studying attention with mental chronometry requires that the response be time-locked to some new event (Donders, 1868/1969). Critically, for our purposes, that event is usually the object of inquiry. For example, if we wanted to know whether a given stimulus orients attention, we would probe for a response with a target at the location of that stimulus and compare the consequent reaction time to those for probed responses elsewhere. This paradigm has proven productive and pervasive, generating decades of research on the causes, effects, and functions of visual orienting (Wright & Ward, 2008). However, as we noted, this approach confounds orienting to a cued location with the presence of a new event at that location; in the new-event paradigm, *the new event is also the object of study*. To decouple orienting from the detection of a new event, our innovation is to change all items in a visual array except one, which we call a "nonset" cue, to distinguish it from the typical onset cue. In other words, our cue is defined by the absence of newness (or, if one prefers, the absence of change). This method provides a fair and strong test of whether attention can be summoned involuntarily to stimuli other than new events. In short, we have designed a stimulus that elicits orienting without the sensory baggage caused by transient changes at that location.

The experiments

We modified Posner's exogenous spatial-cueing paradigm to make the cue a distinct nonevent. Each trial begins with an array of six bright placeholder stimuli centered on fixation. After a short delay, the placeholder stimuli dim at five locations, leaving one location unchanged. This static stimulus is the "nonset" cue. After a short (150-ms) or a long (1,000-ms) interval, a dim target appears inside a random placeholder. In Experiment 1 the target was a dim square, which required a simple detection response. In Experiment 2 the target was a dim line, whose orientation was discriminated with a response. Canonical patterns of facilitation followed by inhibition centered on the nonset would suggest that involuntary shifts of attention can be dissociated from the locations of novel visual events. Conversely, if new events capture attention, we would expect the five new events to attract attention to their center of gravity (Christie, Hilchey, Mishra, & Klein, 2015; Klein, Christie, & Morris, 2005), which in this case would be in the opposite direction from the nonset. Simply, we pitted a single nonset against multiple onsets to see whether the nonset could generate the classic biphasic reaction time pattern.

Method

Participants

Thirty-seven students (18 in Exp. 1, 19 in Exp. 2) participated in exchange for course credit or $10. All students were naïve to the purpose of the experiment and provided informed consent.

Materials

The stimuli were displayed on CRT monitors running Psychophysics Toolbox. All sessions were conducted in a dim room, and head position was fixed using a chinrest 44 cm from the display.

The stimuli consisted of a fixation cross (0.8 deg; 255, 255, 255 RGB) surrounded by six placeholder circles (0.8 deg; 255, 255, 255 RGB) evenly spaced from center (8.0 deg). The cue was introduced by simultaneously dimming five of the placeholder circles (100, 100, 100 RGB). The target (100, 100, 100 RGB) matched the luminance of the dimmed circles. In Experiment 1 this target was the onset of a square, and in Experiment 2, the onset of a slanted line.

Procedure

A trial began with a fixation cross for 500 ms, followed by the preview array of six bright circles (see Fig. 1). After a random delay between 500 and 1,000 ms, five of the circles dimmed, leaving the sixth circle—the nonset cue—completely unchanged. After a short (150-ms) or long (1,000-ms) interval, the target appeared. The intertrial interval was 1,000 ms. Critically, the nonset cue was uncorrelated with the target location, so there is no obvious utility to attending it.

In Experiment 1, participants were required to press the space bar as fast as possible upon detecting the target. Participants were instructed that they should fixate the cross, that eye movements were forbidden, and that all target stimuli would appear in the placeholders. Some trials (one of every seven) were catch trials, meaning that they did not contain a target. On these trials, participants were instructed to withhold responses. Participants were given a discouraging error message if they responded in advance of target onset, if they responded on a catch trial, or if they did not respond within 2,000 ms of target onset. In Experiment 2 everything was the same, except (1) the orientation of the target line was discriminated with the "z" or the "/" key, respectively, and (2) there were no catch trials.

The experiment had a 6 (cue location) × 6 (target location) × 2 (cue–target interval) factorial design, with 432 experimental trials broken into blocks. Experiment 1 included additional catch trials. Participants began with a short practice block of 12 randomly selected trials and were given breaks between blocks.

