한국심리학회지 : 인지 및 생물
The Korean Journal of Cognitive and Biological Psychology
2015, Vol. 27, No. 2, 253-274

Adaptive visual search in the distractor previewing effect: Focusing on feature previewing history and task context*

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The nature of adaptive visual search was investigated using the distractor previewing effect (DPE). In a color oddball search task, search times increase for targets whose colors were previewed in a preceding target-absent display (TAD) compared to distractors whose colors being previewed in the TAD. Thus, target-color previewing (TP) trials are typically slower than distractor-color previewing (DP) trials, and this response time (RT) difference is the DPE. For the purpose of the study, color previewing history was varied to examine temporal integration of visual experience with trial-by-trial adjustments being simultaneously made, and task context were manipulated to induce (un)predictable target appearance times. TADs ranging from 0 to 5 (Exp. 1) or from 0 to 2 (Exp. 2) were presented prior to a target-present display, and the number of TADs was blocked (Exp. A) or randomized (Exp. B), resulting in four experiments 1A, 1B, 2A, and 2B being conducted. All experiments similarly showed: (a) increased RTs for TP than for DP trials; (b) increased RTs with increasing TADs; and (c) different DPEs as a function of the TAD. In addition, Experiments 2A and 2B showed that search times depended on the colors of the TAD, immediately rather than remotely preceding the target display. Differences were also found between the block (predictable) and random (unpredictable) designs. Compared to no color previewing trials, all TP trials were slower in both designs, but DP trials differed in that RT was faster in all TADs in the unpredictable context but only in the 1TAD and 2TADs in the predictable context. Moreover, the unpredictable context did not showed a DPE after one TAD presentation unlike the predictable context. These results suggest that (a) visual experience leaves memory traces and is accumulated into memory while trial-by-trial adjustments are made; and further (b) depending on the demand that a given task requires humans exert their top-down control of attention accordingly.

Key words : adaptive, visual search, the distractor previewing effect (DPE), previewing history, attentional control

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* This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government. [NRF-2011-354-H00011]

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Research has shown that humans have the ability to make a cognitive adjustment in trial-by-trial and gradual manners as they gather information and learn regularities in a given task situation (Ariga & Kawahara, 2004; Maljkovic & Nakayama, 1994; Chun & Nakayama, 2000; Meyer et al., 1995; Shin, Fabiani, & Gratton, 2004). Such adjustment suggests that we adapt to a given situation by changing the manners in which we respond to stimuli. In visual search, trial-by-trial adjustments can be found in the distractor-previewing effect (DPE), which refers to increasing search times when visual features associated with the current *target* features were shown in preceding target-absent displays (TADs) compared with when those associated with the current *distractor* features were shown in the preceeding TADs in visual oddball search tasks. For example, as illustrated in Figure 1 the target-color previewing (TP) condition shows a slower reaction time (RT) than the distractor-color previewing (DP) condition in a color-oddball search task. This RT difference between the TP and DP conditions is used as an index of the DPE. Hence, the DPE demonstrates that searching a visual scene for a target is influenced by recent search history.

Given the facilitating effect of repetition priming (e.g., Maljkovic & Nakayama, 1994), the fact that repeating visual features slows

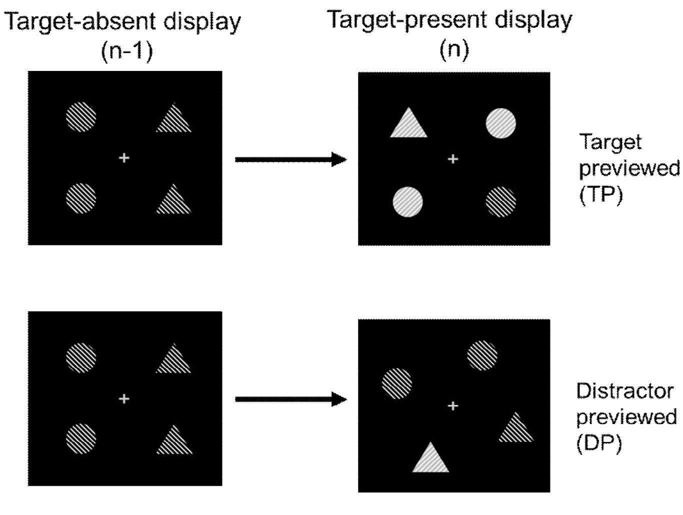

Figure 1. The illustration of a DPE paradigm. Typically, a target-absent display (TAD) is followed by a target-present display, and participant is asked to respond to a color oddball (i.e., target) using the hand pre-assigned to some attributes of the target (e.g., shape). In the current study red or green could be the target and its shape (circle or triangle) determined the hand for responding. Note that the different orientations of the diagonal lines represent the different colors red and green

down RTs may be counterintuitive. However, the mere repetition of target-related features across multiple displays does not necessarily produce a DPE (e.g., Exp. 1 in Lleras, Kawahara, Wan, & Ariga, 2008). For the generation of a DPE, response should be made based on both the presence and the characteristics of an oddball target. That is, the oddball target should be identified instead of detected, and thus focused attention is required to do the task (Lleras et al., 2008; Lleras, Levinthal, & Kawahara, 2009; Treisman & Gelade, 1980).

Lleras and colleagues (2008) put forward an attentional account of the DPE (see also Lleras et al., 2009). It suggests that visual features associated with the absence of a target are implicitly assessed as failed (or rejected) features in the attentional system. This implicit assessment in turn leads the visual information to be negatively tagged in memory. Consequently, attention is shifted away from items containing the failed features in a subsequent trial. This attention account was supported by an event-related potential (ERP) study (Shin, Wan, Fabiani, Gratton, & Lleras, 2008) in which the N2pc, an index of attention allocation to a target location (Luck & Hillyard, 1994), corresponded with the DPE in latency. In addition, Scalf and her colleagues (2014) reported that both face and house targets preceded by the same categorical stimuli elicited greater activation in the TP than in the DP condition in the ventral attentional network, but did not show any difference in the category sensitive fusiform face area (Kanwisher, McDermott, & Chun, 1997) and parahippocampal place area (Epstein & Kanwisher, 1998). These results contradict with the idea that the DPE occurs due to a reduced salience of a previewed task-relevant stimulus attribute in the current trial (Goolsby, Grabowecky, & Suzuki, 2005), emphasizing the role of sensory suppression in the generation of the DPE. Rather these results strengthen the notion that the DPE is an attentional, not sensory, phenomenon.

