



Multiple attentional control settings at distinct locations without the confounding of repetition priming

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Abstract

An attentional control setting (ACS), which is based on the task goal, induces involuntary attentional capture by a stimulus possessing a target-defining feature. It is unclear whether ACSs are maintained for multiple targets defined as conjunctions of a color and location. In the present study we examined the possibility of local ACSs for dual targets defined as combinations of color and location, using different paradigms: visual search in Experiment 1, and spatial cueing in Experiment 2. In Experiment 1, a distractor captured attention only when its features matched the ACSs. Likewise, in Experiment 2, a significant attentional capture effect was found only with a matching cue, whose color and location were in line with the conjunction of the target definition. Importantly, the identical pattern of attentional capture was also obtained for a neutral-color target, which was unlikely to be primed by any color of the cue. Thus, these findings imply that the attentional bias depending on the match between the cue and target did not result from cue–target repetition priming. The present study highlights that top-down attentional control can be set flexibly to accomplish a complex task goal efficiently.

Keywords Attentional capture · Visual search · Selective attention

Attention is a mechanism that determines the priorities of cognitive processes, by selectively facilitating the processing of some information while inhibiting that of others. Theories about attentional control have been proposed to explain how attentional priority is involuntarily determined. On one hand, stimulus-driven attentional control accounts have suggested that attention is captured involuntarily by physically salient stimuli in a bottom-up manner (Theeuwes, 1991, 1992; for a review, see Theeuwes, 2010). On the other hand, goal-driven attentional control accounts have argued that attention is involuntarily deployed on stimuli that contain the target-defining feature in a top-down fashion (Folk, Leber, & Egeth, 2002; Folk & Remington, 2006; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Pratt & Hommel, 2003; Remington, Folk, & McLean, 2001). Specifically, Folk, Remington, and Wright hypothesized that an *attentional control setting* (ACS) efficiently generates goal-driven attentional capture, which is called contingent attentional capture, by stimuli having target-defining features such as color, onset or motion and overrides stimulus-

driven attentional capture by physically salient stimuli. For instance, if a person searches for a red letter, any red object would capture attention, whereas a green or blue object would not.

As for the complexity of ACS, previous studies have revealed that it can be tuned not only to a single feature but also to multiple features of stimuli (Folk & Anderson, 2010; Grubert & Eimer, 2016; Irons, Folk, & Remington, 2012; Lien, Ruthruff, & Johnston, 2010; Roper & Vecera, 2012). For example, in Irons et al.'s Experiment 5, in which the target was presented in one of two different colors (e.g., red or green) in a spatial cueing experiment, they found that noninformative cues matching either target color produced a cue-validity effect, but that a nontarget color cue (e.g., blue) did not. This result indicates that participants can maintain multiple ACSs for more than one target-defining feature. Importantly, recent studies have questioned whether multiple ACSs for different targets could be maintained simultaneously at separate locations. Adamo, Pun, Pratt, and Ferber (2008) instructed participants to search for a target that was defined as a function of color and location in their experiments. For example, participants were to respond only to a go target, which was defined as either a blue target presented in the left one of two placeholders or a green target appearing in the right placeholder. Participants were instructed to ignore the green target on the

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left or the blue on the right, which were no-go targets. A noninformative peripheral cue colored either blue or green, classified as a matching or a nonmatching cue, was presented at one of the two placeholder locations before the onset of the target display. The color and location of the matching cue were identical to those of the go targets, whereas the nonmatching cues were compatible with the no-go targets. The results showed that a significant attentional capture effect was obtained with the matching but not with the nonmatching cue, indicating that multiple ACSs were maintained for separate locations at once. Adamo, Wozny, Pratt, and Ferber (2010) also demonstrated that, when targets were defined as one of two colors at one location and one of two shapes at the other, an attentional bias was observed when the cue matched the target-defining feature at a specific location. Additionally, it was reported that significant interference was evident in a modified version of rapid serial visual presentation (RSVP) when the peripheral distractor contained the same features of the central target, defined in terms of shape and color (Ito & Kawahara, 2016; Moore & Weissman, 2010, 2011). These results of the attentional interference by the matching distractor indicated that the ACS was produced to correspond to the target definition, such as a function of color and shape.