Results and discussion

Experiment 1—Detection task

Reaction time (RT) was measured as the time between target onset and response. Trials faster than 100 ms were excluded as errors of apprehension (<1%). One participant was removed prior to the analysis because of an exceptional error rate (48 false alarms on catch trials, misses, and responses made before target onset, as compared to the mean of 9).

The mean participant RTs were entered into a 2 (cue–target interval: 150 or 1,000 ms) × 4 (cue–target angular distance: 0, 60, 120, or 180 deg) repeated measures analysis of variance (ANOVA). We found an effect of cue–target interval, $F(1, 16) = 7.70$, $p = .014$, $\eta_p^2 = .325$, but not of cue–target distance, $F(3, 48) = 1.11$, n.s. Critically, these variables interacted, $F(3, 48) = 5.14$, $p = .004$, $\eta_p^2 = .243$, indicating that the effect of the cue depended on the delay between cue and target (see Fig. 2). These cueing effects are best characterized as separate facilitative and inhibitory effects, which can be assessed with separate ANOVAs on cue–target angular distance for each level of cue–target interval. At 150 ms there was an effect of cue–target distance, which indicates a facilitative gradient emerging from the nonset, $F(3, 48) = 3.39$, $p = .025$, $\eta_p^2 = .175$. At 1,000 ms there was an inhibitory effect, such that responses were especially slow to targets at the nonset location, $F(3, 48) = 3.48$, $p = .023$, $\eta_p^2 = .179$.

These findings are consistent with the classic biphasic RT pattern that is typically observed using onset cues. That is, responses are particularly fast to targets at the nonset at the early cue–target interval, followed by particularly slow responses to targets at the nonset at the later cue–target interval. The RT effect is clearly centered on the nonset, unambiguously determining its origin (Bennett & Pratt, 2001; Maylor & Hockey, 1985; McCormick & Klein, 1990; Pratt, Spalek, & Bradshaw, 1999; Taylor, Chan, Bennett, & Pratt, 2015).

Experiment 2—Discrimination task

Incorrect responses, anticipatory responses, and timeouts were discarded (5.1%). Applying the same analysis as in Experiment 1, we found effects of cue–target interval, $F(1, 18) = 16.35$, $p < .001$, $\eta_p^2 = .476$, and cue–target distance, $F(3, 54) = 6.37$, $p < .001$, $\eta_p^2 = .261$. Critically, again there was an interaction, $F(3, 54) = 5.01$, $p = .004$, $\eta_p^2 = .218$, indicating that the effect of the cue depended on the delay between cue and target. Unlike in Experiment 1, responses tended to be slowest to targets at the nonset location at both

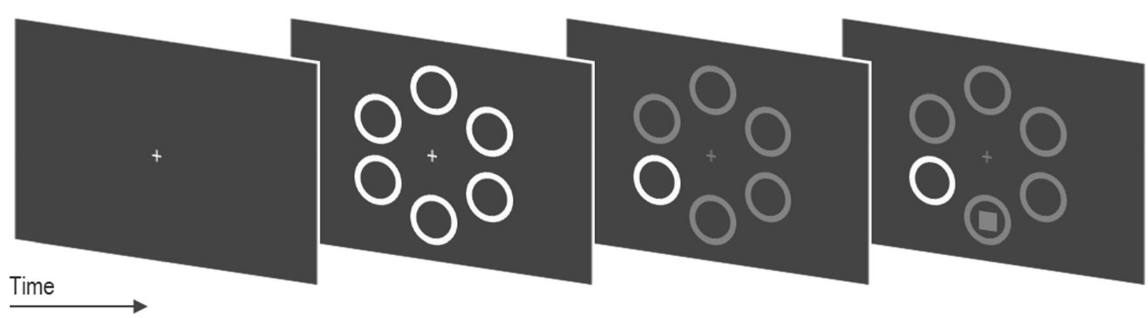

Fig. 1 Basic trial structure for both experiments. The sequence shows a trial from Experiment 1, in which a bright nonset occurred either 150 or 1,000 ms before an onset detection target. Experiment 2 was identical, except that the target was a slanted line that required a left–right discrimination. The stimuli are not shown to scale