Rationale of the study

The current study investigated the nature of this top-down attentional biasing in color-oddball search tasks. Two factors, color previewing history and task context, were introduced. Color previewing history aimed to examine systematically how past visual experience is integrated and how attention is shifted in a DPE paradigm. The attention account suggested by Lleras et al., (2008) points out two components in the DPE phenomenon: first, memory connecting past visual experience to the current search with an evaluative tagging of the experience (success or failure); second, attentional bias modulated by the evaluative tagging (i.e., memory). Priming of pop-out (PoP) is another example of inter-trial effects as in a pop-out task search times for color-oddball targets decrease when target colors are repeated than when target and distractors switch colors in subsequent trials (Maljkovic & Nakayama, 1994). Studies have shown that target identification became faster as the same target color was repeatedly presented (Maljkovic & Nakayama, 2000; Brascamp, Pels, & Kristjánsson, 2011). This build-up effect indicates that past search experience leaves a memory trace and is accumulated over time, which influences the speed of target identification in the current search trial. The DPE is similar to PoP in the sense that target items are not fixed and can change every trial (e.g., red to green). Thus, participants have to respond to every trial solely based on what it offers. To this limited search condition, keeping a record of past search history and biasing attention according to the record would be an active attempt to optimize search processes.

Hence, the present study investigated if the DPE shows cumulative effects across successive trials. Here, cumulative effects mean that target search times change as the number of the TAD increased. How the change occurs may depend on the degree to which inhibition and facilitation occur in the TP and the DP condition, respectively. According to the attention account (Lleras et al., 2008, 2009), past search failure biases attention toward novel features in the subsequent search. The present study probed this idea by comparing two successive TADs where the same color was repeated or different colors alternated. Further, when two successive TADs show different colors, the order of the colors was manipulated, such that the color shown in the first and the second TAD could end up defining a target and distractors or vice versa. In other words, some trials showed a target color followed by a distractors color, and other trials showed a distractors color followed by a target color. These manipulations allowed for revealing how color previewing experience is integrated over time and how attention is adaptively shifted based on the color previewing history.

Task context aimed to investigate how participants exert their top-down control of attention depending on attentional needs that the task requires. Specifically, if participants are able to predict the time of target appearance in the stream of target-present and TAD presentations, they may strategically ignore the TADs and selectively attend to the target-present displays. In contrast, if participants are unable to predict a target appearance time, they may show sustained attention to all displays. In other words, the (un)predictability of a target appearance time could modulate the degree to which participants attend to the TADs, and it may result in different DPE patterns. Previously, Goolsby and colleagues (2005) investigated how a DPE is generated as a function of whether the TADs were actively attended or ignored (in Experiments 3.2-3.3B). They found that DPEs were generated regardless of the attention conditions, indicating that simply viewing items generates a DPE. However, this study used external cues directing participants to attend to or to ignore. In the current study, explicit cues were not used to induce top-down control. Instead, participants learned the time of target appearance as each task block progressed, in order to induce internally generated top-down control of attention. Studies have shown that as humans learn a task their attentional control changes accordingly (Chun & Jigang, 1998; Chun & Nakayama, 2000). For example, it has been reported that search times become faster as participants learn the spatial layout of items (Chun & Jiang, 1998). This facilitation suggests that as participants learn global context the deployment of spatial attention becomes more efficient, which highlights the adaptive nature of human cognition. Hence, it was expected that the difference in the predictability of target appearance time might differentially influence top-down control of attention, and this should be manifested in DPE results.

Introduction of four experiments

Using block and random designs two different task contexts were generated in the same search tasks. In one task (Experiment A), a fixed number of TADs was presented prior to the appearance of the target display within a block, allowing participants to learn to know when to respond to color-oddball targets. In the other task (Experiment B) the target displays appeared unexpectedly, and thus participants were unable to predict the time of responding to the targets. In addition, each experiment was divided into two sub-experiments in which color previewing history was manipulated. In Experiments 1A and 1B (abbreviated to 1A-B), the TAD was presented 0 to 5 times prior to the target display. Specifically the colors selected for the items in the TADs did not change and were shown as the color of a target or distractors in the target display. In Experiments 2A and 2B (abbreviated to 2A-B), the TAD was presented 0 to 2 times prior to a target appearance. Particularly, during the two successive TAD presentations the color of items could be repeated or changed. Some trials presented the target displays without showing the TADs (i.e., no color-previewing trials). These trials provided RT information representing the time required

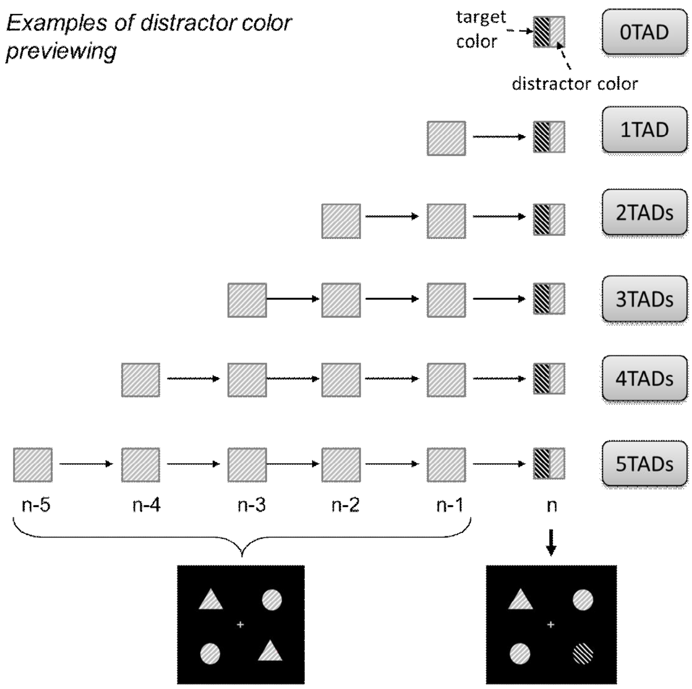

Figure 2. Schematic descriptions of trial sequences and conditions used in Experiments 1A and 1B. The numbers that accompany the "TAD" indicate the number of TAD presentations before the target display. Thus, 0TAD represents search trial without color previewing. Due to limited space, only distractor color previewing conditions are shown here. The locations of the four items shown in the example displays could be changed for each display

for identifying the targets with no influence of color previewing.

