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Investigating Distractor-induced Effects in Visual Search Utilizing Eye-Tracking

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Abstract

The present study provides an insightful look into the effects of distractors using behavioral and eye-tracking measures. In this study, two eye-tracking experiments utilizing a feature search task were conducted to investigate the distractor-induced early quitting effect with a target prevalence of 50% rather than the 100% target prevalence typical of attentional capture studies. In Experiment 1, two independent variables of target (present/absent) and distractor (target/present) were examined with behavioral measures (accuracy and response time) as well as eye-tracking methods (total fixations, total fixation durations, and total distractor saccade percentages). Distractors were categorized as salient due to their red color, larger size, and delayed onset of 100 milliseconds after the presentation of other stimuli. In Experiment 2, all methodology was replicated with the exception that the salient item was occasionally the target. Experiment 1 demonstrated a robust replication of the distractor-induced early quitting effect on measures of accuracy and response time. Participants also fixated on fewer objects in the visual search task on distractor-present when they were most susceptible to distractor-induced early quitting. Additionally, participants tended to avoid making a saccade to the distractor on distractor-present trials. Experiment 2 demonstrated replication of data on participants' accuracy, response time on target-present trials, and total fixations on target-present trials. Additionally, participants reported the opposite effect on total distractor saccade percentage, as participants had higher percentages of saccades to the distractor on distractor-present trials. However, other measures were not replicated.

Keywords: attentional capture, distractor-induced early quitting, eye-tracking, computer-aided detection

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Many adults in North America may recall completing *Where's Waldo* puzzles (Handford, 1987) in children's books when they were younger. Waldo, a gentleman dressed in a red-and-white striped shirt, winter hat, glasses, and jeans, is hidden in a scene containing dozens of people and objects. To add to the complexity of the puzzle, many of the other individuals or objects possess the same features as Waldo, notably the red-and-white striped clothing (Handford, 1987). Even though these puzzles are marketed to children, *Where's Waldo* is, at its core, a challenging visual search task. In the real world, medical imaging and baggage screening rely heavily upon the same principle as *Where's Waldo*: visually sifting through irrelevant objects to find a possible target. Understandably, the ability to conduct efficient and accurate visual search is critical to various occupations in which making mistakes could be costly.

Background on Attention and Distraction

According to Wolfe's (2021) Guided Search 6.0 (GS6), a model of visual search, attention helps observers select items in visual search scenes so that their features can be visually processed and interpreted. Five main types of pre-attentive information are frequently utilized to aid in efficient visual search: top-down feature guidance, bottom-up feature guidance, prior history/priming, reward, and scene syntax or semantics (Wolfe, 2021). The last type of pre-attentive information refers to the context of an object in a scene, in which a bed in the bathroom would be a semantic violation, whereas a bottle of shampoo placed next to the toilet would be a syntactic error (i.e., shampoo is associated with showering) but semantically congruous with a bathroom scene (Võ, 2021). The five components of pre-attentive information create what Wolfe (2021) terms a "priority map" for guiding attention. Notably, target items located near the point of fixation, often near the center of a visual search scene, are preferentially attended to compared to objects farther away in the visual field (Wolfe, 2021). Additionally, if observers do not perceive a target to be present, they will cease visual search when a quitting signal threshold has been reached (Wolfe, 2021). These general principles of visual search can be applied to study factors that can disrupt the process of selective attention, such as distraction.

Regarding distraction, even the most experienced drivers can attest that captivating billboards can draw their attention away from highway driving for a few seconds. Switching focus to the billboard while driving is a prime example of a phenomenon in cognitive neuroscience known as attentional capture. In this scenario, unattended stimuli, like a perceptually salient billboard, interrupt other attentional processing and direct attention to the novel stimulus (Simons, 2000). There are two different types of attentional capture that are frequently discussed in the literature – explicit and implicit attentional capture. Explicit attentional capture occurs when observers become aware of a salient and previously unattended stimulus and attend to the object (Simons, 2000). In contrast, implicit attentional capture does not need to be consciously attended to in the visual search task. In this case, a salient but irrelevant object affects task performance irrespective of whether the observer is aware of the novel stimulus (Simons, 2000). As seen in the billboard scenario, attentional capture can distract observers from where they should be focusing, such as other vehicles on the highway. In one recent comparative study examining motor vehicle accidents during three periods when billboards were present, removed, and restored, researchers reported that billboard removal was associated with a 30-40% decrease in crashes with injuries, whereas billboard restoration was associated with a 40-50% increase in crashes with injuries (Gitelman et al., 2019). Therefore, it is important to examine the mechanisms by which attentional capture occurs to understand how observers may become distracted.

Studies on Attentional Capture

Visual search experiments, especially when used in tandem with eye-tracking software, are typically utilized to study the relationship between attentional capture and eye movements. Saccades, or rapid eye movements that change where the eyes are fixating, can provide valuable information about attentional capture (Purves et al., 2001). Attentional capture in visual search tasks occurs when observers fixate on task-irrelevant objects such as distractors (Theeuwes, 1992). Additionally, Theeuwes (1992) demonstrated that attentional capture occurs when the new object is markedly different in form or feature from the target, or perceptually salient. In a subsequent study, Theeuwes et al. (1998) reported that when colored targets are present on the screen, observers initiate a goal-directed eye movement or saccade. However, the delayed onset of a different object interrupts the goal-directed saccade to begin a second eye movement directed toward the new object (Theeuwes et al., 1998). As evidenced by the shift in eye movements, the delayed onset of a distractor was able to cause attentional capture. However, there is a long-standing dispute over whether attentional capture can be modified by utilizing top-down processing. Bacon and Egeth (1994) and Leber and Egeth (2006) contend that visual processing can induce top-down selectivity and override attentional capture, whereas Theeuwes (1992) argues that parallel search mediated by top-down processing is not possible. More recently, Luck et al. (2021) suggested an intermediate processing state where perceptually salient stimuli can produce a “priority signal,” but attentional capture can be inhibited by a mechanism that suppresses the perceptually salient stimuli.

A series of nine experiments examined the effect of salient non-targets on attentional capture when targets were non-salient (Yantis & Egeth, 1999). In their methodology, the non-target, non-distractor stimuli and the targets were comprised of blue bars/rectangles. The target was a vertical blue bar, whereas the non-target blue bars were tilted 30° to the left or right of vertical. Color singleton distractors, on the other hand, were comprised of red bars/rectangles. Subsequent experiments in this study also utilized motion or multiple dimensions to create salient distractors (Yantis & Egeth, 1999).

Distractor-Induced Early Quitting

The aforementioned literature employs the use of distractors when target prevalence is 100%, similar to how Waldo is always present somewhere in each of the visual search scenes in the children's books. In these visual search studies, the participant is only required to discriminate the target object from non-target stimuli. However, this scenario is not always applicable to real-world occupations. For example, in medical imaging, the presence of tissue abnormalities as a target is rare. Additionally, unlike the 100% target prevalence studies, visual search mimicking medical imaging requires a decisional component for participants. That is, participants must determine how long they want to examine the visual search scene before reaching a quitting threshold or quitting parameter (Moher, 2020). Accordingly, Moher (2020) investigated attentional capture in a "target-detection search" where targets were not always present. In this study, an interesting pattern of response time (RT) and error rates was observed. This study was conducted online utilizing the Amazon Mechanical Turk platform.

The three experimental conditions tested a target prevalence of 50% (Experiments 1 and 3) or 20% (Experiment 2). Experiments 1 and 2 utilized vertical blue rectangle targets among non-target blue rectangles and red rectangle distractors tilted 30° to the right or left, whereas Experiment 3 displayed rotated "T" targets among rotated "L"s (Moher, 2020). Each blue rectangle measured approximately 40 pixels by 8 pixels. This task design was similar to the one utilized in Yantis and Egeth (1999). Notably, distractors were present in 50% of trials and differed from target and non-target objects in color (red), size (80 pixels by 16 pixels), and onset (100 milliseconds after the appearance of target and non-target objects) in the Moher (2020) study. When targets were present, the concurrent presence of distractors increased the number of errors committed. However, when targets were absent, the presence of distractors reliably and robustly reduced response time in each of the three experimental conditions tested. This latter finding is critical to understanding how attentional capture occurs when targets are absent and an area that had not been explored thoroughly prior to the Moher (2020) study.

Moher (2020) termed the target-absent distractor phenomenon the “distractor-induced quitting effect.” That is, when targets do not appear, observers may be more likely to quit the visual search after the delayed onset of the distractor. This study was the first to demonstrate the distractor-induced quitting effect. Moreover, the strength of this effect in variable experimental conditions suggests that it could have considerable influence on occupations where the consequences of getting distracted are grave.

Recently, one study has attempted to replicate the Moher (2020) findings and determine how distractor-induced quitting and reaction times can be modulated by varying the salience of the distractor. Utilizing Amazon Mechanical Turk and methods similar to Moher (2020), Lawrence and Pratt (2021) conducted three experiments where the salient features were altered. In Experiment 1, utilizing the same large, red distractor and delayed distractor onset as Moher (2020), Lawrence and Pratt (2021) demonstrably replicated the distractor-induced quitting effect on target-absent trials. Critically, however, when the size of the distractor was reduced in Experiment 2, no distractor-induced quitting was observed. Additionally, participants’ response times were slower on distractor-present trials than distractor-absent trials when targets were absent (Lawrence & Pratt, 2021). This study suggests that you may need a large, highly salient distractor to generate the distractor-induced quitting effect. Lawrence and Pratt (2021) acknowledge that further research into the distractor-induced quitting effect is needed and that eye-tracking movements may more clearly elucidate how much of target-absent scenes observers explore before reaching their quitting threshold.