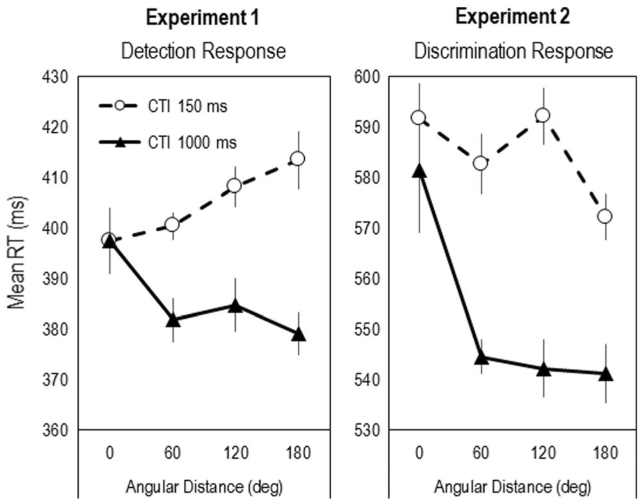

Fig. 2 Results for both experiments. Different panels show mean RTs for the short and long cue–target intervals (CTIs) as a function of cue–target angular separation. Error bars represent one standard error of the mean, corrected within subjects. Note the difference in the *y*-axis scales

the short, $F(3, 54) = 3.57$, $p = .020$, $\eta_p^2 = .165$, and the long, $F(3, 54) = 6.97$, $p < .001$, $\eta_p^2 = .278$, cue–target interval, though the effect was more pronounced at the long cue–target interval.[1]

General discussion

In Experiment 1 (target detection), we observed a classic biphasic RT pattern of facilitation followed by inhibition at the nonset location, suggesting that the nonset captured attention. In Experiment 2 (target discrimination), the pattern was unusual, with inhibition instead of facilitation at the nonset location at the earliest cue–target interval (e.g., Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997). Notably, this nonset-centered inhibition increased with cue–target interval, suggesting that the inhibition was offset early on by another effect, which we ascribe to attentional capture. The experiments collectively reveal that an involuntary shift of attention can be dissociated from the location(s) of new visual events in the classic exogenous spatial-cueing paradigm, addressing a confound that Posner (1980) identified long ago.

Our definition of new events as local dynamic changes (light, color, shape, motion, looming, fading, etc.) is literal, but it is not the only way to define novelty. It also may be plausible to define a new and/or a novel event as any change in the display that causes a stimulus to be perceived as new, regardless of whether the attention-grabbing stimulus changes. Simply, through this metaphysical lens, a nonset might be perceived as a new event, since the changes applied to the other elements in the scene cause the nonset to be perceived as an interruption to an otherwise complete array, despite its local intransience. A danger with this abstraction of novelty (or perceived newness) to a literally unchanging stimulus is that it introduces a form of circularity, such that any evidence of attentional capture, or lack thereof, defines novelty. This alternative definition highlights the fundamental issue at stake: Research in attention can exist in a theoretical limbo between sensation and perception, and the interpretation of empirical findings can vary with whether capture and orienting are viewed as sensory or perceptual phenomena. We followed the lead of a literature strongly rooted in a sensory perspective to define new events literally, as dynamic local changes. From this perspective, nonset stimuli are strange contenders for exogenous orientors, since they are not defined by dynamic sensory signals at their location in any way, shape, or form.