Figures 2 and 3 visualize the sequences and conditions of color previewing history. Figure 2 shows the trial sequences and conditions used in Experiments 1A-B. The TAD was presented once (1TAD), twice (2TADs), three (3TADs), four (4TADs), or five times (5TADs) prior to the appearance of the target display. Within each sequence the multiple TADs (i.e., 2TADs to 5TADs) showed the same color of items, which later defined a target or distractors. Figure 3 shows the trial sequences and conditions used in Experiments 2A-B. The TAD was presented up to 2 times prior to the target display, and the 2TADs were divided into two different sequences in which the items presented in the two successive TADs showed the same color (2TAD-S) and different colors (2TAD-D). The same color defined a target or distractors, yielding TTP and DDP conditions, respectively. Two different colors also defined both a target and disctractors in the target display, but the order could be a target color followed by a

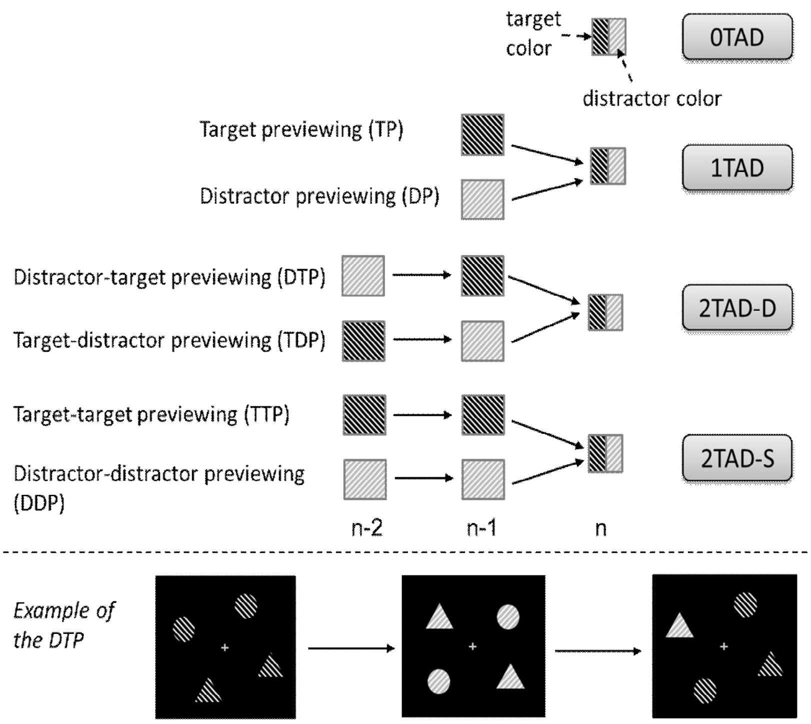

Figure 3. Schematic descriptions of trial sequences and conditions used in Experiment 2A and 2B. The specific conditions TP, DP, TDP, DTP, TTP, and DDP are depicted based on the assumption that the right-downward and left-upward diagonal lines indicate the colors of a target and distractors, respectively. In the example of the DTP, the left-upward diagonal lines represent a target color

distractors color (TDP) or be a distractors color followed by a target color (DTP).

Table 1 summarizes how the four experiments were organized. Experiments A and B investigated color previewing effects using block and random designs. In Experiment 1A, the number of TADs increased 0 to 5, wherein the color of items did not change and was shown later as a target or distractors color in the target display. In Experiment 2A, the TADs were presented 0 to 2 times, and yet the color of items could be identical or different across the successive TADs. Experiment 1-2A was very similar to Experiment 1-2B, except that participants were unable to predict when they had to respond because of a random selection of the TAD sequence.

It was expected that DP trials should be faster than TP trials, and DPEs should be generated in cumulative fashions in all tasks, given the similarities to PoP. If past visual experience leaves a memory trace and is

Table 1. The organization of the four experiments

		Color previewing history	
		TAD presented 0 to 5 times	TAD presented 0 to 2 times
Task context	Predictable (one TAD within a block)	Experiment 1A	Experiment 2A
	Unpredictable (any TADs within a block)	Experiment 1B	Experiment 2B

accumulated over time, RT should increase with increasing TADs. However, the extent of the increase should differ depending on previewing colors as the TP and the DP conditions should drive attention into the opposite directions. In addition, the DTP trials should show slower RTs than the TDP trials if no target previewing biases attention in favor of non-previewed features. However, the pattern of the DPE may differ as a function of whether the time of target appearance is predicted or not because the degree to which attention is required to the displays should differ in the two contexts. Whereas Experiment B requires sustained attention to all displays, Experiment A does not.

Methods

Participants A total of 84 university-students participated (24, 24, 16, 20 in Experiments 1A, 1B, 2A, and 2B, respectively) in exchange of partial course credit after signing written informed consent. Participants reported normal or corrected-to-normal vision, and were screened for color-blindness by an online version of Ishihara color-blindness test.

Apparatus and Stimuli All stimuli were presented against a black background in a dimly lit room. Stimuli comprised the combinations of green and red colors and circle and triangle shapes. Each stimulus subtended approximately 0.80° in visual angle, displayed on a 17-inch color monitor with a resolution of 1,024 × 768 pixels and a refresh rate of 85 Hz in Experiments 1A-B. In Experiments 2A-B, stimuli were displayed on a 17-inch color monitor with a resolution of 1,280 × 960 pixels and a refresh rate of 60 Hz, and each of the stimuli subtended approximately 0.78° in visual angle.

As shown in Figure 2, Experiments 1A-B had six trial sequences, 0TAD to 5TADs prior to the appearance of the target-present display. Within each sequence, the same color of items was presented repeatedly for the multiple TADs, and was used for a target or a distractors color in the target display. Half of the trials were devoted to the TP condition and the other half were to the DP condition in each sequence. However, the 0TAD indicates zero time of color previewing, and thus target search was required without previewing of any colors. Figure 3 shows the sequences of zero, one and two TADs that were used in Experiments 2A-B. Half of 1TAD trials were assigned to TP trials, and the other half were to DP trials. 2TAD trials consisted of DTP, TDP, TTP, and DDP conditions, each taking 25% of these sequence trials. In both TTP and DDP conditions, the *same* color was used for stimuli in the two consecutive TADs, referred to as 2TAD-S. In the TDP and DTP conditions, the stimulus colors were *different* in the two successive TADs, referred to as 2TAD-D.