Regardless of whether altering the salience of distractors can influence the quitting threshold, the potential risks associated with distractor-induced quitting have led to the development of applications to reduce its deleterious effects. For instance, Bouhassoun et al. (2021) investigated the use of frames surrounding a particular area in a visual search scene. In this study with middle school students, distractors that appeared outside the frame did not increase response time on either global or local targets. However, only distractors that appeared inside the frame caused attentional capture and affected the visual processing of local targets (Bouhassoun et al., 2021). The researchers suggest that the use of frames in visual search tasks may aid in reducing distractor-induced quitting, as observers will be less likely to perceive distractors if they are located outside of the frames (Bouhassoun et al., 2021).

Implications for Computer-Aided Detection

The distractor-induced quitting effect demonstrated in Moher (2020) is especially relevant to real-world applications with the use of computer-aided detection (CAD), a form of artificial intelligence, in medical imaging or baggage screening. In the medical world, CAD consists of pattern recognition software designed to alert radiologists or observers to their targets in visual search — potential tissue abnormalities (Castellino, 2005). CAD alerts the radiologist by displaying a salient visual signal in the scene (Castellino, 2005). The purpose of CAD, then, is to reduce the likelihood of receiving a false negative result, or committing a miss error (Castellino, 2005). The United States Food and Drug Administration (FDA) approved the first

CAD system for use in a clinical setting in 1998, specifically for mammography (Yanase & Triantaphyllou, 2019).

However, CAD in medical imaging faces several practical challenges. First, CAD systems will not reach optimum effectiveness if radiologists and other observers are not adequately trained to utilize CAD or interpret its results (Yanase & Triantaphyllou, 2019). Additionally, a study comparing the diagnostic accuracy of mammograms with and without CAD demonstrated that there was no significant difference in cancer detection rate or screening performance. Perhaps more alarmingly, radiologists that completed the study both with and without CAD demonstrated decreased sensitivity in mammogram interpretations when using CAD (Lehman et al., 2015).

Understandably, CAD has since come under fire from insurance companies and hospitals alike, as insurance companies refuse to cover the cost of CAD systems, and hospitals are reluctant to bear the fiscal brunt of operating a costly CAD system that currently offers little to no additional benefit to radiologists (Yanase & Triantaphyllou, 2019). These studies undermining the effectiveness of CAD demonstrate that if radiologists or observers treat computer-aided detection as a distractor and perceive that no target is present, they may be inclined to quit visual search early and critically miss a target with life-threatening consequences. In fact, a recent *Current Problems in Diagnostic Radiology* publication references the Moher (2020) study and notes that distracting objects, such as computer-aided detection signals or marks, in abdominal computer tomography (CT) scans may result in distractor-induced early quitting (Kliewer & Bagley, 2021). Despite the idealistic potential benefits of CAD to help identify relevant targets, the risk of distraction and life-threatening consequences may offset the potential benefits of CAD. As such, future research studies should more thoroughly investigate whether CAD elicits distractor-induced early quitting.

The ongoing issues with the efficacy of CAD prompted researchers to investigate whether computer-aided detection can serve as a distractor in medical imaging-like visual searches (Drew et al., 2012). In this experiment, computer-aided detection was deployed in a visual search task to reveal information about either target location or target identity, and eye movements were tracked to monitor how much of the scene the participants were viewing in the visual search task. The researchers reported that targets not marked by computer-aided detection were more likely to be missed. Perhaps most critically, computer-aided detection caused observers to search less of the scene in both Experiments 1 and 2 (Drew et al., 2012). These findings suggest that computer-aided detection may elicit the distractor-induced early quitting effects described in Moher (2020).

Within computer-aided detection technology, there are two different types of CAD that can be used in medical imaging: binary and analog CAD. Binary CAD, which refers to the simple salient visual signals (“marks”) that alert radiologists, is associated with attentional capture (Drew et al., 2020). Binary CAD derives its name when an all-or-nothing mark is placed next to an area where the computer-aided detection system predicts a target will be present (Cunningham et al., 2017). Echoing the earlier Drew et al. (2012) study utilizing eye-tracking, targets that are missed by the binary CAD system are also likely to be missed by the observer. Notably, the effect of binary CAD as a distractor in visual search was also magnified by low prevalence of targets in an eye-tracking study (Drew et al., 2020). Cunningham et al. (2017) suggest that analog CAD, a graded color signal that conveyed the strength of whether an object was likely to be a target, was more effective than binary CAD at both high and low target prevalence. Given that targets naturally occur with low prevalence in real-world applications like medical imaging, it is imperative to determine if distractor-induced quitting is replicable with eye-tracking and if it can be utilized to explain the poor performance of binary CAD in low-target prevalence conditions.

Present Study

In the present study on attentional capture, we used eye-tracking and behavioral methodologies to compare our eye data (e.g., goal-directed eye movements, fixations on items in the trial) and behavioral data (e.g., keypresses, response time, accuracy) to online studies relying solely on behavioral data. In particular, we hoped to determine if the distractor-induced quitting effect is visible or predictable based on eye movements. For example, we wanted to know if saccades (goal-directed eye movements) to the distractor, quantified by total distractor saccade percentages, are necessary for the participant to quit visual search. Additionally, we wanted to determine if distractor-induced quitting could be demonstrated by differences in total fixations, or the numbers of items that the participant attended to in the trial, as well as total fixation durations. Given that the data from Moher (2020) were collected online through Amazon Mechanical Turk, we hoped to see if distractor-induced quitting is replicable in an in-person laboratory setting with more precise tools to visualize and track attentional capture.

The implications of this present research may be extended to CAD in medical imaging if we can demonstrate that the distractor-induced quitting effect is replicable in a laboratory setting. Eventually, this theoretical investigation of distractor-induced visual search effects may lead to future studies directly examining CAD as a potential distractor and methods for reducing the quitting effect and increasing observer accuracy.

Based on the results from Moher (2020) demonstrating the distractor-induced quitting effect and the Drew et al. (2012) eye-tracking study, we predicted in Experiment 1 that in the target-absent and distractor-present condition, the delayed onset of the distractor would reduce the total area of the scene viewed by the participant if they were inclined to quit visual search early. Additionally, we predicted that the number of items searched (fixations) and the total number of eye movements (saccades) would be reduced in the target-absent and distractor-present condition compared with the target-absent and distractor-absent condition. In accordance with Moher (2020), we also predicted that participants would commit more errors when both the target and distractor were present.

In Experiment 2, we predicted that the presentation of the salient object as the vertical target would exacerbate distractor-induced early quitting by reducing RT and increasing error rates on distractor-present, target-absent trials. Furthermore, we predicted that participants would have lower error rates on trials where the salient item was also the target.

Experiment 1

Method

Participants

Twenty participants from the ages of 18-25 were recruited to participate in this eye-tracking study, consistent with prior eye-tracking studies investigating computer-aided detection. Of the twenty participants, three identified as male, and seventeen identified as female. Two participants identified as Hispanic or Latino, and eighteen participants identified as Not Hispanic or Latino. Eleven participants identified as White, one participant identified as Black or African American, five participants identified as Asian, one participant identified as American Indian or Alaska Native and White, one participant identified as Black or African American and White, and one participant identified as Asian, Native Hawaiian or Other Pacific Islander, and White. The mean age of participants was 20.4 years. Participants were required to have normal or corrected-to-normal vision as well as normal color vision. Compensation was provided through one of two avenues: either course credit for introductory psychology students through the Connecticut College SONA system or paid participation with gift cards to Target, Amazon, or Walmart. Paid participants were primarily recruited through word-of-mouth as well as social media postings and were compensated at the rate of 20 dollars per hour.

Thirteen participants were compensated through course credit, while the remaining seven participants received paid compensation. All participants were enrolled Connecticut College students. The protocol was approved by the Connecticut College Institutional Review Board.

Procedure and Stimuli

The task was displayed to the participant on an ASUS computer monitor using MATLAB® and the Psychophysics Toolbox Version 3 (PTB-3). The experimenter monitor was located adjacent to the participant setup and was utilized to initiate calibration, validation, and drift correction procedures throughout the task. Behavioral data, including response time and error rates, were recorded in text files. Both eye and behavioral data were cleaned and sorted using MATLAB®. All eye data and text files were stored on the laboratory computer.

Participants were instructed to complete a series of 312 visual search trials for roughly 30 minutes. The first 12 trials were practice trials, and the remaining 300 were experimental trials divided into three blocks of 100 trials. To replicate the distractor-induced quitting effects, we roughly followed the methods of Moher (2020). We displayed eight items on the computer monitor on each trial. All eight items were displayed in a random location on a grid system, and the locations of the items would change from trial to trial.

In this version of the experiment, a target was defined as a vertical blue line. All other non-distractor items were also blue in color and tilted 30° to the left or right of vertical, consistent with a feature search task (e.g., searching for a vertical line among tilted lines). According to Rosenholtz et al. (2012), the feature search task is one of the simpler visual search tasks compared to other tasks like configuration search (e.g., searching for T targets among Ls) or conjunction search (see also Kanwisher, 1991; Treisman & Gelade, 1980; Treisman & Schmidt, 1982). The probability of target presence and absence was equal, and target presence occurred randomly. In the context of this experiment, a distractor was categorized as perceptually salient due to its red color, its larger size, as well as its delayed onset 100 milliseconds after the other seven items on the screen. These three features of the distractor mimicked the perceptual salience of computer-aided detection. Additionally, distractors appeared on a randomly selected 50% of all trials.

