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Knowing and avoiding: The influence of distractor awareness on oculomotor capture

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Abstract Kramer, Hahn, Irwin, and Theeuwes (2000) reported that the interfering effect of distractors is *reduced* when participants are aware of the to-be-ignored information. In contrast, recent evidence indicates that distractor interference *increases* when individuals are aware of the distractors. In the present investigation, we directly assessed the influence of distractor awareness on oculomotor capture, with the hope of resolving this contradiction in the literature and gaining further insight into the influence of awareness on attention. Participants completed a traditional oculomotor capture task. They were not informed of the presence of the distracting information (unaware condition), were informed of distractors (aware condition), or were informed of distractor information and told to avoid attending to it (avoid condition). Being aware of the distractors yielded a performance benefit, relative to the unaware condition; however, this benefit was eliminated when participants were told to actively avoid distraction. This pattern of results reconciles past contradictions in the literature and suggests an inverted-U function of awareness in distractor performance. Too little or too much emphasis yields a performance decrement, but an intermediate level of emphasis provides a performance benefit.

At any given moment, the visual system is presented with far more information than it can possibly hope to handle. As a result, attentional mechanisms enable the selection of a portion of that incoming information for further processing. What receives attentional priority is governed by interactions between goal-driven and stimulus-based factors (Posner, 1980). That is, the selection of visual objects can be enhanced by the volitional use of goal-related information (e.g., symbolic cues, attentional sets) or due to an object's salience relative to surrounding objects. The abrupt appearance of a new object represents one such visually salient event the attentional system is particularly sensitive to. When a target appears as an abrupt onset, search is highly efficient; however, the abrupt appearance of a task-irrelevant object is quite effective at disrupting search performance. This capture of attention by abrupt onsets has been demonstrated in both covert (Jonides & Yantis, 1988; Remington, Johnston, & Yantis, 1992; Yantis & Jonides, 1984, 1990) and overt (Boot, Kramer, & Peterson, 2005; Chisholm & Kingstone, 2012; Hunt, von Mühlenen, & Kingstone, 2007; Irwin, Colcombe, Kramer, & Hahn, 2000; Kramer, Hahn, Irwin, & Theeuwes, 2000; Theeuwes, Kramer, Hahn, & Irwin, 1998) attention paradigms.

The effect of making reflexive eye movements to task-irrelevant abrupt onsets is often observed in oculomotor capture paradigms. That is, while participants search for a target—typically, a color singleton—the sudden appearance of a new nontarget object will capture the eyes on a significant number of trials. Despite attending to the abrupt onset, participants may report being unaware of having made erroneous eye movements, as well as being generally unaware of the fact that an extra item was added to the display at all (Kramer et al., 2000; Theeuwes et al., 1998). This observation is quite interesting since it demonstrates significant interference with task performance, with no conscious awareness on the part of the participant. Being aware of which information to attend to and which to suppress presents itself as the quintessential top-down situation for engaging effective attentional control. However, the fact that individuals exhibit

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oculomotor capture without being aware of their own behavior raises the question of the importance of distractor awareness and its relative influence on search performance.

Behavioral and electrophysiological evidence has demonstrated that being aware of the spatial location of an upcoming distractor can give rise to anticipatory inhibition of specific regions in space (e.g., Chao, 2010; Munneke, Van der Stigchel, & Theeuwes, 2008; Ruff & Driver, 2006; Serences, Yantis, Culberson, & Awh, 2004; Van der Stigchel, Heslenfeld, & Theeuwes, 2006; Van der Stigchel & Theeuwes, 2006). Under these circumstances, performance is less affected by the presence of a distractor, since processes can be successfully engaged to suppress their influence. Consistent with this, a study by Kramer et al. (2000) revealed that being aware of the presence of abrupt onsets in an oculomotor capture task could benefit performance. Awareness was manipulated by altering the relative saliency of the abrupt onset distractor across two testing blocks. The abrupt onset was either equiluminant or more salient, as compared with the other display items, establishing *unaware* and *aware* conditions, respectively. Results revealed that being aware of the distractor led to a decrease in oculomotor capture in young adults. For older adults, the pattern of results was reversed, with capture increasing with awareness. The authors suggested that being aware of the distractor allowed one to engage conscious working memory processes to actively inhibit the task-irrelevant information. Furthermore, noting that working memory processes decline with increasing age (e.g., Craik & Jacoby, 1996), the overall data pattern was explained. The broader implication of Kramer et al.'s explanation is that, without awareness, the attentional system is more susceptible to distraction, because conscious inhibitory processes are not engaged to actively suppress the distracting information.