Procedure In Experiments 1A-B, participants were seated about 85 cm from the computer screen. Each block began with a 1500-ms central fixation cross. The TADs containing four identically colored stimuli were shown for 200 ms each, and an 800-ms inter-stimulus interval separated two TADs. The target-present displays containing four items, one of which was uniquely colored (i.e., target), were simultaneously shown for 200 ms, followed by a 1400-ms interval. The four items shown in the TADs and target displays were placed on an imaginary circle (4.44° of visual angle from fixation) within each quadrant. In Experiments 2A-B, participants were seated about 125 cm from the computer screen. Each block began with a 1500-ms fixation cross. The TADs were shown for 225 ms each, and the target display was then presented for 225 ms. A 1500-ms inter-stimulus interval separated the presentations of the two displays. Four items in the displays were placed on an imaginary circle (3.76° of visual angle) within each quadrant.

In all experiments, a fixation cross was present throughout the experiment, and the locations of the four items could change every display, with the constraint that they were 90° apart and that none fell within 5° of the horizontal and vertical meridians. The shape of the four stimuli in the TADs and target displays was selected, with the constraints that there was always at least one circle or one triangle in the display—that is, both circle and triangle were presented for each display.

Participants were asked to respond to color-oddballs as quickly and accurately as possible by pressing one of two buttons on a response box. Target shape indicated the hand to use for responding, which was counterbalanced across participants. Participants were given 1300 ms to respond. For Experiment 1A, a total of 36 blocks were run after one block of a 34-trial practice. Six blocks of 11 trials were assigned to 0TAD trials, and thirty blocks of 22 trials were to 1TAD through 5TADs trials. For Experiment 1B, twenty-two blocks of 34 trials were run in total, preceded by a 34-trial practice block. For Experiment 2A, following one block of a 25-trial practice, 14 blocks of 43 trials were run. For Experiment 2B, a total of 12 blocks of 50 trials were run, preceded by a 50-trial practice block.

In Experiments 1A-B, the five sequences 1TAD to 5TADs were presented with the probability of 0.18 for each. In Experiments 2A-B the sequences 1TAD and 2TADs were presented with the probabilities of 0.29 and 0.57, respectively. 0TAD trials occurred with the probability of 0.09 in Experiments 1A-B, and occurred with 0.14 probability in Experiments 2A-B. These probabilities were determined in order to present each trial type (e.g., TP, DP, TTP DTP, etc.) with an approximately equal probability. Target color and target shape were randomly selected and evenly distributed across trials. Thus, participants were not able to predict which hand to use for responding. In Experiments 1-2A, different sequences were separated by blocks, so that participants were able to learn when to respond to the target as trials progressed within a block. Yet, which sequence would be presented for each block was not known to participants in advance because the occurrence of a specific sequence was randomly determined across blocks. In this block design, participants could predict the time of target appearance (i.e., when to respond to the targets) as they learned the regularities existing in the TAD presentations. However, they could not predict the hand to use for responding in every trial nor do which TAD sequence would be presented before a block began. Experiments 1-2B differed from Experiments 1-2A in that TAD sequences were randomly distributed within a block and thus participants were unable to predict when to respond to the targets.

Results

Results from Experiments 1A-B will be followed by those from Experiments 2A-B. In doing so, each experiment results will be described first and then two experiments (i.e., Experiments 1A vs. 1B and Experiments 2A vs. 2B) will be compared. Because Experiments 1 and 2 have many differences, no direct comparisons were not made between the two experiments.

Experiments 1A and 1B

Within experiment. Only correct response trials were included for RT analysis. Mean RTs were submitted to a 5 (sequence: 1TAD through 5TADs) × 2 (color-previewing: TP and DP) repeated measures analysis of variance (ANOVA).

Figure 4a shows mean RTs obtained in Experiment 1A. RTs were significantly slower for the TP than for the DP trials, $F(1, 23) = 204.56$, $p < .001$, indicating that a robust DPE occurred. Also, both the TP and DP conditions showed significant increases as the TAD increased, $F(4, 92) = 11.12$, $p < .001$, showing a significant sequence effect. Interestingly, this increase was not similar for the TP and DP trials, as indicated by a significant interaction between sequence and color-previewing, $F(4, 92) = 3.46$, $p < .05$, which in turn was corroborated by different rates of the RT increase between the TP and DP conditions (14 ms and 8 ms, respectively). In any case the DPE increased significantly, $F(4, 92) = 3.46$, $p < .05$, at the rate of 6 ms per TAD, on average, demonstrating that the effect of color previewing history was accumulated.

Figure 4b shows mean RTs obtained in Experiment 1B. As Experiment 1A, RTs were significantly slower for the TP than for the DP trials, $F(1, 23) = 253.28$, $p < .001$, indicative of the generation of the DPE. In addition, RT became significantly slower as the number of the TAD increased, $F(4, 92) = 6.74$, $p < .001$. However, this increase differentially evolved between the TP and the DP condition, which was corroborated by a significant sequence × color-previewing interaction, $F(4, 92) = 9.92$, $p < .001$. This significant interaction was also strengthened by a significantly increasing DPE, $F(4, 92) = 9.92$, $p < .001$, at the rate of 10 ms per TAD, approximately. This rate was decomposed by an 8-ms increase per TAD for the TP trials and a 1-ms decrease per TAD for

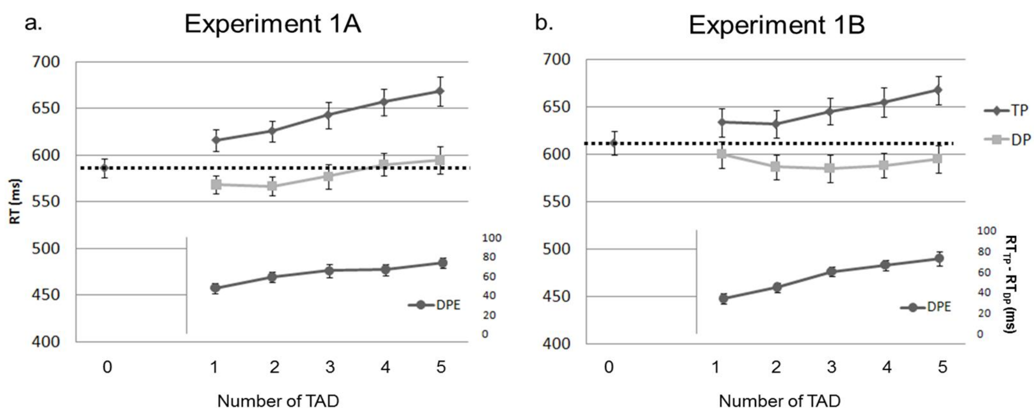

Figure 4. RT results of Experiments 1A (a) and 1B (b). A DPE (RT_{TP} - RT_{DP}) is also plotted for each TAD sequence. The horizontal dotted lines indicate search times with no color previewing (i.e., the 0TAD trials) in both experiments. The vertical bars represent standard errors

the DP trials.