Participants were asked to use a keypress to indicate if the target (vertical blue line) was present. Participants were instructed to perform a keypress of the “m” key if the target was present or the “z” key if the target was absent. Pupil size and eye movements were monitored and recorded utilizing the Eyelink 1000® eye-tracking apparatus and software. Eye movement data were processed using Version 4.2.1 of the EyeLink Data Viewer software (2021). Two different types of eye movements were utilized to elucidate foveal attention in the feature search task: saccades and fixations. Saccades, or quick eye movements made when directing foveal attention to a new location in the scene, were determined by pre-determined velocity and acceleration thresholds in the Eyelink 1000® manufacturer settings (Hutton, 2021). The saccade velocity threshold for the Data Viewer software was 30.0°/second. The saccade acceleration threshold was 8000°/second^2. Additionally, both the fixation duration and saccade amplitude thresholds were 0°. Whenever the eye tracker detected that saccade velocity and acceleration thresholds were exceeded, a saccade was recorded in the Eyelink® Dataviewer system in a .evs file, along with information about the saccade such as amplitude, grid location in x- and y-coordinates, and start and end times. On the other hand, visual fixations were defined as a period of foveal stability during which observers processed visual information (Hutton, 2021). As with other eye-tracking measures like saccades, information about fixations, including average dwell time/duration, x- and y-coordinates, and start and end times, were also recorded in the DataViewer system in a .evs file.

In an effort to elicit high-quality eye-tracking data, participants were required to complete eye-tracking calibration and validation prior to beginning practice trials and also every 100 trials in Experiment 1. Participants were instructed to follow the movements of a white dot that shifted to nine different locations on the computer monitor to complete the calibration and validation steps. Participants were also instructed not to move their eyes off the dot until it had moved to the next location. Additionally, participants were instructed to complete a drift correction, or a secondary calibration check to correct for fixation drifts away from presented stimuli, every ten trials as well as after the two mid-task calibrations and validations to re-focus their fixation on a white dot in the middle of the screen. This consistent, scheduled reminder of where to focus on the computer monitor was designed to prevent frequent head movements or participant fatigue that could affect the reliability of the eye-tracking data.

Results

Experiment 1

Behavioral data

Accuracy.

Participants in Experiment 1 generally performed well on the feature search task (*M:* 96.33% accuracy, *SD*: 3.29%). A 2x2 within-subjects repeated-measures ANOVA was performed to analyze the effect of target presence/absence and distractor presence/absence on accuracy. A main effect of target was found, indicating that participants performed better when targets were absent (*M*: 99.5%, *SE*: 0.3%) than when targets were present (*M*: 93.2%, *SE*: 1.4%), $F(1,19) = 21.37$, $p < .001$, $\eta_p^2 = 0.53$. This result suggests that participants found the task easier when targets were absent. Furthermore, a main effect of distractor was found, indicating that participants had higher accuracy when distractors were absent (*M:* 97.2%, *SE*: 0.7%) compared to when distractors were present (*M*: 95.4%, *SE*: 0.9%), $F(1,19) = 15.08$, $p = .001$, $\eta_p^2 = 0.44$. Similarly, when distractors were absent, participants found the task easier. Lastly, a significant interaction between target and distractor was found, indicating that participants' accuracy markedly differed between distractor-present and distractor-absent trials in the target-present condition and remained similarly high in target-absent conditions, $F(1,19) = 8.87$, $p = .01$, $\eta_p^2 = 0.32$.

Paired-samples t-tests were conducted for further comparisons between conditions. If a target was present, participants' accuracy was higher if the salient distractor was absent (*M:* 94.8%, *SD:* 5.8%) than if the distractor was present (*M*: 91.6%, *SD*: 7.2%), $t(19) = -3.49$, $p = .002$. On target-absent trials, participants performed better when the distractor was absent (*M:* 100%, *SD*: 1%) than when the distractor was present (*M*: 99.28%, *SD*: 1.5%), $t(19) = -2.60$, $p = .02$. These findings suggest that the absence of targets and distractors increased accuracy. That is to say, participants performed better when task-relevant or salient objects were not present in the trial. These findings replicate the distractor-induced quitting effect in Moher (2020), as participants made more errors when distractors were present, but only on target-present trials. As such, the presence of distractors caused participants to miss targets that were present, which is a finding from Moher (2020) that was robustly reproduced in Experiment 1.

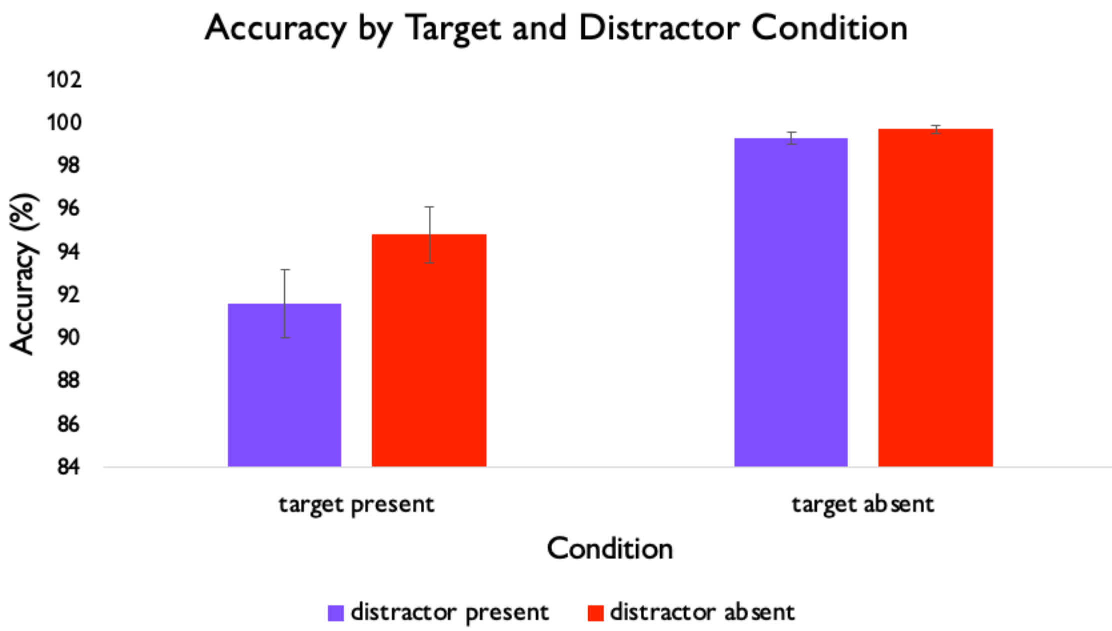

Figure 1 Accuracy by Target and Distractor Condition. Error bars were calculated using standard error.

Response time (RT).

Participants' average overall response time (RT) was 1.46 seconds (*SD*: 0.42 seconds). Similarly, a 2x2 within-subjects repeated-measures ANOVA was performed to analyze the effect of target presence/absence and distractor presence/absence on response time (RT). A main effect of target was found, suggesting that participants responded faster when the target was present (*M*: 1.12 seconds, *SE*: 0.05 seconds) compared to when the target was absent (*M*: 1.78 seconds, *SE*: 0.14 seconds), $F(1,19) = 49.49$, $p < .001$, $\eta_p^2 = 0.72$. This result suggests that participants could more quickly indicate their keypress response if a target was present. A main effect of distractor was not found, suggesting there was no significant difference in RT when the distractor was present (*M*: 1.43 seconds, *SE*: 0.09 seconds) or absent (*M*: 1.47 seconds, *SE*: 0.1 seconds), $F\ (1,19) = 2.36$, p = .14, $\eta_p^2 = 0.11$. However, participants' response times were differentially based on a significant interaction between specific target and distractor conditions, $F(1,19) = 19.64$, $p < .001$, $\eta_p^2 = 0.51$. As such, the interaction between the presence or absence of targets or distractors resulted in significantly differing response times.

To further elucidate this significant interaction, a paired-samples t-test was conducted to examine the differences in RT between distractor-present and distractor-absent conditions on target-present trials. This within-subjects comparison revealed that participants took longer on distractor-present trials (*M*: 1.16 seconds, *SD*: 0.27 seconds) than distractor-absent trials (*M*: 1.08 seconds, *SD*: 0.24 seconds), $t(19) = 2.48$, $p = .02$. This finding demonstrates the attentional capture phenomenon, in which participants took longer to respond on target-present/distractor-present trials due to attentional capture by the salient distractor.

Critically, another paired-samples t-test revealed that when targets were absent, participants responded faster when distractors were present (*M*: 1.71 seconds, *SD*: 0.57 seconds) than when distractors were absent (*M*: 1.86 seconds, *SD*: 0.66 seconds), $t(19) = -4.02$, $p = .001$. This specific t-test comparison suggests that participants quit their visual search early when a distractor was present, replicating the distractor-induced early quitting effect robustly demonstrated in the three experiments in Moher (2020). The findings from the present study suggest that the distractor-induced early quitting effect can be reliably reproduced in an in-person laboratory setting.

In conjunction with the accuracy data, these results reveal that when the distractor was present, participants not only quit visual search early, but they also missed more targets and hence made more errors. This speed/accuracy tradeoff represented by the behavioral data in Experiment 1 suggests that participants experienced distractor-induced early quitting when the distractor was present.