However, attentional capture by the matching cue was confounded with cue–target repetition priming, which is an alternative explanation for the findings of Adamo et al.'s (2008) experiment. That is, the shortest mean reaction time (RT) was obtained when the target color was repeatedly presented at the same location, because both the color and location of the cue were identical to those of the target. Moreover, the greatest delayed responses were found when both features of the target differed from the features of the cue, where no repetition priming effect was expected. Thus, the results of Adamo et al.'s (2008) experiment were possibly due to the cue–target repetition-priming effect rather than to multiple ACSs.

Becker, Ravizza, and Peltier (2015) pointed out this alternative possibility and tested independent ACSs at distinct locations using a visual search paradigm in their Experiment 1. Participants were instructed to search for a red letter on one side of the display and a green letter on the other. Importantly, half of the trials contained a distractor. The color of the distractor was either red or green, but its location was not compatible with the target definitions. To examine whether the ACSs for the two targets were generated location-specifically or globally, the interference effect by the nonmatching distractor was measured. The results demonstrated that search performance was impaired when the distractor was presented, although the distractor did not match the target-defining conjunctions of color and location. Likewise, in the RSVP paradigm in their Experiment 2, a significant interference effect by nonmatching distractors was also found, although the features of the distractor were incompatible with those of the targets, which were also

defined as a function of color and location. Accordingly, Becker et al. concluded that the ACS for each color was applied widely rather than location-specifically. In the same vein, another line of evidence for global ACSs was reported in a study by Irons and Remington (2013), in which, even though the distractor was not fully matched with the target-defining features, it induced attentional interference.

However, the examination for multiple ACSs in Becker et al.'s (2015) and Irons and Remington's (2013) studies was limited, because they tested for the possibility of local ACSs only through interference by nonmatching distractors, but not through interference by matching distractors. In their experimental design, when both the color and location of the distractor were fully matched with those of the target, it was exactly same as the target. Thus, it was impossible to measure the amount of interference by the matching distractor using their methods. Importantly, if the ACSs for color targets at distinct locations are applied globally rather than locally, the interference effect of the distractor would not differ, regardless of the match of features between the target and distractor. However, if an ACS for each color target is generated for a specific location, a distractor would capture attention only when its features corresponded with the conjunction of the target features.

Present study

The goal of the present study was to investigate whether multiple ACSs are generated locally at distinct locations when targets are defined as conjunctions of color and location. Critically, the examination of the possibility of location-specific ACSs in the present study was twofold, accomplished through a comparison of the effects of distractors, depending on whether their features matched the ACS (Exp. 1), and an examination of the repetition-priming effect on cue validity (Exp. 2). To generate multiple ACSs at separate locations, two colors were applied as target-defining features, but each color was restricted to a distinct location, such as the left or the right side of the display, as in the previous studies (Adamo, Pun, & Ferber, 2010; Adamo et al., 2008; Becker et al., 2015; Irons & Remington, 2013; Parrott, Levinthal, & Franconeri, 2010).

Experiment 1 was intended to examine the specificity of ACSs by comparing the interference effects from ACS-matching distractors and ACS-nonmatching distractors. For this, two separate phases (e.g., training phase and test phase) were used in Experiment 1. A training phase was conducted in order to produce multiple ACSs at distinct locations, and a test phase to examine the attentional interference by the two types of distractors. It had previously been reported that an ACS was persistently maintained in a subsequent task, beyond the end of the task in which it had been generated (Cosman & Vecera,

2013; Leber & Egeth, 2006a, 2006b; Sha & Jiang, 2016). Note that this generalized influence of ACS is conceptualized as *selection history* (Awh, Belopolsky, & Theeuwes, 2012), which refers to the prioritized attentional processing of features that have been attended before, independently of top-down or bottom-up modulations of attention. Thus, the configuration of ACSs generated in the training phase would be reflected in the test phase as interference effects by distractors with the previous target-defining features. Importantly, supposing that ACSs cannot be generated at distinct locations simultaneously, the ACSs for multiple targets would be applied widely in the training phase, even though participants were to search for targets defined as the conjunction of color and location. Accordingly, in the test phase, no different interference effect would be obtained, irrespective of whether the color and location of the distractor were compatible with the target-defining features.