Between experiments. Similar to Experiment 1A, Experiment 1B showed both DPEs and cumulative color previewing effects. Nonetheless, they appeared to differ in how these effects occurred. Possible differences were tested by a 2 (experiment: 1A and 2A) × 5 (sequence: 1TAD to 5TADs) × 2 (color-previewing: TP and DP) mixed factorial ANOVA with repeated measures on the second and third factors. Although a three-way interaction was not significant, $F(4, 184) = 0.67$, *ns*, a significant two-way (experiment × sequence) interaction was found, $F(4, 184) = 4.25$, $p < .001$, indicating that the RT increase across the five sequences was reliably slower in Experiment 1B than in Experiment 1A (see Figure 5). This significant interaction could have been driven by the facilitating effect of distractor color-previewing as shown in Figure 4. Thus, two ANOVAs were performed to test the RT changes observed in the two experiments, separately for the TP and DP trials. Results showed that search times in the TP condition similarly increased in the two experiments, $F(4, 184) = 1.78$, *ns*, and yet the DP condition was significantly different across the five sequences between the two experiments (i.e., a significant experiment × sequence interaction), $F(4, 184) = 5.63$, $p < .001$.

The 0TAD trials provided information about search times on which color previewing history did not influence. The TP and DP trials were compared with these trials to examine more closely the effects of target and distractor color-previewing history in the different sequences. In Experiment 1A, both the TP and the DP condition were deviated from the 0TAD (M = 586 ms; SD = 48) into the opposite directions. This kind of divergence was tested for all five sequences using paired *t*-tests. A significant increase was found for the TP trials in all the sequences, $ts(23) > -7.36$, $ps < .001$, but only the 1TAD and 2TADs sequences showed significantly faster RTs for the DP trials compared to the 0TAD trials, $ts(23) < 4.33$, $ps < .001$. These results demonstrate that both inhibitory and facilitory effects of target- and distractor-color previewing occurred in identifying the targets. However, whereas the inhibitory effect was maintained as long as a target color

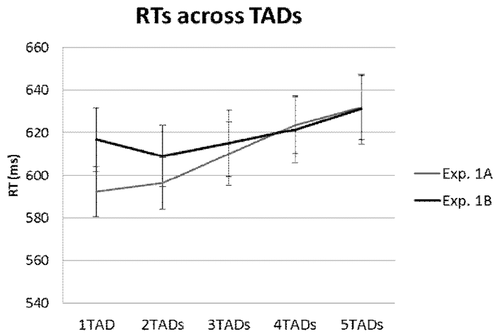

Figure 5. RT increase across the five TAD sequences in Experiments 1A and 1B. The vertical bars represent standard errors.

was repeatedly previewed, the facilitory effect was limited up to the 2TADs. Experiment 1B also showed both the inhibitory and facilitory effects as the RTs in the TP and DP conditions were deviated from the 0TAD trials (M = 614 ms; SD = 61) into the opposite directions. However, the pattern of these effects were different from Experiment 1A in that the effects were maintained across all the TAD sequences. For the TP trials, a significantly slower RT was found in all five sequences, $ts(23) > -6.18$, $ps < .006$. For the DP trials, a significantly faster RT was found in all the sequences, $ts(23) > 2.45$, $ps < .05$. Note that the RT in the 0TAD appears to be faster in Experiment 1A than in Experiment 1B, but did not significantly differ between the two experiments, $F(1, 46) = 3.13$, $p < .084$.

Table 2 shows accuracy in the different conditions across the different sequences for Experiments 1A-B. Overall high accuracy was observed across the different conditions. Both experiments showed that the DP conditions were significantly more accurate than the TP conditions, $Fs(1, 23) > 1.08$, $ps < .004$. However, neither a main effect of sequence nor an interaction was significant, $Fs(4, 92) < 2.32$, ns.

Experiments 2A and 2B

Within experiment. Only correct response trials were included for RT analysis as in the other experiments. Mean RTs were submitted to a 3 (sequence: 1TAD, 2TAD-D, and 2TAD-S) × 2 (color-previewing: TP-like and DP-like) repeated measures ANOVA. Here, the TP-like color previewing includes the DTP and TTP conditions as well as the TP condition. The DP-like includes the DP, TDP and DDP conditions.

Table 2. Accuracy across the different conditions across the difference sequences for Experiments 1A and 1B. Standard deviations are in parentheses

		1TAD	2TADs	3TADs	4TADs	5TADs	0TAD
Exp. 1A (n = 24)	TP	0.94 (0.04)	0.95 (0.04)	0.95 (0.04)	0.94 (0.04)	0.95 (0.05)	0.94 (0.04)
	DP	0.95 (0.03)	0.96 (0.02)	0.97 (0.03)	0.97 (0.03)	0.96 (0.03)	
Exp. 1B (n = 24)	TP	0.91 (0.06)	0.91 (0.07)	0.91 (0.05)	0.91 (0.06)	0.90 (0.06)	0.91 (0.07)
	DP	0.92 (0.06)	0.93 (0.06)	0.95 (0.05)	0.95 (0.05)	0.94 (0.06)	