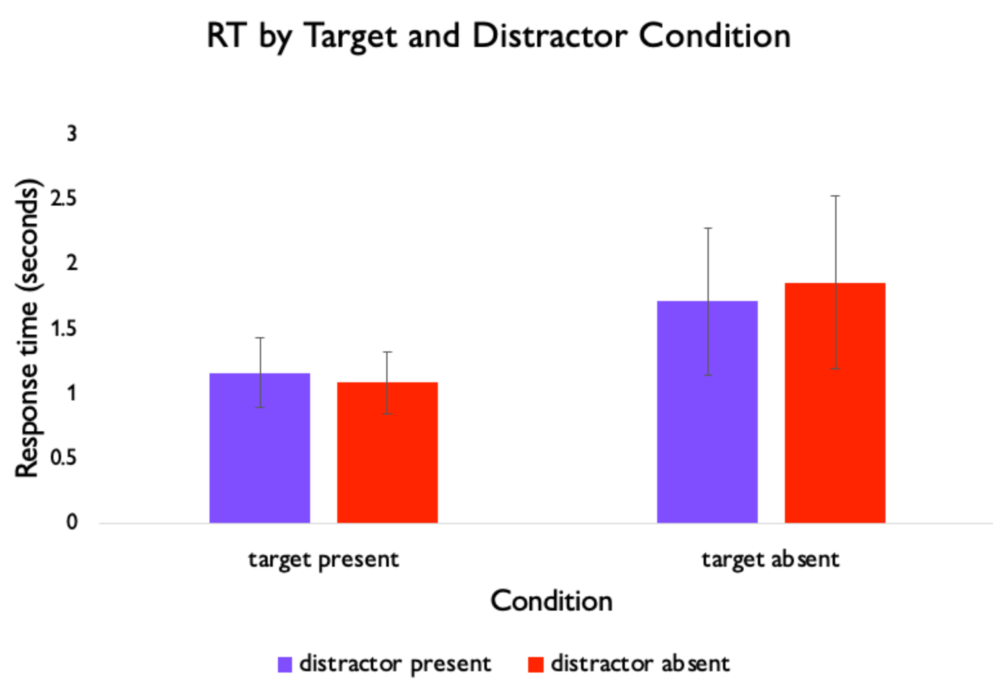

Figure 2 Response time (RT) by Target and Distractor Condition. Error bars were calculated using standard error.

Eye-tracking

Total fixations.

In Experiment 1, a 2x2 within-subjects repeated-measures ANOVA was performed to analyze the effect of target presence/absence and distractor presence/absence on total fixations, or the number of fixations on items in each trial. A main effect of target was found, indicating that participants fixated on more items in the feature search task when targets were absent (*M*: 8.58, *SE*: 0.47) than when targets were present (*M*: 5.02, *SE*: 8.58), $F(1,19) = 99.36$, $p < .001$, $\eta_p^2 = 0.84$. As such, the absence of a target as a task-relevant stimulus caused participants to fixate on more items in the feature search task. A main effect of distractor was also found, suggesting that participants fixated on more objects when the distractor was absent (*M*: 6.9, *SE*: 0.32) than when the distractor was present (*M*: 6.70, *SE*: 0.31), $F(1,19) = 4.361$, $p = .05$, $\eta_p^2 = 0.19$. This result signified that salient items such as the distractor caused participants to fixate on fewer items in the visual search task. Additionally, a significant interaction between target and distractor was found, indicating that participants' total fixations on distractor-present and distractor-absent trials differed markedly in the target-absent condition while remaining similarly low in the target-present condition, $F(1,19) = 23.941$, $p < .001$, $\eta_p^2 = 0.56$.

Paired-samples t-tests were also performed to compare specific within-subjects conditions. Further analysis of the comparison between target-present/distractor-present (*M*: 5.16, *SD*: 1.06) and target-present/distractor-absent (*M*: 4.89, *SD*: 0.83) conditions revealed a significant difference, with participants making more total fixations when both targets and distractors were present, $t(19) = 2.15$, $p = .045$. This finding illustrated that the concurrent presence of task-irrelevant, salient distractors on target-present trials elicited attentional capture.

Furthermore, the difference between the target-absent/distractor-present (*M*: 8.25, *SD*: 1.91) and target-absent/distractor-absent (*M*: 8.90, *SD*: 2.30) conditions was also significant, with fewer fixations recorded when the distractor is present, $t(19) = -4.58$, $p < 0.001$. The interaction between target and distractor, as well as the paired-samples t-tests, suggest that the presence of targets only increases fixations when distractors are also present. However, when targets are absent entirely, participants fixate on more objects in the feature search task. This effect is exacerbated when a distractor is not present. This new finding demonstrates that participants fixate on fewer items, and thus view less of the visual scene, when experiencing distractor-induced early quitting. This phenomenon is tantamount to a radiologist perceiving a salient distractor such as computer-aided detection and consequently viewing only part of an X-ray instead of the full image.

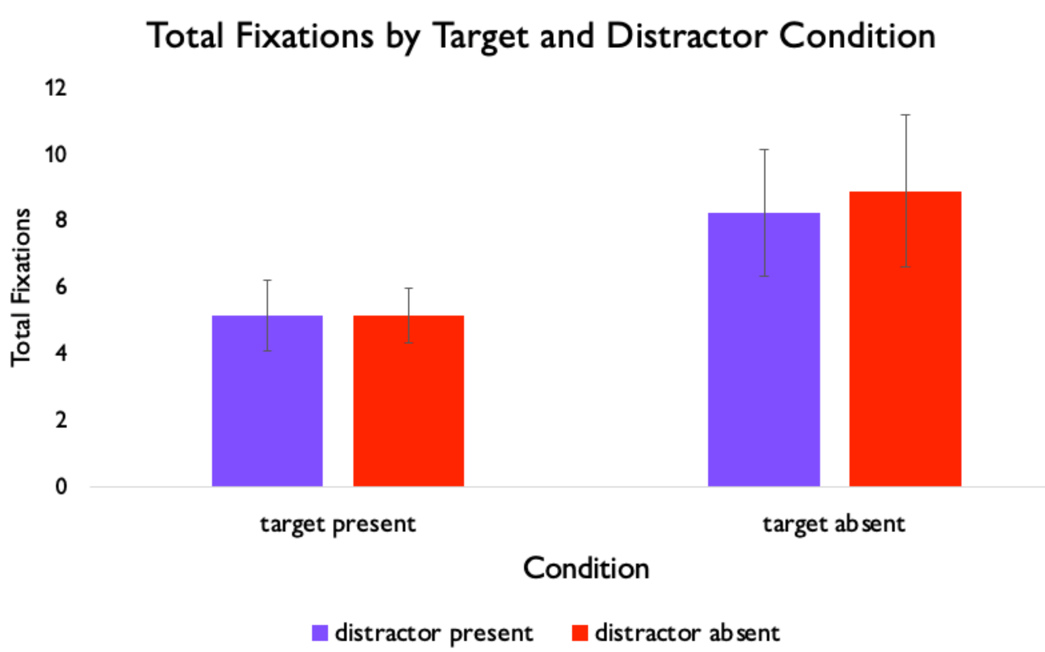

Figure 3 Total fixations by Target and Distractor condition. Error bars were calculated using standard error.

Total fixation duration.

Similarly, a 2x2 within-subjects repeated-measures ANOVA was also performed to analyze the effect of target presence/absence and distractor presence/absence on total fixation duration, or the length of time a participant fixated on objects in the visual search task. A main effect of target was not found, suggesting there is no statistical difference in total fixation duration when targets are present (*M*: 293.94 milliseconds, *SE*: 9.87 milliseconds) or absent (*M*: 291.56 milliseconds, *SE*: 8.06 milliseconds), $F(1,19) = 0.39$, $p = .54$, $\eta_p^2 = 0.02$. Similarly, a main effect of distractor was not found, which indicates that total fixation duration when distractors were present (*M*: 290.33 milliseconds, *SE*: 9.15 milliseconds) or absent (*M*: 295.17 milliseconds, *SE*: 9.10 milliseconds) did not significantly differ, $F(1,19) = 1.023$, $p = .32$, $\eta_p^2 = 0.05$. Furthermore, no significant interaction between targets and distractors were found in total fixation duration, $F(1,19) = 0.79$, $p = .39$, $\eta_p^2 = 0.04$. The lack of main effects or interactions suggests that participants' total fixation duration does not differ markedly between different conditions.

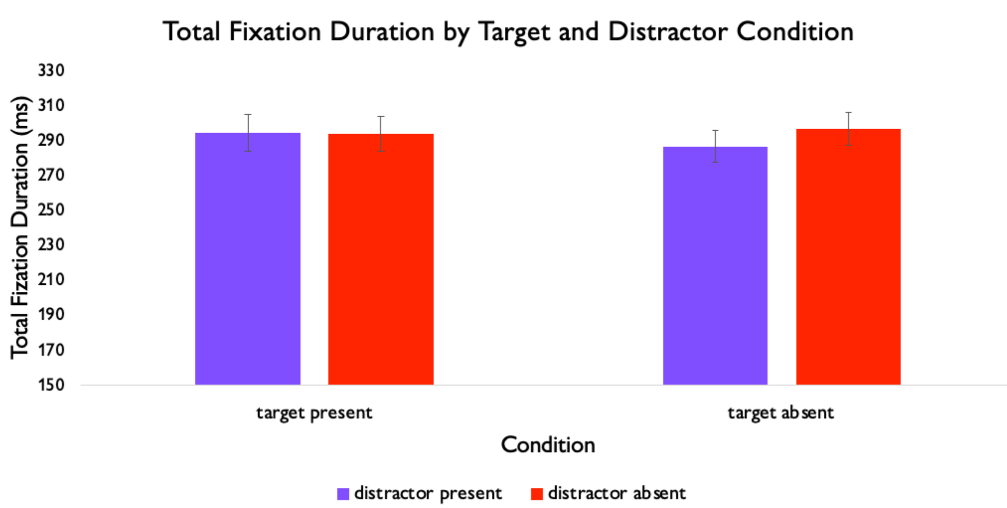

Figure 4 Total fixation duration by Target and Distractor condition. Error bars were calculated using standard error.

