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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 36(36)

ISSN
1069-7977

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Publication Date
2014

Peer reviewed

The Effect of Immediate Accuracy Feedback in a Multiple-Target Visual Search Task

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Abstract

Visual search is one of the most common behaviors in daily life. Studies of visual search, however, have mainly focused on how visual properties of stimuli affect search efficiency. The current study examined the effects of immediate auditory feedback for each selection during a multiple-target visual search task. In a feedback condition, one of two different sounds was played, indicating whether the subject had reported a correct detection, i.e., was fixating a target. In the neutral sound condition, subjects always received the same sound, regardless of whether they had visually selected a target or a distractor. We analyzed overall performance measures such as trial duration and the proportion of correct target detections and correctly completed trials. Furthermore, we analyzed pupil size as a measure of cognitive effort. The results show that pupil dilation was greater and search accuracy was better when subjects were given feedback than when they only received a neutral sound. In summary, the present study demonstrates that immediate feedback may increase cognitive effort, leading to more accurate task performance, with enhancement of specific components of search behavior.

Keywords: Attention; visual search; eye movements; pupil dilation; auditory feedback.

Introduction

Visual search is arguably the most common task in our daily life. It has therefore received substantial research interest, with a focus on the factors that may affect the search performance. In a typical visual search task, participants are asked to report if a visually distinctive target is present among a set of distractors in a given scene. The gauge for the task difficulty is the accuracy and the "search slope", i.e., the slope of the response time (RT) that typically increases linearly with greater search set size. Wolfe (1998) used the term "search efficiency" as a term describing how search for a target can be influenced by distractors being added to the visual search display. Most studies of visual search have varied either the visual features of the stimuli or the prior experience participants bring to the task. For example, Duncan and Humphreys (1989) manipulated the similarity between targets and distractors in their study, and Cohen and Ivry (1991) used the density of objects to vary the search difficulty instead. Variation in previous knowledge included experiments in which the features (i.e., color or shape) of the target and distractors were maintained from trial to trial and then were reversed unpredictably (Bravo & Nakayama, 1992).

Another way of influencing visual search performance is the presentation of feedback to the subject. Feedback was used in many previous studies after each trial only to indicate if the trial has been passed or failed (see Bravo & Nakayama, 1992; Donnelly et al., 2007; Giesbrecht, Sy, & Guerin, 2013). Such "between trials reinforcement" rarely occurs in the real world. That is, during natural viewing, observers typically bring their line of sight to the location of an expected search target. If the fixated object is consistent with their initial expectation, observers will keep the same viewing strategy. Otherwise, the search strategy has to be modified. These confirming and modifying processes based on the instant feedback seem to be commonly used in our search performance. The role of feedback on this sequential search behavior, however, is not well understood.

Some prior studies have found that receiving feedback can facilitate search performance. Chun and Wolfe (1996) suggested that viewers use feedback to set their decision criterion in visual search tasks. This feedback can either be implicit (the viewers already know they were correct because they were able to identify the target) or explicit (the viewers are told whether they were correct or incorrect). Wolfe et al. (2007) showed that explicit feedback can have an impact on tasks with low target prevalence, i.e., tasks in which targets appear infrequently and typically yield high proportions of missed targets. Schwark, Sandry, MacDonald, and Dolgov (2012) examined the effect of false feedback on finding targets in a visual search task. They controlled participants' perceived number of misses through explicitly misleading feedback. In the false-feedback condition, participants were falsely informed that they had missed a target even though they had indicated "target absent" correctly. Their result indicated that participants committed a higher number of false alarms due to a shifted criterion but they were able to find low prevalence targets more successfully. Though these studies have shown that feedback can change searchers' decision criterion and thereby affect search performance, they only used feedback after each trial. As noted above, however, in natural viewing we rarely receive feedback after search performance is terminated. In fact, we normally receive visual feedback on each fixation. This within-trial based feedback has been neglected in most studies.

Finally, it is also important to note that sound can affect search performance. Only very few studies investigated the effect of the sound presented during visual search.

Iordanescu and Grabwecky (2008) demonstrated that characteristic sounds facilitated visual localization of objects. For example, their experiment showed that finding an animal's picture was easier when the sound of the animal was played during scene presentation. In addition, sound did not help find the animal's written name. Other studies showed that search performance was improved when a sound was presented at the location of a visual target in a simultaneous manner (e.g., Bolognini, Frassinetti, Serino, & Làdavas, 2005; Frassinetti et al., 2002; Stein, Meredith, Huneycutt, & McDade, 1989). These studies examined the auditory-visual interactions during visual search but did not answer the question on how online auditory feedback during visual selection can help ongoing visual search. Auditory presentation of such feedback would be most appropriate as it does not directly interfere with the visual task.