In Experiment 2 we aimed to examine the possibility of multiple ACSs at separate locations via the spatial cueing paradigm, in which the impact of cue repetition priming was controlled. For instance, a target letter was presented at one of four placeholder locations; the target was defined as a conjunction of color and location, such as a red letter in one of the left two placeholders and a green letter in one of the right two placeholders. However, participants were to ignore the opposite cases, such as a red letter in the right side of the display and a green letter in the left side, and to withhold their response. Critically, prior to the target presentation, a noninformative cue colored either red or green was presented in one of the four placeholders. Therefore, the specificity of ACSs for multiple targets would be reflected by the amounts of attentional capture by the color cues. If the ACS for each color was generated independently at each corresponding location, the attentional capture would be modulated depending on the compatibility between the features of the cue and target. For example, if the targets were defined as a left red letter and a right green one, the cue-validity effect would be obtained by the left red cue and the right green cue, but not by the left green cue and the right red cue. Unlike in previous studies, a *neutral target* color, blue, was used as well, to avoid the confounding effect of cue–target repetition priming. Participants were instructed to respond to the blue target regardless of its location. Because the color of the spatial cue was either red or green, the blue target was never primed by any cue color. Thus, the cue-validity effect for the neutral target was not confounded with cue–target repetition priming, which allowed us to test for the possibility of multiple ACSs at distinct locations without the cue–target repetition priming effect. Critically, if dual ACSs could be maintained locally, the cue would capture attention only when its features were congruent with those of the targets, independent of cue–target repetition. Specifically, the cue-validity effect by the matching cue would be obtained not only for the red or the green target, but also for

the blue target. On the contrary, if asymmetrical cue validity depending on the match between the cue and the target resulted from cue–target repetition, the cue-validity effects of the matching and nonmatching cues would be similar for the neutral target, due to the lack of cue–target repetition priming.

Experiment 1

The goal of Experiment 1 was to examine whether multiple ACSs are maintained for separate locations simultaneously by using the visual search paradigm. Each participant performed visual search tasks in two different phases: training and test. In the training phase, to generate two different ACSs at distinct locations, participants were to search for a colored target that was defined as a combination of its color and location. For instance, one target was defined as a red circle on the right side of the display, and the other target was defined as a green circle on the left side. Because each color was restrictedly valid as a target-defining feature in a specific area, an ACS for each target color was assumed to be maintained at a restricted location. Subsequently, in the test phase, participants were to perform another visual search task in which they were instructed to search for a target defined as a diamond shape among circles and to ignore the colors of the stimuli. Of importance, a red or green circle was presented as a color distractor in half of the trials, and its interference effect would occur in accordance with the ACSs generated in the previous training phase. Previous studies showed that an ACS generated in one phase persisted in the subsequent phase (Cosman & Vecera, 2013; Leber & Egeth, 2006a, 2006b; Sha & Jiang, 2016), consistent with the selection history account (Awh et al., 2012). Especially, Sha and Jiang demonstrated that the color that was a target-defining feature in the training phase captured attention in the subsequent test phase, even though it was nonsalient and task-irrelevant. Thus, the ACSs generated in the training phase would elicit a pattern of attentional bias revealing the specificity of ACSs.

If an independent ACS for each color target was generated at a distinct location in the training phase (Adamo, Pun, & Ferber, 2010; Adamo et al., 2008; Adamo, Wozny, et al., 2010), the interference by each color distractor would differ in accordance with its location in the test phase. Specifically, if a red circle on the right side or a green circle on the left side was a target in the training phase, the red distractor would capture attention when it was presented on the right side but not when it was presented on the left side in the test phase, and vice versa for the green distractor. On the other hand, if multiple ACSs for the target colors were not generated locally for different locations in the training phase, attentional interference by a distractor in the test phase would be constant, regardless of the match of the distractor with the ACS. For example, the red distractor would cause the same amount of

interference regardless of its location, as would the green distractor.