Total distractor saccade percentage.

Another 2x2 within-subjects repeated-measures ANOVA was run to analyze the effect of target presence/absence and distractor presence/absence on the total percentage of saccades that go to the salient distractor. The percentage of saccades to the distractor was calculated by examining if the first two saccades were within 100 pixels of the center of the distractor in both the x- and y-dimensions. Paired-samples t-tests were also performed to compare specific within-subject conditions. A random non-target item on distractor-absent trials was chosen to be the designated distractor to make comparisons between distractor-present and distractor-absent conditions. A main effect of target was found, indicating that a greater percentage of participants' saccades went to the salient or designated distractor when targets were absent (*M*: 14.1%, *SE*: 0.7%) than when targets were present (*M*: 11.8%, *SE*: 0.8%), $F(1,19) = 4.41$, $p = .049$, $\eta_p^2 = 0.19$). Additionally, a main effect of distractor was found, indicating that participants had a greater percentage of saccades go to the designated distractor on distractor-absent trials (*M*: 16.5%, *SE*: 0.7%) than on distractor-present trials (*M*: 9.4%, *SE*: 0.9%), $F(1,19) = 28.46$, $p < .001$, $\eta_p^2 = 0.6$. This result demonstrated that participants tended to avoid looking at the distractor when it was present and were more likely to saccade to a non-target object that was marked a "distractor" on distractor-absent trials. Furthermore, an interaction between target and distractor was discovered, again suggesting that a greater percentage of saccades went to the designated distractor when distractors were absent, $F(1,19) = 4.76$, $p = .04$, $\eta_p^2 = 0.2$. This effect was exacerbated when both targets and distractors were absent, suggesting that the effect of target on total distractor saccade percentage depends on whether distractors are present or absent, too.

Further analysis of these four conditions indicates that when targets are present, a greater percentage of participants' saccades go to the designated distractor when the salient distractor is absent (*M*: 14.04%, *SD*: 4.89%) compared to present (*M*: 9.59%, *SD*: 5.96%), $t(19) = -2.73$, $p = .03$. This paired-samples t-test supports the notion that participants avoided the distractor when it was present, realizing its irrelevance to the objective of finding the target in the task. Additionally, a paired-samples t-test was run to compare distractor-present and distractor-absent conditions on target-absent trials. It was found that a greater percentage of saccades went to the distractor when distractors were absent (*M*: 19.02%, *SD*: 4.85%) compared to when distractors were present (*M*: 9.25%, *SD*: 4.85%) on target-absent trials, $t(19) = -5.64$, $p < .001$. Again, this result reinforces the unique finding that participants avoided looking at the distractor on distractor-present trials. This effect of not looking at the distractor had a tremendous cost to participants' performance, as they made more errors on distractor-present trials.

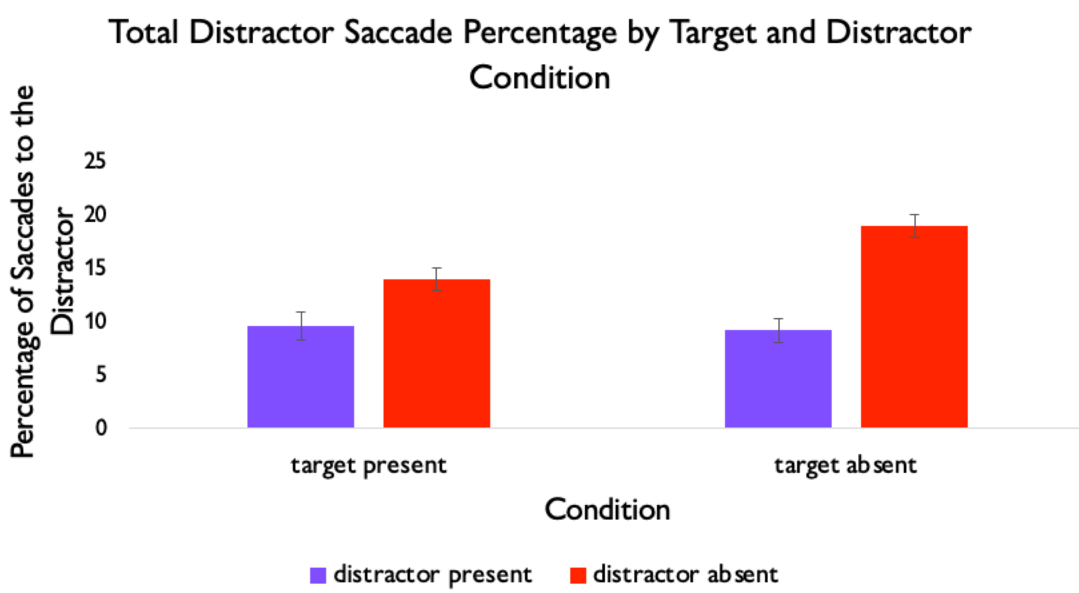

Figure 5 Total distractor saccade percentage by Target and Distractor condition. Error bars were calculated using standard error.

Discussion

In Experiment 1, distractor-induced early quitting was reliably replicated through behavioral results in accuracy and RT. Perhaps more critically, however, participants had fewer total fixations (e.g., viewed fewer items) on distractor-present, target-absent trials when distractor-induced early quitting was occurring. The present study was the first to examine the same task as Moher (2020) with eye-tracking. As a result, the fact that participants viewed less of the visual scene when experiencing distractor-induced early quitting elucidates that the presence of a distracting object causes participants to look at less of the rest of the image or visual scene.

Furthermore, results from the total distractor saccade percentage data suggest that participants tended to avoid looking at the distractor on distractor-present trials. Participants seemed to recognize that the distractor was task-irrelevant and thus were less likely to look at the distractor in the first two saccades of the trial. In conjunction with the total fixation results, the saccade finding was an unexpected result that demonstrated that participants not only look at fewer items when distractors are present, but they try to avoid looking at the distractors too.

Experiment 2

Method

Participants

Ten participants were recruited to participate in a subsequent eye-tracking study. Of the ten participants, nine participants identified as female, and one participant identified as a woman. In terms of racial and ethnic background, two participants identified as Hispanic or Latino, and the remaining eight participants identified as Not Hispanic or Latino. Seven participants identified as White, two participants identified as Asian, and one participant identified as American Indian or Alaska Native and White. The mean age for Experiment 2 was also 20.4

years. One participant was excluded for having approximately 50% accuracy on target-present, distractor-present trials. As with Experiment 1, participants were required to have normal or corrected-to-normal vision as well as normal color vision. Recruitment methods and compensation remained identical for Experiment 2.

Procedure and Stimuli

Participants were instructed to complete 324 visual search trials in a feature search task for approximately 45 minutes. As with the first experiment, the first 12 trials were practice trials. The remaining 312 trials were divided into three blocks of 104 trials. The main difference in Experiment 2 was that the salient item was also the target 50% of the time, appearing as a vertical line. This change made the salient object more task-relevant. Additionally, mid-task calibration and validation procedures took place every 104 trials. In all other respects, the procedure for data collection in Experiment 2 remained consistent with Experiment 1.

Results

Behavioral data

Accuracy.

Participants generally performed well on the feature search task (*M*: 96.26%, *SD*: 2.69%). A 2x2 within-subjects repeated-measures ANOVA was performed to investigate the effects of target presence/absence and distractor presence/absence on participants' accuracy. Trials where the target was salient were excluded from analysis and figures, but descriptive statistics were reported for these trials separately. Accuracy remained high on these trials, likely in part due to the salient nature of the target (*M*: 98.4%, *SD*: 2.49%).

A main effect of target was found, indicating that there was a significant difference between target-present (*M*: 89.2%, *SE*: 2.2%) and target-absent (*M*: 99.9%, *SE*: 0.1%) conditions in terms of accuracy. Participants performed better when targets were absent compared to when they were present, $F(1,8) = 23.03$, $p = .001$, $\eta_p^2 = 0.74$. This significant main effect is consistent with accuracy data from Experiment 1. Similarly, a main effect of distractor was also found, suggesting that there was a statistically significant difference between distractor-present (*M*: 92.5%, *SE*: 1.4%) and distractor-absent (*M*: 96.6%, *SE*: 1.0%) conditions. That is, participants responded more accurately when distractors were absent compared to when distractors were present, $F(1,8) = 19.08$, $p = .002$, $\eta_p^2 = 0.71$. This effect is also consistent with accuracy data from Experiment 1. Lastly, a significant interaction between target and distractor revealed that participants' accuracy markedly differed between distractor-present and distractor-absent trials in the target-present condition and remained similarly high in target-absent conditions, $F(1,8) = 16.56$, $p = .004$, $\eta_p^2 = 0.67$. Again, this result is consistent with a significant interaction for accuracy in Experiment 1. As with the previous experiment, these findings suggest that the absence of task-relevant stimuli makes the task easier for participants.