Our study used auditory feedback during visual search and examined its effect on overall search accuracy. To investigate how the instant feedback may affect the sequential search performance, subjects were asked to search for multiple targets among a set of distractors and make a response by key press whenever they found a target. Different types of auditory feedback were given after the response to indicate whether they made a correct detection. To balance any prolonged time or any difference in oculomotor response due to the key press, a control condition was run in which only a neutral sound was given regardless of whether subjects made a correct response or not. By using the auditory signal as an online feedback during the sequential search, we may be able to dissociate the dual visual processes (i.e., confirming the currently fixated object and planning where to go next) within a single fixation. If online feedback does play a role in determining sequential search performance, we should see the difference in either search efficiency or any eye movement variables. After each trial in either condition, participants notified with a feedback sound if the trial has been passed or failed. This between trials feedback was given to avoid the uncertainty in the blocks with the neutral feedback vs. the blocks with the auditory feedback.

In visual search tasks, attention has been known to contribute to performance (Helmholtz, 1968). Moreover, Palmer, Ames, and Lindsey (1993) measured the effect of attention on simple visual search by testing experimental models using different set sizes. They found that attention affects the decision process but not the perceptual process.

A useful tool to measure the attentional and most behavioral activities during visual search is pupillometry. Using this measurement technique allows the study of moment-to-moment deployment strategies during visual search and monitor cognitive load during the course of a search process even when feedback is involved. For example, Hess and Polt (1964) studied the pupillary response of people engaged in performing mental arithmetic problems of increasing complexity. They found that the level of presentation of the problem correlated positively with pupil diameter (see also Ahern & Beatty, 1979). Pupillary dilation appears to be a function of the cognitive effort and attention required when individuals perform a visual task (see Porter, Troscianko, & Gilchrist, 2007) and it specifically reflects the cognitive effort required to perform in complex visual tasks (Verney, Granholm, & Marshall, 2004). By testing any difference of timing and pupil size across the two feedback conditions, we hope to clarify the role of online feedback in our daily visual performance.

Method

Subjects

Eleven subjects, aged between 19-32 years old, were tested. All had normal or corrected to normal vision and were naïve as to the purpose of the study. Each subject received a $10 honorarium.

Apparatus

Eye movements were tracked and recorded using an SR Research EyeLink-2k system. Its sampling frequency was set to 1000 Hz. Stimuli were presented on a 22-inch ViewSonic LCD monitor. Its refresh rate was set to 75 Hz and its resolution was set to 1024 x 768 pixels. Participant responses were entered using a keyboard.

Stimulus display

A total of 120 displays (1024 x 768 pixels) were generated by a MATLAB script. Each display was composed of 32 Gabor patches (27 distractors and 5 targets) pasted on a gray background, each with a radius of 1 degree. The distractors were oriented randomly other than vertically or horizontally and the targets were oriented vertically or horizontally. The orientations of targets in the same trial were identical. To make sure that the objects did not overlap, we set a minimum distance of approximately 3 degrees between the centers of any two Gabor patches. A sample stimulus is shown in Figure 1.

The target orientation (horizontal or vertical) was randomly selected for each trial. To investigate the effect of instant auditory feedback on search performance, two feedback conditions were tested: One was an auditory feedback condition in which two types of sounds were used to indicate whether the response subjects made (about finding an individual target) was correct or not. The other was a control condition in which subjects always received an identical sound whenever they made a response. Subjects performed 10 trials per block and 6 blocks in each condition (1 for practice and 5 for the real test), and both conditions were presented in an alternating order.

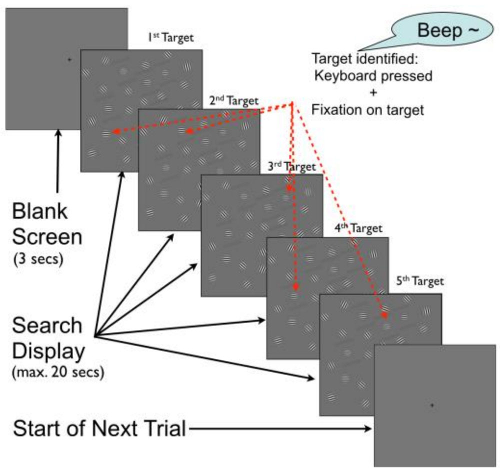

Figure 1. Sample trial and target items for a search task that produces sound as a feedback signal for each target selection during the search.

Procedure

An instruction screen was shown before each block to inform participants about the type of the feedback condition. Each image display was only presented once to each subject, either in the auditory feedback condition or in the neutral sound condition.

Before the actual experiment, subjects had one block of practice in each condition. During each trial, subjects were instructed to search for the five targets and press the 'x' key on the keyboard when they fixated on the target. After they heard a sound (either feedback or neutral sound), they were to continue searching for the next target in the display. The next trial would begin once subjects pressed the space bar to indicate that they found all targets or the stimulus had been shown for 15 seconds (timeout).