Figure 6a shows mean RTs obtained in Experiment 2A. A significant color-previewing effect was found, $F(1, 15) = 111.80$, $p < .001$, as the TP-like conditions showed slower RTs than the DP-like conditions. The DTP and TDP conditions (which were absent in Experiments 1A-B) also showed a significant RT difference, $t(15) = 3.055$, $p < 0.01$, in the way that the TDP condition was significantly faster in the DTP condition. This significant difference is particularly interesting because it suggests that most recently exposed features influenced the speed of target identification more than remotely exposed visual features. Moreover, search times significantly increased as a function of the TAD, $F(2, 30) = 10.91$, $p < .001$, indicative of a cumulative effect of color previewing history. This sequence effect was further examined using paired t-tests, which revealed that the two 2TAD sequences (2TAD-S, 2TAD-D) significantly slowed down RT than the 1TAD, $ts(15) > 2.67$, $ps < 0.05$, and the 2TAD-S significantly delayed RT than the 2TAD-D sequence, $t(15) = 3.06$, $p < 0.01$. These results suggest that both the number of sequences and the order of color previewing history contributed

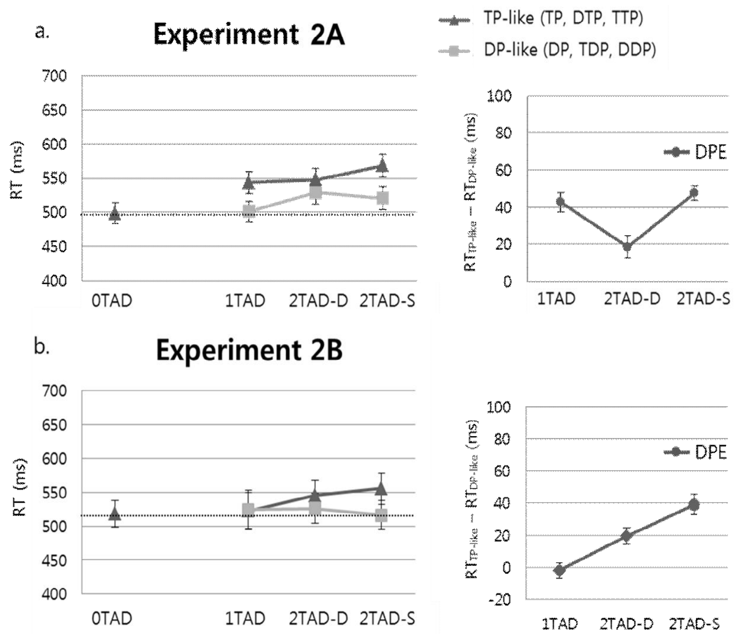

Figure 6. RT results of Experiments 2A (a) and 2B (b). A DPE ($RT_{TP\text{-}like} - RT_{DP\text{-}like}$) is also plotted for each TAD sequence. TP-like includes the TP, DTP, and TTP conditions, and DP-like includes the DP, TDP, and DDP conditions. The horizontal dotted lines indicate search times with no color-previewing (i.e., the 0TAD trials) in both experiments. The vertical bars represent standard errors

to generating these unique DPEs, which resulted in a significant sequence × color-previewing interaction, $F(2, 30) = 41.58$, $p < .001$. This interaction was presumably driven by a smaller DPE in the 2TAD-D compared to both the 1TAD and 2TAD-S sequences. Follow-up *t*-tests confirmed that the DPE was significantly smaller in the 2TAD-D than in the 1TAD, $t(15) < 4.63$, $p < .001$ and also than in the 2TAD-S, $t(15) < 5.28$, $p < .001$. However, the DPE did not significantly differ between the 2TAD-S and the 1TAD, $t(15) = 1.21$, *ns*.

Figure 6b shows mean RTs obtained in Experiment 2B. Search times significantly increased as the TAD increased, $F(2, 38) = 11.56$, $p < .001$, suggesting that a cumulative effect of color previewing occurred. This sequence effect was further examined using planned comparisons, which revealed that both the 2TAD-S and the 2TAD-D showed significantly slower RTs than the 1TAD, $ts(19) > 2.76$, $ps < 0.05$, as in Experiment 2A. The 2TAD-S and 2TAD-D sequences did not significantly differ, $t(19) = 1.68$, *ns*, unlike Experiment 2A. The color-previewing effect (i.e., the DPE) was significant, $F(1, 19) = 18.97$, $p < .001$, but was not equally distributed across the sequences (see Figure 6b). This observation was substantiated by a significant sequence × color-previewing interaction, $F(2, 38) = 32.52$, $p = 0.001$, and was associated with a significant linear trend of the DPE, $F(2, 38) = 24.96$, $p < .001$. The DPEs were further examined for each sequence using paired *t*-tests. In the two 2TAD sequences, the TP-like conditions showed significantly slower RTs than the DP-like conditions, $ts(19) > 3.16$, $p < .005$, but no significant difference was found in the 1TAD sequence, $t(19) = 0.00$, *ns*.

Between experiments. Both experiments consistently showed cumulative effects of color previewing with the influence of the previewing order. However, the DPE patterns across the sequences differed between the two experiments. Thus, a mixed factorial ANOVA was performed with experiment (2A and 2B) submitted as a between-subjects factor and sequence (1TAD, 2TAD-D, and 2TAD-S) and color-previewing (TP and DP) as within-subject factors.

As in Experiment 1A-B, a significant experiment × sequence interaction was found, $F(2, 68) = 5.16$, $p < .01$, as RT increased more slowly in Experiment 2B than in Experiment 2A (see Figure 7). An interaction between experiment and color-previewing was also significant, $F(1, 34) = 21.48$, $p < 0.001$, as Experiment 2A showed a larger difference between the TP-like and DP-like conditions than Experiment 2B. Finally, a significant experiment × sequence × color-previewing interaction was found (see Figure 6), $F(2, 68) = 3.85$, $p <$

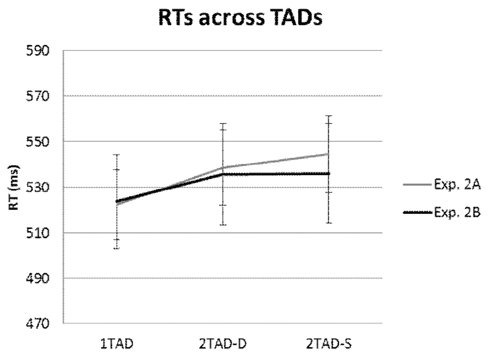

Figure 7. RT change across the TAD sequences in Experiments 2A and 2B. The vertical bars represent standard errors

.05, as the two experiments showed different DPE patterns across the sequences. This three-way interaction suggests that the effect of color-previewing history occurred differentially as a function of search context. The 0TAD trials showed similar RTs between the two experiments, $t(34) = 0.79$, *ns*, similar to Experiments 1A-B.