Paired-samples t-tests were also conducted to further explore the significant main effects and interactions by performing comparisons between specific conditions. On target-present trials, participants performed significantly better when distractors were absent (*M*: 93.24%, *SD*: 6.08%) compared to when distractors were present (*M*: 85.2%, *SD*: 8.28%), $t(8) = -4.23$, $p = .003$. This significant t-test comparison replicates Experiment 1 results. However, on target-absent trials, there was no significant difference in accuracy on distractor-absent trials (*M*: 100%, *SD*: 0%) compared to distractor-present trials (*M*: 99.86%, *SD*: 0.41%), $t(8) = -1.00$, $p = .35$. The lack of a significant t-test comparison on target-absent trials is inconsistent with Experiment 1 results, although this result may be partially explained due to the smaller sample size in Experiment 2. Despite this nonsignificant result on target-absent trials, the fact that participants made more errors on distractor-present trials still replicates the distractor-induced early quitting effect as described in Moher (2020). That is to say, participants still make more errors when distractors are present, but only on target-present trials. As was the case in Experiment 1 and the Moher (2020) experiments, the presence of distractors caused participants to miss targets that were present.

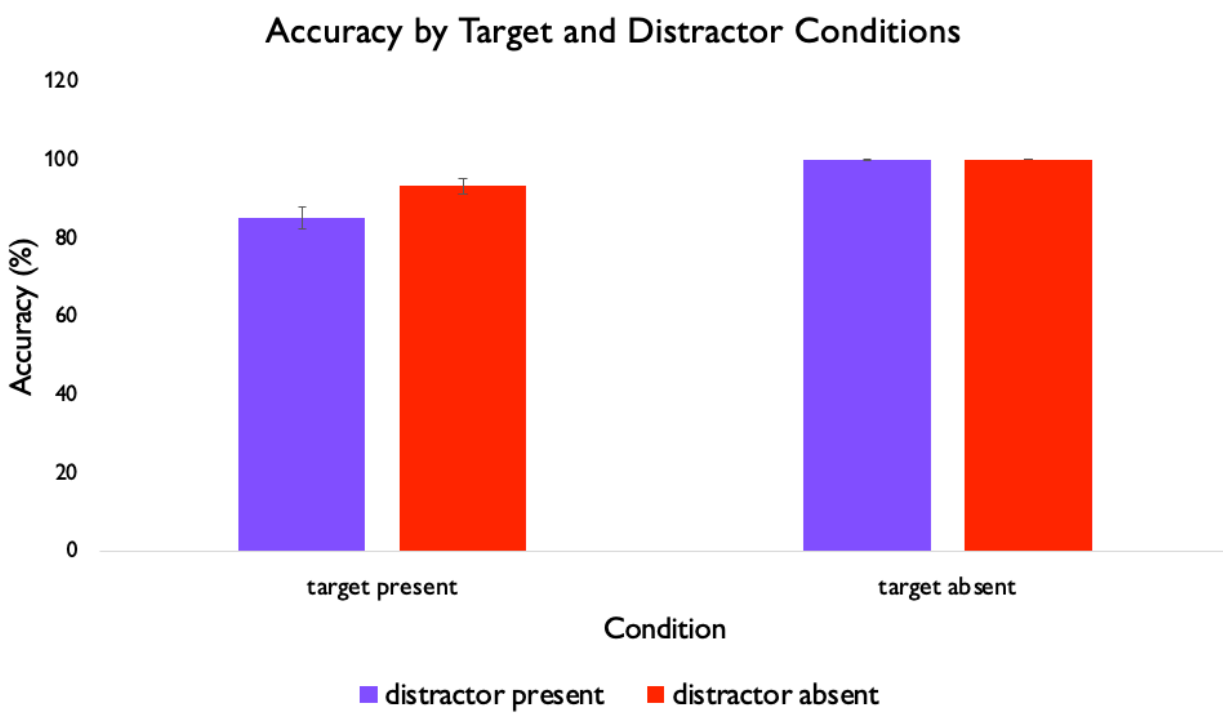

Figure 6 Accuracy by target and distractor condition. Error bars were calculated using standard error.

Response time.

The average response time for participants in the task was 1.39 seconds (*SD*: 0.33 seconds). Another 2x2 within-subjects repeated-measures ANOVA was conducted to examine the effects of target presence/absence and distractor presence/absence on participants' response times. Trials where the target was salient were excluded from analysis and figures, but descriptive statistics were reported for these trials separately. In this condition, participants generally responded quickly due to the salient nature of the target (*M*: 0.94 seconds, *SD*: 0.2 seconds).

A main effect of target was found, indicating that there was a significant difference between target-present (*M*: 1.13 seconds, *SE*: 0.09 seconds) and target-absent (*M*: 1.69 seconds, *SE*: 0.16 seconds) conditions in participants' response times. This result suggests that participants responded faster when a target was present compared to when a target was absent, $F(1,8) = 22.67$, $p = .001$, $\eta_p^2 = 0.74$. This significant main effect for target is consistent with Experiment 1 findings for response time. However, a main effect of distractor was not found, indicating that there was no significant difference in participants' response times when distractors were present (*M*: 1.43 seconds, *SE*: 0.12 seconds) and when distractors were absent (*M*: 1.39 seconds, *SE*: 0.10 seconds), $F(1,8) = 1.81$, $p = .22$, $\eta_p^2 = 0.18$. Again, this nonsignificant main effect of distractor is consistent with Experiment 1 findings for response time. In contrast, a significant interaction was found, indicating that participants' response times were differentially dependent on the interaction between specific target and distractor conditions, $F(1,8) = 11.62$, $p = .01$, $\eta_p^2 = 0.59$. As with the other repeated-measures ANOVA results for RT in Experiment 2, this significant interaction is consistent with RT data from Experiment 1.

Further analysis of t-test comparisons between specific conditions reveal that on target-present trials, participants responded faster on distractor-absent trials (*M*: 1.08 seconds, *SD*: 0.23 seconds) than distractor-present trials (*M*: 1.18 seconds, *SD*: 0.31 seconds), $t(8) = 3.23$, $p = .01$. However, on target-absent trials, there was no significant difference between distractor-present (*M*: 1.67 seconds, *SD*: 0.48 seconds) and distractor-absent (*M*: 1.70 seconds, *SD*: 0.46 seconds) trials, $t(8) = -0.87$, $p = .41$. As with the accuracy data in Experiment 2, the nonsignificant paired-samples t-test for target-absent trials is not consistent with Experiment 1 findings, although it numerically trends in the same direction as Experiment 1. With regards to the significant t-test comparison on target-present trials, participants responded faster when distractors were absent. This finding is indicative of the attentional capture effect, which was also demonstrated in Experiment 1. However, a larger sample size would be needed to explore if the inclusion of the salient target condition influenced the distractor-induced early quitting effect.

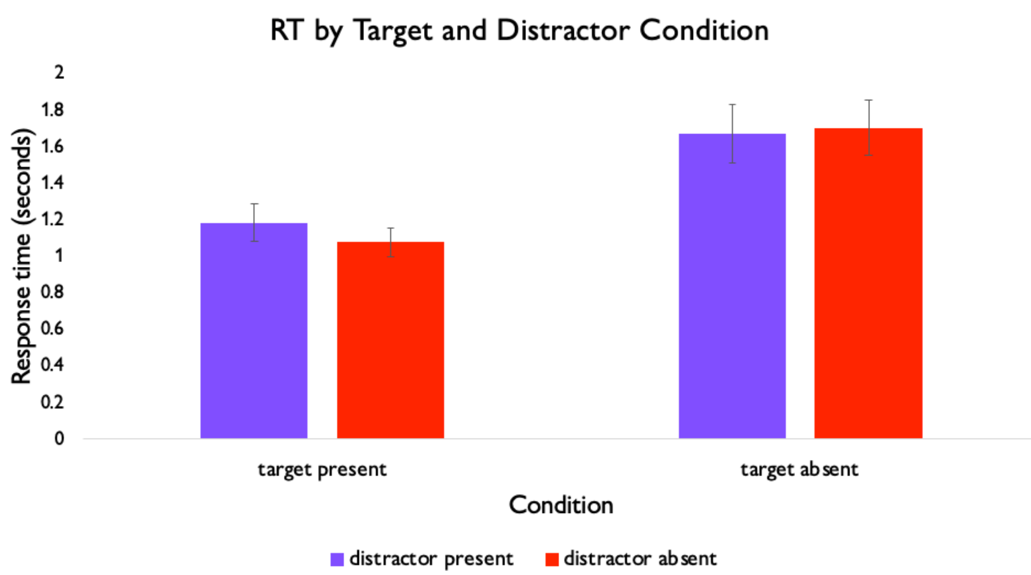

Figure 7 Response time by target and distractor condition. Error bars were calculated using standard error.

Eye-tracking data

Total fixations.

Similar to Experiment 1, a 2x2 within-subjects repeated-measures ANOVA was conducted to explore the effects of target presence/absence and distractor presence/absence on total fixations. Again, trials where the target was salient were excluded from analysis and figures, but descriptive statistics were reported for these trials separately. Due to the salient nature of the target in this condition, participants fixated on fewer stimuli (*M*: 4.09, *SD*: 0.62).

A main effect of target was found, indicating that participants fixated on fewer items in the task when targets were present (*M*: 4.9, *SE*: 0.29) compared to when targets were absent (*M*: 8.03, *SE*: 0.62), $F(1,8) = 39.633$, $p < .001$, $\eta_p^2 = 0.83$. This result suggests that participants explore less of the visual search scene when targets are present. Additionally, this significant main effect is in line with Experiment 1 results for total fixations. However, a main effect of distractor was not found, suggesting that the number of fixations in distractor-present conditions (*M*: 6.42, *SE*: 0.46) does not significantly differ from the number of fixations in distractor-absent conditions (*M*: 6.51, *SE*: 0.39), $F(1,8) = 0.23$, $p = .65$, $\eta_p^2 = 0.3$. This finding is inconsistent with the results for total fixations in Experiment 1, although this may be partially explained due to the small sample size of Experiment 2. In contrast, a significant interaction between target and distractor was found, suggesting that participants' fixations differentially depended on specific combinations of target and distractor conditions, $F(1,8) = 9.42$, $p = .02$, $\eta_p^2 = 0.54$.