Method

Participants Twenty-four undergraduate students (mean age = 23.08; 14 male, ten female) from Korea University participated for a monetary reward of KRW 6,000 (about 5 USD). All participants had normal or corrected-to-normal visual acuity and color vision by self-report. The present and following experiments were approved by the Institutional Review Board at Korea University (KU-IRB-16-138-A-1).

Apparatus All experiments were programmed and presented using the E-Prime software (Version 2.0, Psychology Software Tools, Inc.) running on a personal computer. Stimuli were presented on a 17-in. CRT monitor at a viewing distance of approximately 60 cm in a dimly lit room. Responses were collected using a standard computer keyboard.

Stimuli All stimuli were presented on a black background. In the training phase, each trial consisted of a fixation display, a search display, and a feedback display (see Fig. 1). In the fixation display, a white fixation cross ($0.75^\circ \times 0.75^\circ$ visual angle; RGB: 255, 255, 255; CIE color coordinates: $x = .270, y = .297$) was presented at the center of the display. The search display consisted of the fixation cross and six colored circles ($2.3^\circ \times 2.3^\circ$ each), three on each side of fixation. The four circles, two of which were located in either the upper or the lower area, were presented at the

corners of an imaginary square ($7^\circ \times 7^\circ$), and the middle two circles were located at the horizontal meridian and 4.6° away from the vertical meridian on either the left or the right side. The target was defined as a red (RGB: 255, 0, 0; CIE color coordinates: $x = .581, y = .346$) or a green (RGB: 0, 255, 0; CIE color coordinates: $x = .285, y = .599$) circle, and the colors of each nontarget circle were randomly selected from a set of blue (RGB: 0, 0, 255; CIE color coordinates: $x = .152, y = .080$), yellow (RGB: 255, 255, 0; CIE color coordinates: $x = .388, y = .513$), magenta (RGB: 255, 0, 255; CIE color coordinates: $x = .262, y = .148$), purple (RGB: 127, 0, 255; CIE color coordinates: $x = .183, y = .099$), orange (RGB: 255, 127, 0; CIE color coordinates: $x = .498, y = .418$), and gray (RGB: 127, 127, 127; CIE color coordinates: $x = .274, y = .297$), without replacement. Each circle contained a white line segment. The orientation of the line was either vertical or horizontal inside the target circle and was tilted 45° to the left or right inside the nontarget circles. When a correct response was made, the feedback display informed participants that their response was correct by showing written feedback: 맞습니다 (“Correct” in Korean). For an incorrect response, a 1000-Hz tone sounded for 500 ms.

In the test phase, each trial consisted of a fixation display, a search display, and a feedback display, as in the training phase (see Fig. 2). The test phase differed in that the search display consisted of six shapes in which the target was defined as a diamond shape ($2.5^\circ \times 2.5^\circ$) among circles ($2.3^\circ \times 2.3^\circ$ each). The color of the diamond was randomly selected from a set of blue, yellow, magenta, purple, orange, and gray but was never a target color from the training phase.