However, research has revealed that inhibiting known distractors may not be efficient in all circumstances. Although Kramer et al.'s (2000) conclusion was that working memory processes are engaged to inhibit distraction, recent work has demonstrated that performance is more negatively affected when the contents of working memory match the distractor information presented (e.g., Downing, 2000; Han & Kim, 2009; Olivers, 2009; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005; however, see Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Woodman & Luck, 2007).

In addition, two recent studies have also demonstrated that participants consistently attended to known to-be-ignored distractor locations, an observation that has been referred to as the attentional white bear phenomenon (Lahav, Makovski, & Tsal, 2012; Tsal & Makovski, 2006). Evidence has been provided to suggest that known to-be-ignored distracting information must first be attended prior to being suppressed. For example, evidence for the time course of distractor suppression comes from the use of a visual masking paradigm (Watson & Humphreys, 1997). In this task, a preview display is presented to indicate locations that will not contain a target. As revealed by performance in a probe detection task, attention is often first committed to the previewed nontarget locations. Probe detection was thus facilitated at distractor locations when they appeared earlier in time (200 ms following preview), but this facilitation was eliminated later in time (Humprhreys, Stalman, & Oliver, 2004). A similar pattern of results was demonstrated by Moher and Egeth (2012) when cuing to-be-ignored distractor features. They revealed that locations containing the to-be-ignored features were first attended, early in time, but then later suppressed. Moher and Egeth thus proposed a "search and destroy" model for distractor suppression, noting that such a strategy may be useful for prolonged search, when to-be-ignored information appears prior to a search display, but is likely inefficient when known distractor information appears simultaneously with a target.

Taken together, there appears to be a conflict in the reviewed findings regarding the relative influence of distractor awareness on the efficiency of visual search. Specifically, Kramer et al. (2000) demonstrated a benefit in search performance when participants become aware of the to-be-ignored information; however, a collection of more recent studies suggests that distractor awareness can, at least early in time, negatively affect performance. Since these investigations employed different paradigms and only Kramer et al. explicitly manipulated awareness, it is difficult to directly compare these results. Therefore, the aim of the present investigation was to further assess the role of distractor awareness in visual search performance, with the intent of discovering a way to possibly reconcile these divergent findings.

In order to evaluate whether awareness is critical for the modulation of capture, we employed a direct manipulation of awareness, without altering any stimulus properties. Specifically, distractor awareness was manipulated by providing participants with different information prior to beginning an oculomotor capture task. One group of participants was informed that an abrupt onset could appear in the display (aware group), and a second group was not provided with any distractor information (unaware group). Critically, since display parameters were held constant across all conditions, if awareness alone is sufficient to modulate capture, a difference in the degree of oculomotor capture is predicted between the aware group and the unaware group. In case our simple awareness manipulation was not sufficiently strong to influence capture, a second manipulation was introduced whereby participants were informed about the distractor and instructed to avoid being captured by it (avoid group).

Method

Participants

Data from 36 participants (26 females, 16–28 years of age) recruited from the University of British Columbia are reported. Participants were divided equally among the three conditions. All participants provided written consent, reported normal or corrected-to-normal vision, and received course credit or monetary compensation for their participation.

Apparatus and task

Stimuli were presented on a 17-in. LCD monitor. Participants were seated approximately 65 cm away from the monitor and rested their head in a chinrest. An Eyelink 1000 desk-mounted eye-tracking system (SR Research) was used to track and record eye movements at a sampling rate of 1000 Hz. A standard optical mouse was used for manual responses.

The visual display consisted of six circles evenly spaced around the circumference of an imaginary circle with a visual angle of 14.7°. Each circle was placed at the same location on every trial, separated by 60° around the imaginary circle. A black square (0.3°) was placed at the center of each circle (2.35°), and a small indent was applied to the left or right of the square found within the target circle. Pilot testing confirmed that it was necessary to fixate the target in order to discriminate the position of the indent. The target appeared at each of the possible six positions around the imaginary circle an equal number of times, with the location of the abrupt onset appearing an equal number of times 90° or 150° from the target. The task-irrelevant abrupt onset randomly appeared on half of the trials within each block and was identical to the other nontarget items in the display. All stimuli were presented on a black background (Fig. 1).