Paired-samples t-tests were performed to analyze differences between groups further. On target-present trials, there was no significant difference in total fixations on distractor-present (*M*: 5.00, *SD*: 1.07) and distractor-absent (*M*: 4.79, *SD*: 0.74) conditions, $t(8) = 1.02$, $p = .34$. This result is inconsistent with total fixations findings from Experiment 1. Similarly, when targets were absent, there was no significant difference in total fixations on distractor-present (*M*: 7.84, *SD*: 1.93) and distractor-absent (*M*: 8.22, *SD*: 1.85) conditions, $t(8) = -1.94$, $p = .09$. Again, this result is inconsistent with the total fixation findings from Experiment 1. The interesting finding that participants fixated on fewer items in distractor-present conditions in Experiment 1 did not replicate in Experiment 2, although the lack of significant t-test comparisons may be due to the small sample size of nine participants for Experiment 2.

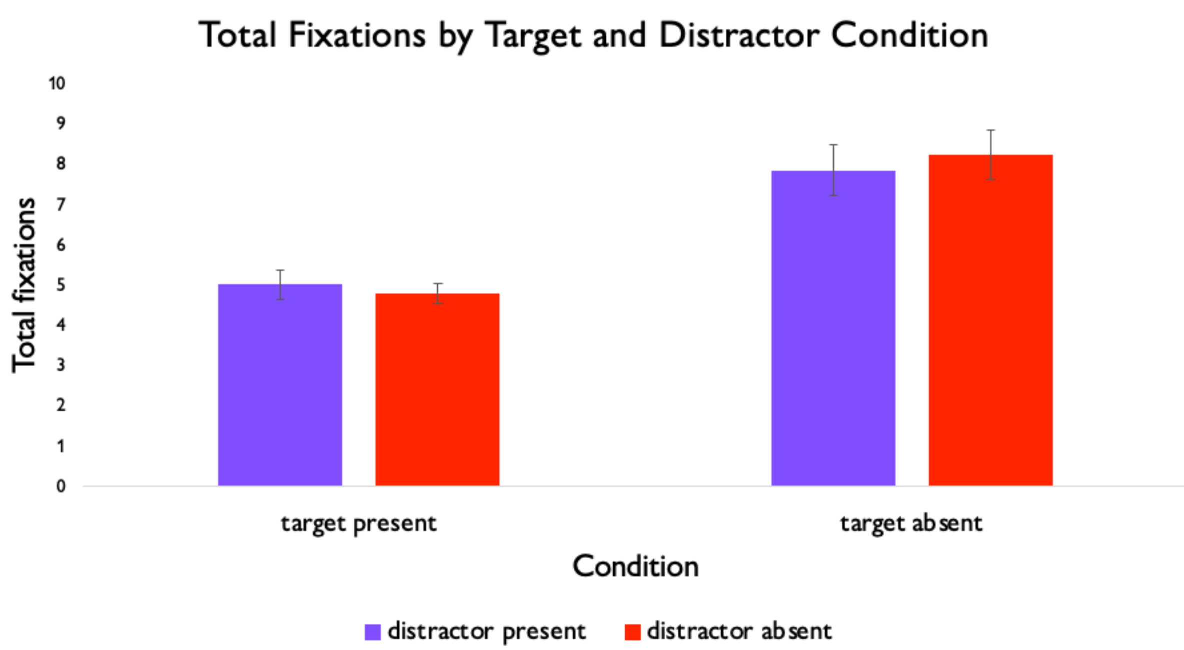

Figure 8 Total fixations by target and distractor condition. Error bars were calculated using standard error.

Total fixation duration.

A 2x2 within-subjects repeated-measures ANOVA was performed to examine the effects of target presence/absence and distractor presence/absence on total fixation durations. Trials where the target was salient were excluded from analysis and figures, but descriptive statistics were reported for these trials separately. Total fixation durations in this condition were generally shorter than in other conditions due to the salient nature of the target (*M*: 277.95 milliseconds, *SE*: 50.88 milliseconds).

A main effect of target was not found, suggesting that the difference in total fixation duration when targets were present (*M*: 297.89 milliseconds, *SE*: 15.76 milliseconds) and targets were absent (*M*: 285.05 milliseconds, *SE*: 16.71 milliseconds) was not significant, $F(1,8) = 2.173$, $p = .18$, $\eta_p^2 = 0.21$. Similarly, a main effect of distractor was not found, indicating that there was no significant difference in total fixation duration between distractor-present (*M*: 292.89 milliseconds, *SE*: 16.04 milliseconds) and distractor-absent (*M*: 290.25 milliseconds, *SE*: 16.20 milliseconds) conditions, $F(1,8) = 0.1$, $p = .76$, $\eta_p^2 = 0.01$. Additionally, an interaction between target and distractor conditions was not found. This result suggests that total fixation durations did not differentially depend on the interactions between specific target and distractor conditions, $F(1,8) = 0.22$, $p = .65$, $\eta_p^2 = 0.03$. Furthermore, these results are consistent with the lack of main effects or an interaction in total fixation duration in Experiment 1. These findings suggest that total fixation duration does not differ markedly between groups.

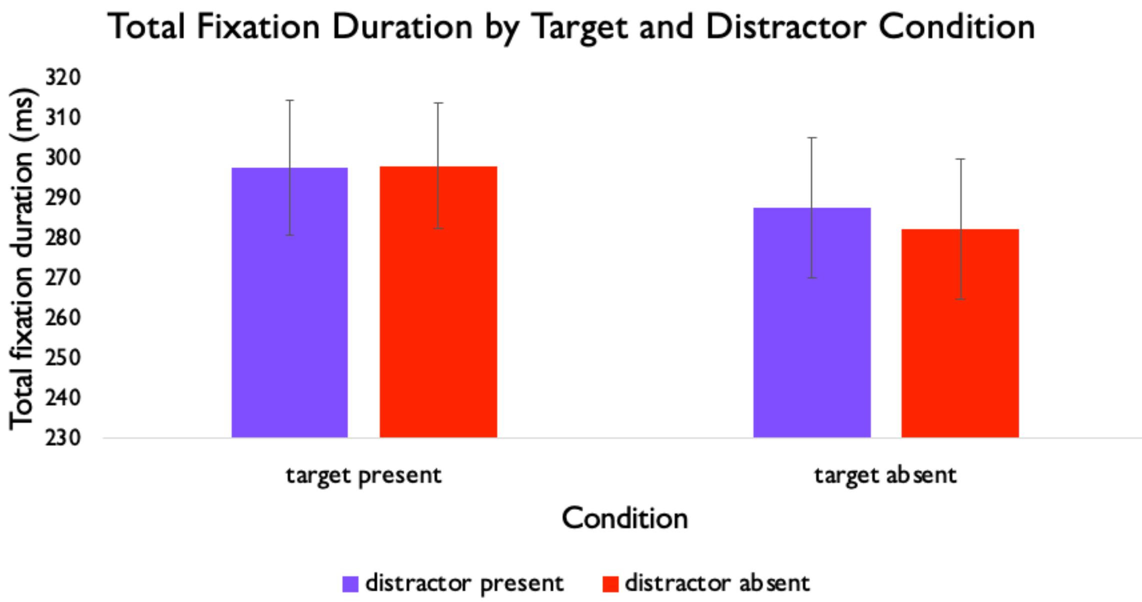

Figure 9 Total fixation duration by target and distractor condition. Error bars were calculated using standard error.

Total distractor saccade percentage.

A 2x2 within-subjects repeated-measures ANOVA was conducted to explore the effects of target presence/absence and distractor presence/absence on the percentage of saccades to the distractor. Trials where the target was salient were excluded from analysis and figures, but descriptive statistics were reported for these trials separately. Due to the nature of the target, participants reported a high percentage of saccades to the distractor (*M*: 69.71%, *SD*: 12.95%). As with Experiment 1, a random non-target stimulus was selected as the “distractor” on distractor-absent trials to enable comparisons between distractor-present and distractor-absent trials for this eye-tracking measure. A main effect of target was not found, indicating that there was no significant difference between target-present (*M*: 21.4%, *SE*: 2.3%) and target-absent (*M*: 23.9%, *SE*: 2.5%) conditions, $F(1,8) = 0.97$, $p = .35$, $\eta_p^2 = 0.11$. This result is inconsistent with Experiment 1 findings, although it numerically trends in the same direction.

In contrast, a main effect of distractor was found. This result suggests that there was a significant difference between distractor-present (*M*: 29.1%, *SE*: 4.0%) and distractor-absent (*M*: 16.2%, *SE*: 1.4%) conditions in total distractor saccade percentages. Unlike Experiment 1, this main effect of distractor suggests that participants made a greater percentage of saccades to the distractor when it was present rather than when participants made a saccade to the designated distractor on distractor-absent trials. This result could be explained by the fact that the salient item was also the target 50% of the time. Thus, the increased task relevance of the salient item may have affected whether participants were likely to make a saccade to the distractor.

Similar to the main effect of target, a significant interaction was not found between target and distractor in terms of total distractor saccade percentages. The lack of an interaction suggests that participants' total distractor saccade percentages were not differentially impacted by specific combinations of target and distractor conditions, $F(1,8) = 2.01$, $p = .19$, $\eta_p^2 = 0.20$.