Table 3 shows accuracy in the different conditions across the different sequences in Experiments 2A-B. First, a sequence × color-previewing repeated measures ANOVA was performed for each experiment. In Experiment 2A, accuracy significantly increased, $F(2, 30) = 7.36$, $p < .01$, as the number of the TAD increased. In addition, the DP-like trials showed significantly higher accuracy rates than the TP-like trials, $F(1, 15) = 7.16$, $p < .05$. This difference was most evident in the 1TAD sequence than in any other sequences, resulting in a significant sequence × color-previewing interaction, $F(2, 30) = 4.28$, $p < 0.05$. Unlike Experiment 2A, Experiment 2B did not show any significant main effects, $Fs < 0.44$, *ns,* nor an interaction, $F(2, 38) = 0.65$, *ns*.

Discussion

The present study used a DPE paradigm to investigate the adaptive nature of top-down control of attention in color-oddball search tasks. Temporal integration of attention shift was investigated by manipulating the number of TADs and the order of previewing colors, which was later associated with target and distractor

Table 3. Accuracy rates across the different conditions in Experiments 2A and 2B. Standard deviations are in parentheses. Note that "NP" means no color previewing

	1TAD		2TAD-D		2TAD-S		0TAD
	TP	DP	DTP	TDP	TTP	DDP	NP
Exp. 2A ($n = 16$)	0.91 (0.07)	0.95 (0.05)	0.95 (0.06)	0.96 (0.05)	0.95 (0.05)	0.96 (0.04)	0.91 (0.06)
Exp. 2B ($n = 20$)	0.95 (0.04)	0.95 (0.04)	0.95 (0.05)	0.96 (0.05)	0.95 (0.04)	0.96 (0.05)	0.95 (0.06)

colors. In addition, using different experimental designs block and random, two task contexts were induced in order to manipulate the extent to which top-down control of attention was needed. These two factors color-previewing history and task context were combined, resulting in four experiments (Experiments 1A and 1B, 2A, and 2B) being conducted for the current study. Experiments 1 and 2 differed in color previewing history, and Experiments A and B differed in the predictability of target appearance time.

All four experiments showed that (a) RTs were faster for the DP and DP-like trials than the TP and TP-like trials (i.e., color previeweing effect); (b) RT increased as the TAD was repeatedly presented (i.e., sequence effect); and (c) the magnitude of a DPE differed as a function of the TAD sequences (i.e., color previewing × sequence interaction). Moreover, Experiments 2A-B showed that RTs were significantly slower for the DTP than for the TDP trials. Despite these similarities, differences were also found between the different task contexts. First, Experiments 1A-B in which the TADs were presented up to five times showed differently increasing rates of RT. The random design (Experiment 1B) showed significantly slower increase than the block design (Experiment 1A), which might have been driven by the different facilitation effects found in the DP conditions of the two experiments. Whereas the facilitation was observed in all sequences for Experiment 1B, it was limited up to the 2TADs for Experiment 1A. Likewise, Experiment 2B showed significantly slower RT increase than Experiment 2A. Further, the DPE change shown across the sequences also differed between Experiments 2A and 2B.

The fact that RT increased across the sequences indicates that past visual experience leaves a memory trace and is accumulated into memory. This build-up of implicit memory traces has been found in PoP (Brascamp, Pels, & Kristjánsson, 2011; Maljkovic & Nakayama, 2000), but has not been found in the DPE. Thus, this is the first to test and show a cumulative effect of visual experience using a DPE paradigm, to my knowledge. Further, this cumulative effect differed by previewing colors as the difference between the TP and DP conditions became larger with the increasing TAD sequences. This interaction suggests that the effects of inhibition and facilitation were solidified for both the TP and the DP trials as the number of TADs increased. Furthermore, search times were faster in the TDP than in the DTP condition. This can be explained by dynamic shifts of attention (Lleras et al., 2008, 2009): in the DTP condition, the search failure in the second TAD presentation had shifted attention *away from* the colors that defined targets in the target-present displays, thus requiring the time to shift attention back to the target colors. In contrast, in the TDP condition attention had been shifted *toward* the colors that defined targets in the target displays, consequently saving the time to reallocate attention to the target colors. Because the 2TAD-D sequence presented two different colors for each display, shifting of attention could have differed following the two successive TADs. The current study manipulated color previewing history in order to investigate how past visual experience is integrated over time and attention is shifted in a DPE paradigm. All four experiments suggest that humans take each visual experience into the systems (e.g., attention and memory) and integrate it over time while responding to each trial according to the integrated result available up to the point.

A larger scale of attentional control was investigated by providing different task contexts in which participants were able or unable to predict when target would appear. The predictable context (Experiment 1A) showed faster RT increase than the unpredictable context (Experiment 1B). This difference may be explained by the different pattern of RT change shown in the DP conditions. In Experiment 1B, RT was facilitated in all sequences, and yet such facilitation was observed only in the 1TAD and 2TADs in Experiment 1A. This reflects that the top-down control of attention was exerted in different ways. In Experiment 1B participants may have attended to all displays because they were unable to predict when to respond to the target. However, in Experiment 1A RT was facilitated up to the 2TADs, it is possible that participants could have maintained attention to all displays in the blocks of 1TAD and 2TADs, but may not have maintained attention to all displays in the blocks of larger TAD sequences. In other words, participants may have attended to the displays temporally close to the target displays as they could have predicted when they would show up. Experiments 2A-B also showed a few differences. As Experiments 1A-B, RT increased slowly with the TAD sequences in Experiment 2B compared to Experiment 2A. In addition, the difference between the TP-like and DP-like conditions was larger in Experiment 2A than in Experiment 2B. These differences were qualified by a significant DPE change occurring across the sequences between the two experiments, which indicates that the extent to which attention was deployed depended on task context. Particularly, the unpredictable context (Experiment 2B) showed no DPE in the 1TAD unlike the predictable context (Experiment 2A). Although the reason for this specific difference is unclear, two things in Experiment 2B results are noteworthy. First, the RT in the TP condition did not increase and was similar to that in the

DP condition—that is, no generation of a DPE. Second, both the 0TAD and 1TAD sequences showed similar RTs. These results suggest that in the unpredictable context attention was not shifted against previewed colors despite the experience of search failure. Participants may have attended to whichever was presented, and it might have happened up to one TAD presentation. All these differences support the notion that humans exert their top-down control of attention according to the given context.