Why has the sensory (or, if one prefers, transient-centric) model of exogenous orienting dominated the literature? One reason for its appeal may be the apparent simplicity of the neurophysiology explaining the relationship between new events and orienting: The primate superior colliculus, for example, which helps drive (oculomotor) orienting, is especially sensitive to motion and luminance transients; moreover, the magnitude of capture induced by onset cues correlates with the activity of visuomotor neurons residing in the intermediate layers of the superior colliculus (Fecteau & Munoz, 2005). Given the oculomotor-orienting system's hard-wired sensitivity to transient information, it is easy to understand why researchers treat sensory novelty as the de facto criterion for exogenous orienting (e.g., Theeuwes, Mathôt, & Grainger, 2013), and why orienting is modeled as a response to local differences in bottom-up signals (Itti & Koch, 2000). Crucially, the data here show that not all forms of involuntary orienting are inextricably chained to the locations or center of gravity of new luminance events. That said, it remains plausible that relative differences in the visual environment and the representation thereof can account for attentional capture (Fecteau & Munoz, 2006), so long as it is accepted that the locations of new events are not always represented as being imperative for orienting. Although this perspective is not strictly incompatible with existing viewpoints, it is generally overlooked.

In the present experiments, the nonset cue and the target were singletons, raising the concern that the nonset captured attention because participants were strategically attending to singletons (so-called "singleton detection mode"; Bacon & Egeth, 1994). First, while this account is potentially true, we do not think that this in any way diminishes the observation that involuntary capture can occur through a nonevent. In fact, the nonset method could be imported into the research on attentional control settings to ensure that the target does not resemble the cue in terms of onset, newness, or transience.

[1] Post hoc linear trend analyses were conducted on the distance effects to quantify their shape; in Experiment 1, both cue–target intervals exhibited significantly linear trends, $Fs > 7.23$, $ps < .016$. In Experiment 2, only the late cue–target interval exhibited a linear trend, $F(1, 18) = 8.81$, $p = .008$. We thank an anonymous reviewer for recommending these analyses.

Second, it is important to note that the present pattern of results is quite different from the typical demonstrations in the contingent-capture literature. Most critically, cues that capture attention because they resemble the target at some level do not often result in inhibitory effects at late cue–target intervals (Gibson & Amelio, 2000; Pratt, Sekuler, & McAuliffe, 2001b).

Somewhat perplexingly, a gradient of facilitation was observed only in the detection task. The discrimination task showed a relatively weak and localized inhibitory cueing effect at the short interval, and an even larger one at the late interval. It is unclear why the typical onset cue usually results in a prolonged period of facilitation in discrimination tasks, whereas the nonset cue here did not (see Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014, for a review). One possibility is that it was easier to disengage from the nonset cue in the discrimination than in the detection task (e.g., Danziger & Kingstone, 1999; Taylor et al., 2015), but this inverts the more common perspective that disengagement takes more time in discrimination tasks (Klein, 2000), and it is hard to see why this should be the case here.

An alternative possibility that we currently favor is that the inhibitory aftereffect is independent of attentional capture, perhaps reflecting some sort of object-updating cost (Carmel & Lamy, 2015). Our experiments seem to satisfy the conditions for object-updating costs, insofar as the nonset exposure duration was long (i.e., it did not onset or offset), could be consciously perceived, and was more easily distinguished from the target event than the target event could be distinguished from the onset stimuli (e.g., Lamy, Alon, Carmel, & Shalev, 2015). In this account, assuming constancy in the object-updating cost as a function of cue–target interval here, an additional effect, such as attentional capture, would be needed to explain both the facilitatory effect in the detection task and why object updating was greater at the long than at the short interval in the discrimination task. In deference to the possibility of object-updating costs, the preferred explanation for the present nonset findings is that two parallel, opponent processes operate (e.g., Posner & Cohen, 1984). On the one hand, an object-updating cost at the nonset location remains constant across the cue–target intervals, and on the other, an attentional capture effect at the nonset location decays as a function of cue–target interval. These two processes, together with the well-established foreperiod effect (e.g., Bertelson, 1967), provide a good account of the data. The reason for this difference between the discrimination and detection tasks remains unknown, but according to this conceptualization, it would reflect a greater contribution of attentional capture and/or object updating in one task than in the other.

To summarize, by modifying Posner's landmark exogenous spatial-cueing paradigm, we showed that a completely unchanging stimulus can capture attention when all other objects around it change. In so doing, we clearly demonstrated that some form of exogenous orienting can be dissociated from the locations of new visual events. These capture effects may reflect local differences in the stimulus-driven or priority-driven representation of the visual environment, through which the location of the nonset triumphed over the locations of the new visual events in guiding attention.

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