Data Analysis

Our analysis only included the correct trials in which participants found the five targets. This was decided because trials with responses within less than five targets might add noise to the analysis.

The responses were identified as either a hit or a miss based on the eye fixation made during the button press. Participants were trained to look at the item that they identified as a target while they pressed the key on the keyboard. Some fixations landed on the blank area rather than on any search item. When this happened, we assumed this fixation to be aimed at the nearest item, i.e., the one whose center had the shortest Euclidean distance to the current fixation location. If the Euclidean distance was greater than a threshold which was set to 3.8 degrees, the fixation was not assigned to any of the items. In addition, a target response was considered a hit if subjects fixated on the target while making a response on the keyboard. A miss was counted if a selected item had already been previously selected during the same trial (a revisit), or the fixation during the response was on a distractor.

Experimental Results and Discussion

Search Performance

Reaction time. We analyzed the reaction times (RTs) that were measured from the onset of the image display to the space bar response that participants used to indicate task completion, i.e., having found all five targets. The average RT in the auditory feedback condition was 13.05 s, which was slightly, but significantly longer than in the neutral sound condition (12.53 s), $t(10) = 2.37$, $p = 0.039$.

Overall Accuracy. Search accuracy was measured by the proportion of correct trials, in which all five targets were found. Overall search accuracy for participants in the auditory feedback condition was 79.5%, while they only achieved 67.7% in the neutral sound condition, $t(10) = 3.52$, $p < .05$.

Eye Movements

The most essential question in the current study is whether and how the online instant feedback can affect search performance. In order to examine how auditory feedback can help visual search, we compared the time interval between two consecutive correct responses in both conditions, that is, how long it took to find the next target once a correct response was made. The probability of two consecutive target responses with each correctly reporting a target was above 90% for both conditions. Figure 2 shows that the average search duration between two hits (correct detection) was 250 ms faster in the auditory feedback (2.02 sec) than in the neutral sound condition (2.27 sec) across all participants, $t(10) = 3.46$; $p < .05$.

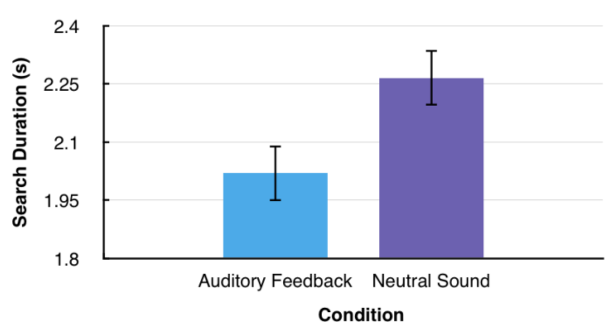

Figure 2. Search duration between two correct target responses. Error bars indicate standard error of the mean.

This result suggests that auditory feedback facilitates search performance and helps subjects find the next target faster. Note that the time we measured here was between two correct detections as reported by key press and did not consider the duration for each fixation on the target. Thus, it is likely that the greater search efficiency in the feedback condition we found (see Fig. 2) was not due to the longer pause duration before key press. To examine this possible confound, we compared the gaze duration on a target when subjects made a response between both conditions. The results show that the average gaze duration when fixating on a target while making a response was similar between the two conditions. The average gaze duration for all participants was 700 ms for auditory feedback and 680 ms for the neutral sound, which was not a statistically significant difference, $t(10) = 1.02$, $p > 0.1$. This implies that the better search efficiency we found (see Fig. 2) was not due to the longer planning time but some other cognitive factors.

Since the better performance evidently did not result from the longer fixation duration on target items, it is possible that subjects may have devoted more attentional resources to the search process when they received positive feedback during the search. To test this hypothesis, we compared the pupil size to investigate whether different cognitive effort was devoted depending on the feedback condition during the continuous visual search. For this purpose, the mean pupil size (in pixels in the camera image) was computed during each trial.

Figure 3 shows that pupil dilation was greater in the feedback condition than in the control condition, $t(10) = 6.59$, $p < .05$. This finding suggests that subjects did spend more effort on search when they received feedback than when they received neutral sound.

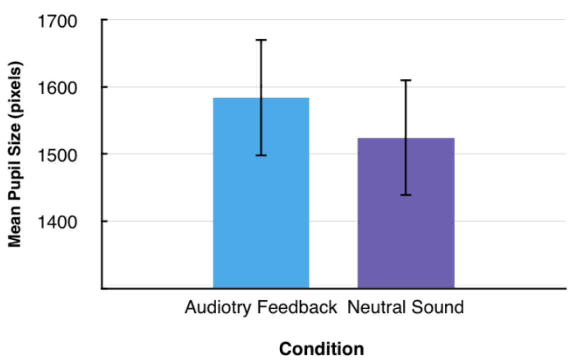

Figure 3. Mean pupil dilation for each of the experimental conditions. Error bars indicate standard error of the mean.