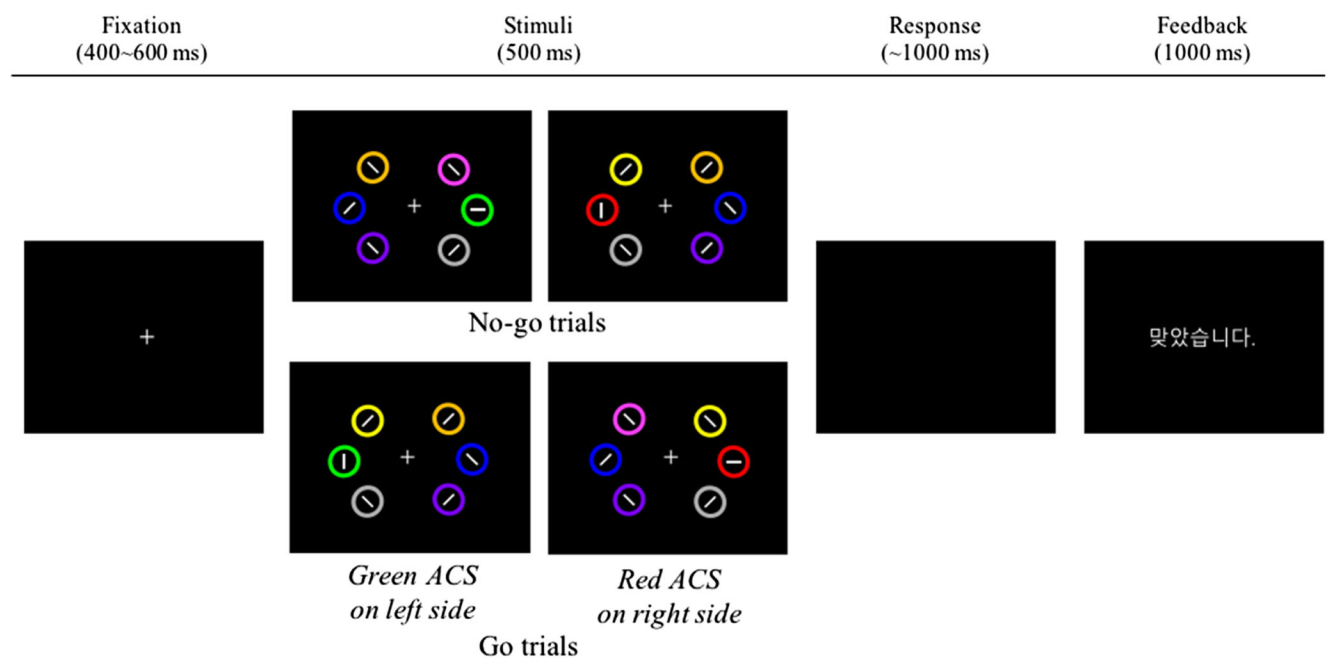


Fig. 1 Example of a trial sequence in the training phase of Experiment 1

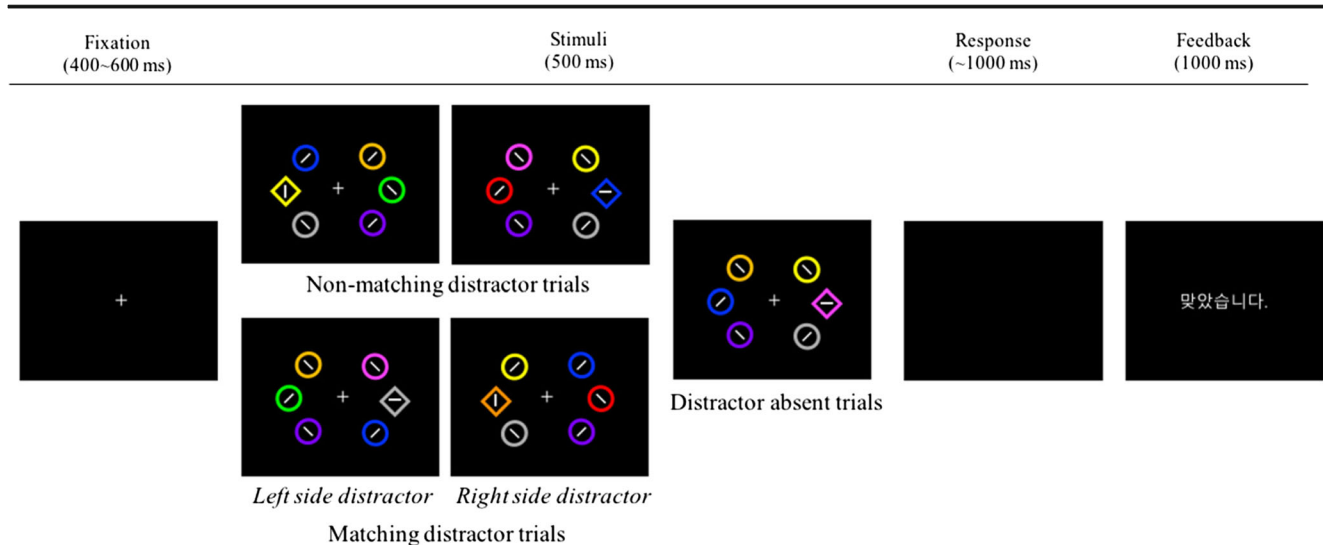


Fig. 2 Example of a trial sequence in the test phase of Experiment 1

Procedure In the training phase, participants performed 576 trials, which were preceded by 36 practice trials. Each trial began with the fixation display for a random interval of 400, 500, or 600 ms. After the fixation display, the search array was presented for 500 ms, followed by a blank display until a response, within the time limit of 1,000 ms. The feedback display was presented for 1,000 ms.

Participants were asked to respond to the orientation of the line in the target color circle (e.g., red or green) among heterogeneous color circles only when the target was presented on a particular side of the display (e.g., red circle on the right side and green circle on the left side; go trials), whereas they were to make no response when a target-color circle was presented on the opposite side (e.g., red circle on the left side and green circle on the right side; no-go trial). For go trials, participants were instructed to press the “f” key for a vertically oriented bar and the “j” key for a horizontally oriented bar inside the target circle. For no-go trials, participants were instructed to withhold a response.

In the test phase, participants performed 288 trials, which were preceded by eight practice trials. The procedure was identical to that of the training phase, with the exception that the target was a diamond shape among circles, and a red or green circle was included as a distractor in half of the trials. Participants were instructed to respond to the orientation of the line inside the diamond. Importantly, red and green circles were included equally as distractors in half of the trials, and the distractor location was balanced between the left and right sides. When the distractor was presented on the side where a go response had been required in the training phase, this distractor was called a “matching distractor” (e.g., a red circle on the right side or a green circle on the left side). Otherwise, it was called a “nonmatching distractor” (e.g., a red circle on the left side or a green circle on the right side).

Design In the training phase, half of the trials were go trials, and the others were no-go trials. The target location, line orientation, and target color were fully crossed and counterbalanced. Trials were presented in a random order, so that the target color and location varied unpredictably. The color–location combination and stimulus–response mapping were counterbalanced across participants.