Procedure

All participants received the exact same general task instructions prior to beginning the task. The critical manipulation was the information participants received about the presence of a distractor. Participants assigned to the *unaware* condition received only the task instructions and were not informed of the possible appearance of an abrupt onset. In addition to task instructions, participants assigned to the *aware* condition were informed that an extra circle could appear on some of the trials. Finally, participants assigned to the *avoid* condition were informed that an extra circle could appear and that they should try to actively avoid looking at it.

Each trial began with a central fixation point (0.7°) presented for 150 ms, followed by six gray circles, each presented at equal distances from the central fixation point. After 2,500 ms, all but one gray circle (target circle) changed to blue. Participants were instructed to make an eye movement toward the target item. Once fixating the target, participants pushed either the left or the right mouse button to indicate whether the location of an indent was on the left or the right, respectively, of a black square within the target circle. Quick and accurate responding was emphasized.

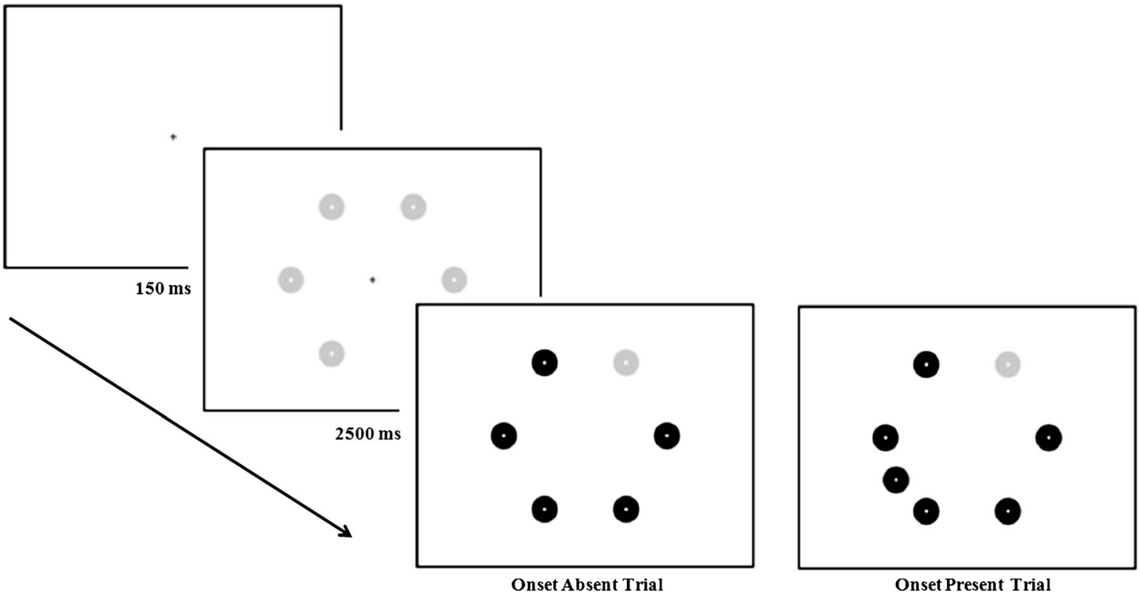

Fig. 1 Example sequence of events for onset-absent and -present trial types

On half of the trials, an additional blue circle (abrupt onset) was added to the display simultaneously with the appearance of the target. After a response was made, participants were presented with a blank screen for 500 ms. Trials where participants failed to respond within 2,000 ms would time out, and the next trial would be initiated. Each participant first received a brief practice session of 12 trials and was questioned, upon its completion, to confirm that they could properly detect the target circle among the nontargets, as well as identify the location of the indent within the target. Participants in the aware and avoid conditions were also asked to confirm that they noticed the presence of an abrupt onset distractor. Following the practice block, participants completed six experimental blocks, each consisting of 48 trials, for a total of 288 trials. Before each block, participants completed a nine-point calibration process to ensure proper eye tracking. At the end of each block, the average reaction time of their manual responses was provided as feedback, which participants were asked to read aloud to the experimenter.