In order to further investigate how the cognitive resources were distributed throughout the search process, we examined the participants' pupil size when they performed the search task during their search for each individual target. For example, we measured the mean pupil size from the start of the trial to the first target detection response. Then, we measured the mean pupil size from the search that began after the first hit to the next hit (for the second target), and so on, until the fifth target. The average pupil size was taken, and its mean across subjects is shown in Figure 4.

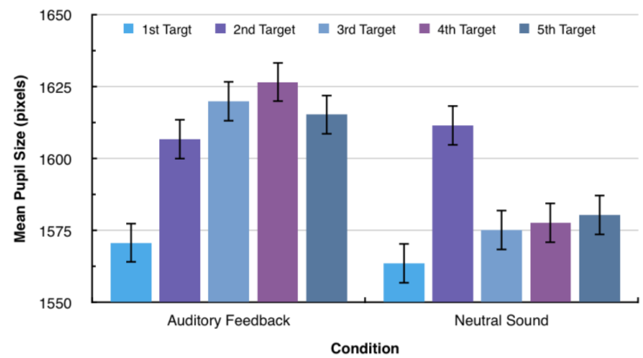

Figure 4. Mean pupil dilation per each correct response interval during the search task. Error bars indicate standard error of the mean.

Paired-sample t-tests were conducted to analyze the difference in mean pupil size for each individual search interval. This difference in pupil size between the two conditions was significant starting at the search for the third target until the fifth target, all $ts(10) = 2.77$, $ps < .05$. It thus seems that the effect of the auditory feedback was not present before detecting the first target, i.e., before receiving the first feedback signal. Due to the delay of the cognitive pupil response, only after detecting the second target, subjects showed a significant pupillary response to the auditory feedback, having a significantly greater pupil size in the auditory feedback condition.

Conclusions

The goal of the present study was to investigate how instant feedback during a sequential search task could affect search performance by using moment-to-moment auditory feedback during the search rather than only providing the feedback after each trial. The link between cognitive load and search efficiency had been the subject of several previous studies (e.g., Schwark, Sandry, MacDonald, & Dolgov, 2012). Our study yielded novel insight by using immediate, auditory feedback. Similar to the prior studies, we also used pupil size as the main measure to test how cognitive load may vary during search.

Our results show that providing online instant feedback during the sequential search task improved the search performance and helped subjects find the next target faster. Interestingly, this increase in search efficiency was not due to the longer pause duration associated with target responses as suggested by other studies on visual selection, in which the longer planning time could result in a better target selection (Cohen et al., 2007; Wu & Kowler, 2013). Instead, the better performance was likely due to the greater cognitive effort. That is, when the feedback was provided, the pupillary dilation increased, indicating that more attentional resources may have been devoted than when only neutral sound was provided in the control condition.

In addition, when the pupil size data were categorized for each individual target search interval (Fig. 4), the difference between the two conditions became even more prominent. In the early stage of search, both conditions may have involved similar amounts of attentional resources so that there was no difference in the pupil size while searching for the first two targets found. However, after the second target was found, more attentional resources seemed to be used in the feedback condition than in the control condition. Moreover, the amount of attentional resources devoted on each target was not uniform. The increase in pupil size in the feedback condition can also imply the more pronounced use of working memory in the planning of the sequential search task.

It is possible that in the feedback condition, subjects tried to focus more strongly and spent more time correcting their mistake whenever a false alarm occurred, and this may require slightly more time to complete the trial. Note that we do not claim that once more cognitive effort was devoted, the search process would be facilitated by improving the selection for the next saccade. That is, it is unlikely that the sensitivity of subjects' peripheral vision could be enhanced by the correct feedback to help localize the target, since the Gabor patches used in the current study were too small to be distinguished without directly fixating it. Nevertheless, the feedback may enhance other visual processes. To understand which factors contribute to this improvement of search efficiency, further studies are needed.

In summary, the present study demonstrates that immediate auditory feedback leads to more accurate but overall slightly slower search, with enhancement of specific components of search behavior. The increased effort observed in the feedback condition might have mediated the accuracy effect, but further work is required to make this causal connection.

Our technique was able to improve the cognitive engagement as suggested by the greater effort being devoted to the search task, even though the fixation time on the items in both conditions was similar.

Acknowledgments

Part of the study was supported by Grant R01 EY021802 from the National Institutes of Health (NIH) to Marc Pomplun. We would like to thank the Saudi Arabian Cultural Mission - Ministry of Higher Education for supporting the first author with a Ph.D. scholarship awarded to her.

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