Additionally, a paired-samples t-test was performed to examine the differences between specific conditions further. On target-present trials, there was a significant difference in participants' total distractor saccade percentages between distractor-present (*M:* 29.32%, *SD*: 11.5%) and distractor-absent (*M*: 13.5%, *SD*: 5.27%) trials, $t(8) = 4.31$, $p = .003$. This finding suggests that when targets were present, participants were more inclined to look at the distractor rather than saccade to a "designated distractor" on distractor-absent trials. Compared to Experiment 1, this paired-samples t-test comparison is significant in the opposite direction. However, this finding may reflect the influence of including a task-relevant salient stimulus in the feature search task.

Furthermore, a paired-samples t-test was conducted to explore differences in total distractor saccade percentages on target-absent trials. In this condition, there was no significant difference between distractor-present (*M*: 28.86%, *SD*: 15.14%) and distractor-absent (*M*: 18.87%, *SD*: 5.23%) conditions, $t(8) = 1.78$, $p = .11$. This finding is inconsistent with the results of Experiment 1 but may be partially due to the small sample size of nine participants in Experiment 2.

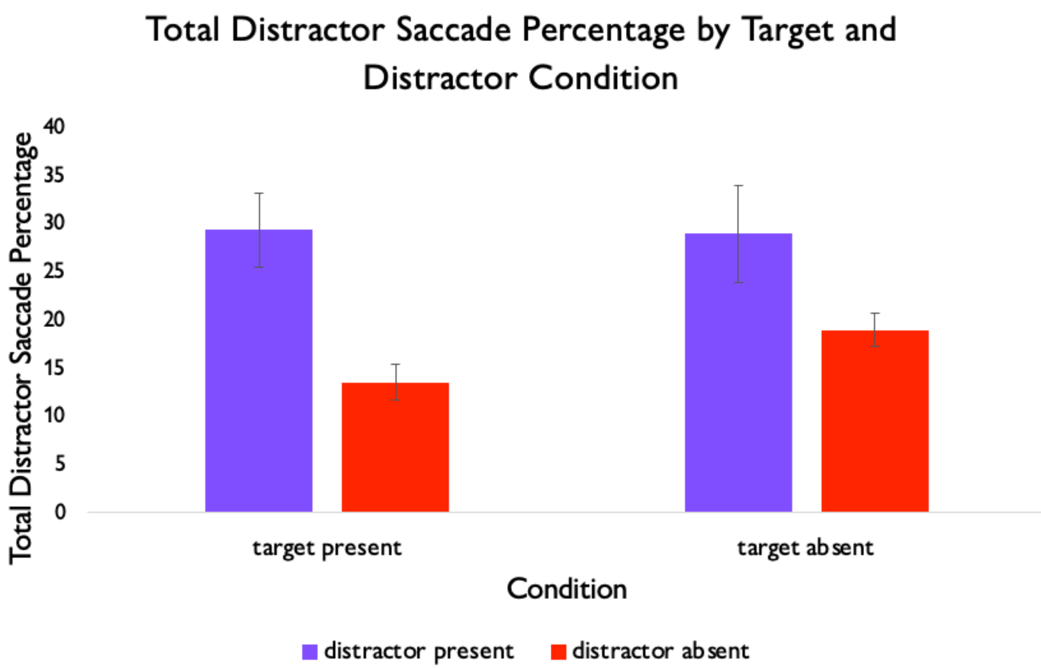

Figure 10 Total distractor saccade percentage by target and distractor condition. Error bars were calculated using standard error.

Discussion

Despite having 50% fewer participants than in Experiment 1, results on accuracy, response time on target-present trials, and the main effect of total fixations in Experiment 2 generally replicated Experiment 1. Some results differed markedly between Experiment 1 and Experiment 2, notably the lack of significant t-test comparisons in total fixations and the complete opposite main effect of distractor with total distractor saccade percentage. These results may be explained due to the modification to make the salient item more task-relevant or the small sample size.

Interestingly, the total distractor saccade percentage effect in which participants avoided looking at the distractor in Experiment 1 completely reversed in Experiment 2. This result could be due to the fact that the salient item was also the target 50% of the time, so participants were incentivized to saccade to the distractor in Experiment 2. However, the early quitting effect patterns were generally still present overall, even when the salient item was sometimes task-relevant.

General Discussion

In the present study, a feature search task similar to Moher (2020) and Yantis and Egeth (1999) was utilized to examine distractor-induced effects with eye-tracking. The purpose of this study was to understand the behavior of humans better when targets are not always present. Although always-present targets are commonplace in visual search tasks, they are not reflective of real-world conditions in which targets are rare, such as medical imaging and baggage screening.

In Experiment 1, the distractor-induced early quitting effect was robustly replicated with accuracy and RT data. Interestingly, total fixation data revealed that participants fixated on fewer objects when experiencing distractor-induced early quitting. This result is a novel finding that enriches the understanding of the distractor-induced early quitting phenomenon. Not only do we know that participants experiencing distractor-induced early quitting respond quickly and perform poorly, but they also fixate on fewer items in the task. Perhaps more surprisingly, participants tended to avoid looking at the task-irrelevant distractor in Experiment 1, as demonstrated by the total distractor saccade percentage data.

Subsequently, in Experiment 2, the distractor-induced early quitting effect could only be replicated in terms of accuracy due to the small sample size. The novel finding with total fixations did not replicate in Experiment 2. However, the total distractor saccade percentage data revealed an interesting reversal of the significant main effect of distractor as was previously demonstrated in Experiment 2. In fact, in Experiment 2, participants made more saccades to the distractor on distractor-present trials rather than saccades to the "designated distractor" on distractor-absent trials. The fact that the target was sometimes salient in the same manner as the distractor may have increased participants' likelihood of making a saccade to the distractor.

The results from Experiments 1 and 2 have tremendous implications on medical imaging, in which targets are rare but distractors such as computer-aided detection (CAD) may pose a significant risk through the distractor-induced early quitting effect. In particular, the total fixation and distractor saccade percentage data suggest that if this pattern held for radiologists, they would be more likely to view less of the medical imaging scene and avoid the region in which the CAD cue was deployed. In the cases in which CAD correctly signaled to a region where a target may be present, avoiding looking at distractors can have life-threatening consequences for patients.

One potential solution to errors in the detection of low prevalence cancers recently explored by Kunar (2022) is the use of interactive CAD. In this study, naïve observers were assigned to an automatic condition, in which CAD cues appeared at the same time as the visual search display, or a confirm condition, in which participants were shown the entire visual scene before CAD cues were deployed. The confirm condition was designed to create an interactive CAD format. Kunar (2022) found that the confirm condition demonstrated fewer miss errors, which could be one method of improving the effectiveness of CAD. Future studies could also incorporate a similar interactive CAD system to test if this modification of the technology could eliminate the distractor-induced early quitting effect.

Furthermore, future research should focus on the potential to use more medical-like images as the visual scene background to represent better what computer-aided detection looks like to radiologists. Eventually, it would be helpful to replicate this experiment with radiologists. Additionally, preliminary research on offset distractors has suggested that removing a salient distractor after the participant made a saccade to the distractor can attenuate the distractor-induced early quitting effect (Pendergast, 2022). Accordingly, future studies in computer-aided detection could utilize offset distractors to attempt to solve the issue radiologists have been facing utilizing this imperfect artificial intelligence technology in the clinic.

Additionally, research on distractor-induced early quitting could be extended to any instance of a computer delivering a salient signal to a human participant in a visual search task. Notably, baggage screening is another area where missing rare targets due to the presence of a distracting salient signal could have deleterious consequences on the safety of airplane passengers and crew. Interestingly, Muhl-Richardson et al. (2021) reported that “targetless” visual search tasks could be effectively utilized to train Transportation Security Administration agents in baggage screening. This study was helpful in getting trainees to become comfortable with the low prevalence of targets (e.g., weapons or other prohibited items) in everyday baggage screening. Although the Muhl-Richardson et al. (2021) study is useful for occupations where target prevalence is very low, it is essential first to study how targets and distractors interact in low target prevalence conditions before extending the applications to the field, as the present study sought to do.

One major limitation for Experiment 2, in particular, was the small sample size. Twenty participants were recruited for Experiment 1, consistent with the minimum sample size needed for similar eye-tracking studies. However, Experiment 2 was only able to recruit ten participants, of which one had to be excluded due to poor accuracy on target-present/distractor-present trials. Additionally, many participants in both Experiments 1 and 2 reported visual fatigue, especially during the second and third blocks. Occasionally, some participants would begin to close their eyes as if they were falling asleep, and the experimenter would have to gently remind the participants to stay alert during the feature search task. This participant-related visual fatigue may have influenced the data, as more alert morning participants could have performed better than afternoon participants exhausted from a long day of school or work. This issue could likely be solved by instituting more breaks during the task or consistently recruiting participants for morning slots when participants are expected to be the most alert.

The present study demonstrates the robust nature of the distractor-induced early quitting effect when targets are rare. The replication of distractor-induced early quitting in an in-person laboratory setting with accuracy and RT data in Experiment 1 provides validity to the Moher (2020) study. Moreover, the novel findings on fewer total fixation in distractor-present, target-absent trials and fewer saccades to the distractor in distractor-present trials in Experiment 1 provide insight into how eye movements are linked to distractor-induced early quitting. Ultimately, this newfound knowledge can hopefully be utilized to understand the shortcomings of computer-aided detection better and create solutions to problems with real-world consequences.

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