In the test phase, half of the trials included a distractor, and the others did not. Again, half of the distractor-present trials contained a matching distractor presented equally on the left or the right side, whereas the other half included a nonmatching distractor on either side equally. The target location and bar orientation were fully crossed and counterbalanced, and trials were presented in a random order. Thus, trial type, target color, and location varied unpredictably. The color–location combination and stimulus–response mapping were counterbalanced across participants.

Results

Trials were excluded from the analyses if RTs were shorter than 150 ms or longer than three standard deviations (*SDs*) above the mean for each participant (2.63% of the trials in the training phase and 2.26% of the trials in the test phase), and only correct trials were included in the RT analyses. Mean correct RTs and percent errors (PEs) were calculated for each participant as a function of go target location (left or right) in the training phase and distractor type (matching distractor, nonmatching distractor, or distractor absent) in the test phase. Repeated measures analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with those variables as within-subjects factors for each phase.

Training phase The overall mean RT in go trials was 778 ms. The mean hit rate was 93.9% (*SD* = 6.1), and the mean false

alarm rate was 3.9% ($SD = 4.6$). Sensitivity (d') and response criterion (C) were 3.31 and -1.76 , respectively. The main effect of go target location was significant, $F(1, 23) = 9.67$, $MSe = 1,103.5$, $p = .0049$, $\eta_p^2 = .2960$, indicating that responses to the left go targets ($M = 761$ ms) were faster than responses to the right go targets ($M = 791$ ms). The overall PE was 6.06%, with no significant main effect of target location in the PE data (Table 1).

Test phase The overall RT was 627 ms. Importantly, the main effect of distractor type was significant, $F(2, 46) = 14.62$, $MSe = 308$, $p < .0001$, $\eta_p^2 = .3887$. Scheffe's post-hoc analysis revealed that the mean RT was significantly greater for the matching distractor ($M = 644$ ms), which was presented in the location where it had been a target in the go trials of the training phase, than for the nonmatching distractor ($M = 622$ ms), which was presented in a location from the no-go trials, or for when a distractor was absent ($M = 619$ ms). This indicated that the matching distractor captured attention, resulting in significant attentional interference (25 ms), whereas the nonmatching one did not (3 ms; see Fig. 3). The overall PE was 4.01%. No main effect or interaction reached significance in the PE data (Table 2).