Unlike the experiments with the 0 to 2 TADs, the experiments with 0 to 5 TADs did not show a significant interaction with the DPE and sequence (i.e., a three-way interaction). The reason for this difference may lie in how much participants made use of the learned knowledge (predictable or unpredictable) while performing the tasks. In Experiments 2A-B, participants must have made use of the information, but they may not have in Experiments 1A-B. Compared to the continuously increasing DPEs in the five sequences in Experiment 1B, Experiment 1A showed that the sequences 3TADs and 4TADs resulted in very similar DPEs (66 and 67 ms, respectively) unlike the sequences 1TAD, 2TADs, and 5TADs (48, 59, and 74ms, respectively). This suggests that participants may not have used the information about target appearance time equally well for all the sequences in Experiment 1A, leading to a mixture of both predictable and unpredictable context effects.

The effects of color previewing history and task context demonstrate the adaptive nature of human cognition in visual search in hierarchical manners. The color previewing history effects reflect trial-by-trial changes in attentional biases, prioritizing specific features for upcoming visual scenes. This top-down biasing appears to be contingent upon visual experience accumulated each time, and is exerted without volitional control because participants were not given explicit instructions for biasing attention to specific features. Moreover, this implicit attentional control was shown to be influenced by the task contexts in which participants gradually learned the tasks and applied different strategies. This indicates that another layer of top-down control of attention exists and such control adaptively guides search strategy by making use of information available in the given context.

Neural involvement in these hierarchical operations is hard to pinpoint. Ver y few neuroimaging studies of the DPE have been published so far (Scalf et al., 2014; Shin et al., 2008; Shin & Bartholow, 2013). The N2pc, which corresponded with the DPE (Shin et al., 2008; Shin & Bartholow, 2013), is typically observed in posterior areas, presumably generated from the extrastriate cortex (Luck, Girelli, McDermott, & Ford, 1997). Using functional magnetic resonance imaging, Scalf and colleagues (2014) found that the ventral attentional network including the right supramarginal gyrus (oft referred to as the temporal parietal junction) and the right middle frontal gyrus activated more in the TP than in the DP condition. These brain regions reflect the application of attentional bias to the stimuli shown in the current target display. Specific areas recruited for biasing attention are not so clear. Studies using PoP and dimensional weighting (Müller, Heller, & Ziegler, 1995) point to anterior prefrontal cortex (Pollmann, 2004) as a place for implicitly biasing attention. The same area can be involved in the DPE.

To conclude, visual search is influenced by both feature previewing history and task context. The effects of these two factors suggest that humans constantly collect information and learn the rules that may exist, and adjust the manners in which they search for a target by making use of the information and knowledge available at the moment. This in turn highlights the fact that human cognition is not fixed but adaptive in nature.

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1 차원고접수 : 2015. 03. 20
수정원고접수 : 2015. 04. 25
최종게재결정 : 2015. 04. 27

한국심리학회지: 인지 및 생물
The Korean Journal of Cognitive and Biological Psychology
2015, Vol. 27, No. 2, 253-274

방해자극 미리보기 효과(distractor previewing effect)를 이용한 적응적 시각 탐색 연구: 미리보기의 역사와 과제 맥락을 중심으로

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인간의 적응적 시각 탐색을 방해자극 미리보기 효과(distractor previewing effect, 이후 DPE)를 이용하여 연구하였다. 보통 특이색(color oddball) 탐색 과제에서 목표자극의 색을 목표자극 부재 화면(target-absent display, 이후 TAD)에서 미리 보았을 경우가 방해자극의 색을 미리 보았을 경우보다 탐색 시간이 길다. 다시 말해 목표자극의 색을 미리 보는 시행이 방해자극의 색을 미리 보는 시행보다 느리고, 이 둘 간의 반응시간 차이가 DPE이다. 적응적 시각 탐색 연구는 색깔 미리보기와 과제 맥락을 조작함으로써 진행되었다. 전자는 시각 경험의 시간적 통합성을 매 시행에서 나타나는 주의 이동과 함께 조사하기 위해 다양화되었고, 후자는 목표자극 출현 시기에 대한 예측가능성을 조절하는 것으로 조작되었다. 목표자극이 있는 화면이 나타나기 전 0에서 5개까지(실험1) 또는 0에서 2개까지(실험2) TAD가 제시되었는데, 실험A에서는 그 개수가 블록 당 분리되어 제시되었고 실험B에서는 무작위적으로 제시되었다. 결과적으로 네 개의 실험 1A, 1B, 2A, 2B이 실시되었고 유사한 결과와 함께 다른 결과도 나타났다. 공통적인 결과들은 다음과 같다. 첫째, 목표자극 색을 미리 본 경우가 방해자극 색을 미리 본 경우보다 느렸다. 둘째, TAD 개수가 증가할수록 반응시간도 증가하였다. 셋째, DPE가 TAD 개수에 따라 다르게 나타났다. 추가적으로 실험2A와 실험2B에서 TAD가 두 번 제시된 경우 목표자극에 대한 반응시간이 두 번째 TAD에서 제시된 색의 영향을 크게 받았다. 차이점들은 다음과 같다. 먼저, 실험1A와 실험1B 모두 색깔 미리보기 없는 시행들과 비교하여 목표자극 색을 미리 본 경우 더 느린 반응시간이 관찰되었으나, 방해자극 색을 미리 본 경우에는 예측불가능한 맥락(실험2B)에서 모두 빨리 반응한 반면 예측가능한 맥락(실험2A)에서는 제한적으로 빨랐다. 실험2A와 실험2B에서는 예측가능한 맥락(실험2A)과 달리 예측불가능한 맥락(실험2B)에서 TAD가 1번 제시된 후 목표자극이 제시되었을 경우 전형적인 DPE가 나타나지 않았다. 이 결과들이 시사하는 바는 다음과 같다. 인간은 매 회 시각 경험을 흔적으로 남기고 축적하여 그것을 기억체계에 쌓는 동시에 과제가 요구하는 정도에 따라 주의를 조절하며 과제를 수행한다.

주제어 : 적응적, 시각 탐색, 방해자극 미리보기 효과, 미리보기 역사, 주의 통제