At the end of the experiment, participants completed a questionnaire to confirm whether they were or were not aware of the abrupt onset. Specifically, participants were asked to indicate whether a number of aspects of the experiment were true or false—for example, all trials began with six circles (true), circles changed to red (false). Critically, one item asked whether an extra circle appeared on some of the trials. Reporting this statement as true and also answering the majority of the other questions correctly (mean 88%) was taken as evidence that the participant had been aware of the presence of the onset. Only those in the unaware condition who failed to report being aware of the abrupt onset via the postexperiment questionnaire were included in any analyses.[1]

Results

Trials were excluded from analysis if participants failed to maintain initial fixation within 2° of center, generated an initial saccade with amplitudes less than 2° or a velocity less than 30°/s, or had response latencies less than 100 ms or greater than 500 ms. This resulted in the loss of 13.4% of the trials. To categorize accurate and capture trials, the following criteria were used. If a saccade landed within a window of ±35°, centered on the target, the trial was considered accurate. If a saccade landed within the same window size but centered on the abrupt onset, the trial was considered a capture trial. Saccades in any other direction were considered error trials and were omitted from any analysis.

Performance data are shown in Table 1. On trials where no abrupt onset appeared in the display, the majority of saccades (>80%) were oriented correctly to the target. An analysis of saccade accuracy revealed no differences across groups on onset-absent trials, $F(2, 35) = 1.13$, $p > .05$. This was also the case for saccade latency on onset-absent trials, $F(2, 35) < 1$, indicating that all groups were equally able to perform the task. On trials where an abrupt onset did appear, a comparison of the proportion of trials where the initial saccade was oriented toward the abrupt onset was the critical analysis to assess the effect of awareness on oculomotor capture. Analysis of these data revealed a significant effect of condition, $F(2, 35) = 4.53$, $p < .05$. Post hoc analysis demonstrated that participants in the aware condition experienced significantly less capture (29%) than those in the unaware (45%, $p < .05$) and avoid (44%, $p < .05$) conditions, whereas the unaware and avoid conditions did not differ ($p > .05$).[2]

A 3 × 2 repeated measures ANOVA of manual reaction time, with condition (unaware, aware, avoid) and onset presence (absent vs. present) as factors, mirrors the saccadic data pattern. There was a main effect of onset presence, $F(2, 33) = 3.77$, $p < .05$, indicating that all groups produced longer manual RTs when an onset appeared in the display. There was also a significant interaction, $F(2, 33) = 3.77$, $p < .05$, indicating that when the onset distractor was present, performance was slowed to a greater extent for participants in the unaware (59 ms) and avoid (63 ms) groups than for those in the aware group (39 ms), reflecting the cost of making more saccades to the abrupt onset in the former two groups. A similar analysis of the manual response errors revealed that performance did not differ between onset-present versus -absent trials, $F(1, 33) = 1.54$, $p > .05$, or groups, $F(2, 33) < 1$, and these factors did not interact, $F(2, 35) < 1$.

Discussion

The aim of the present study was to determine whether distractor awareness would influence oculomotor capture. Our data were unequivocal. A comparison of the unaware

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[1] Thirty-two participants were tested to obtain 12 who were fully unaware of the distractor.

[2] Given that "unawareness" was assessed post hoc, and not directly manipulated, a degree of caution needs to be applied when drawing a causal connection between the lack of distractor awareness and capture. That said, an analysis of the capture data from 18 of the participants (2 excluded due to equipment issues) in the unaware condition who were excluded because they reported becoming aware of the distractor at some point during the study provides converging evidence for a causal link. If distractor awareness causes a decline in capture, the performance for the participants who became aware during the study should reveal less capture than for the unaware participants and greater capture than for the (always) aware participants. This is precisely what our results revealed: Capture for the participants excluded from the unaware condition (36%) fell between the capture observed for the participants in the unaware (45%) and aware (29%) conditions but did not differ from either (*p*s > .05).

Table 1 Mean Saccade Accuracy and Saccade Latency in Onset Absent Trials, and Mean Oculomotor Capture and Cost to Manual RTs Across Conditions (standard error of the mean in parenthesis)

Onset Absent Trials				
Condition	Saccade Accuracy	Saccade Latency	Oculomotor Capture	Manual RT Cost
Unaware	83.1% (2.2)	238ms (5.4)	44.6% (4.9)	59ms (7.3)
Aware	87.6% (2.6)	252ms (9.7)	29.0% (4.0)	39ms (7.4)
Avoid	83.7% (2.0)	250ms (11.0)	43.9% (3.4)	63ms (4.3)

and aware conditions revealed that participants who were made aware of the presence of a task-irrelevant onset distractor were less susceptible to its interfering effect, relative to those unaware of its presence. Our study also indicates that there is an important boundary condition to distractor awareness. When participants were made aware of the distractor and told to avoid being captured by it, the benefit of distractor awareness was abolished.

Given the present pattern of results, we feel our data help to reconcile the divergent findings in the previously reviewed literature. Specifically, when considering the unaware condition as a baseline for oculomotor capture, we clearly demonstrate a benefit associated with being made aware of task-irrelevant information. This finding is convergent with Kramer et al.'s (2000) finding that an increase in distractor awareness can reduce oculomotor capture. However, by placing greater emphasis on the distractor information, through a direct instruction to avoid being distracted, we eliminated the benefit associated with distractor awareness. This finding is consistent with recent evidence demonstrating that attempts to actively avoid distractor features can interfere with the ability to keep attention away from the to-be-ignored information (Moher & Egeth, 2012; Olivers, 2009). Thus, the present findings appear to map on well to an inverted-U function where susceptibility to distraction changes with the emphasis placed on the distracting information.

Convergent with the above explanation, Kramer et al. (2000), made their participants aware of the distractor in a manner akin to our aware group, and like us, they found a benefit of distractor awareness on saccadic performance. Furthermore, the studies that failed to observe a benefit of distractor awareness placed greater emphasis on the distractor (akin to our avoid group) by (1) presenting participants with known to-be-ignored spatial locations (Lahav et al., 2012; Tsal & Makovski, 2006), (2) asking participants explicitly to maintain distractor information in working memory (Downing, 2000; Olivers, 2006; Soto et al., 2005), or (3) explicitly informing participants to ignore upcoming distractor features (Moher & Egeth, 2012; Olivers, 2009).

One can speculate at the neural mechanisms that may lead to these observed effects. Activity in the prefrontal cortex is thought to maintain working memory processes and is responsible for maintaining goal-directed behavior and inhibiting reflexive saccades (Gaymard, Ploner, Rivaud, Vermersch, & Pierrot-Deseilligny, 1998; Guitton, Buchtel, & Douglas, 1985; Olk, Change, Kingstone, & Ro, 2006). This is partially achieved via the inhibitory projections the prefrontal cortex sends to the superior colliculus (SC), which is largely responsible for the generation of saccades (Everling, Dorris, Klein, & Munoz, 1999; Schall, 1995; Wurtz & Optican, 1994). When individuals are made aware of the distractor, this allows for prefrontal processes to be brought to bear to inhibit SC activity, and the probability of being captured by the distractor declines. However, when they are unaware of the distractor, this precludes the possibility of conscious prefrontal-based control, leaving participants more susceptible to distraction. Placing too much emphasis on the distractor, however, could result in prefrontal resources being drawn away from the primary task and interfere with saccadic inhibition (e.g., Roberts Hager, & Heron, 1994)—for example, by either establishing distractor avoidance as a competing primary task or increasing the relative saliency of the distractor, which, in turn, requires greater prefrontal/working memory activity to inhibit this heightened bias toward the distractor.

There is, however, an alternative explanation for our data. Previous work has demonstrated that oculomotor capture is sensitive to the latency at which target-directed eye movements are initiated, with faster eye movements being more likely to be captured (van Zoest, Donk, & Theeuwes, 2004). It is therefore possible that the unaware and avoid groups in the present study had shorter saccadic latencies than the aware group and that this is why the unaware and avoid groups had higher capture rates than the aware group. Comparison of the target saccadic latencies for distractor-present and -absent displays revealed no differences between groups [all Fs(2, 35) < 1], indicating that the difference in capture rates between groups is not due to a speed–accuracy trade-off.

Conclusion

In the present investigation, we assessed the influence of a direct manipulation of distractor awareness on performance in an oculomotor capture task. We demonstrated a performance benefit associated with being aware of the presence of a distractor; however, this benefit is eliminated when an explicit instruction to avoid being distracted is provided. We suggest that our findings reconcile divergent findings in the literature on the influence of distractor awareness. Specifically, our results suggest that one's susceptibility to distraction is related to the relative emphasis placed on distracting information. While moderate emphasis of distractor information can benefit performance (Kramer et al., 2000), too much emphasis or a complete lack of distractor awareness can, instead, result in less efficient search performance. One outstanding question to be examined in the future is whether these findings are specific to overt oculomotor responses or whether they generalize to covert attention and/or other response domains.

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