Discussion

Consistent with the idea that multiple ACSs are applied over distinct locations simultaneously, distractor interference was obtained in the test phase as a function of distractor color and its location, indicating that the ACS for each color was generated at a particular location in the training phase. Accordingly, a significant interference effect (25 ms) was evident in the test phase only when the color and location of the distractor matched those of the target in the training phase.

The interference effect obtained was caused by the carry-over effect of past conjunctive ACSs rather than by bottom-up salience or a top-down task goal, because this distractor was neither salient nor task-relevant. Critically, this experience-driven attentional capture was found even when the maintenance of these irrelevant ACSs was counterproductive to searching for a shape singleton target in the test phase in the present study, whereas it had previously been obtained when the past ACS was still compatible with searching for a target in a subsequent search task (Cosman & Vecera, 2013; Leber &

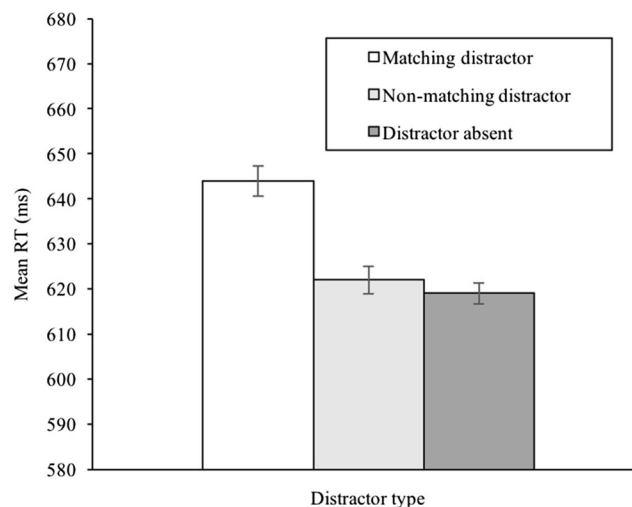


Fig. 3 Mean reaction times (RTs, in milliseconds) as a function of distractor type in Experiment 1. Error bars show ± 1 within-subjects standard error of the mean (Cousineau, 2005)

Egeth, 2006a). Similarly, in Anderson's (2015) Experiment 2B, when reward was associated with conjunctive target stimuli in a training phase, such as a red circle on the right side and a green circle on the left side, distractors with the rewarded targets' features captured attention in a subsequent test phase, even though they were nonsalient and irrelevant to the current task set. Thus, the findings of the present experiment demonstrated that involuntary attentional capture occurred for a stimulus with features that had been previously attended on the basis of the past ACS, independent of physical salience, current goal, or even reward history, consistent with the selection history account (Awh et al., 2012; Sha & Jiang, 2016).

Unexpectedly, in the training phase, locally prioritized processing was observed so that the mean RT of the target on the left side ($M = 761$ ms) was shorter than that of the target on the right side ($M = 791$ ms). This result might have occurred because participants prioritized the ACS for the left location rather than maintaining dual ACSs evenly. However, additional analyses revealed that the interaction of distractor location (left or right) and distractor type (matching or nonmatching) was not significant, $F < 1$ (see Fig. 4). This indicates that, irrespective of the distractor location, the matching distractor elicited longer delay of responses than the nonmatching distractor in the test phase. Thus, even though participants

Table 1 Mean reaction times (RTs, in milliseconds, with standard deviations in parentheses) and percent errors in the training phase of Experiment 1 as a function of target type

	Left go target	Right go target
RT	761 (107)	791 (106)
PE	5.71 (6.26)	6.50 (6.35)

Table 2 Mean reaction times (RTs, in milliseconds, with standard deviations in parentheses) and percent errors in the test phase of Experiment 1 as a function of distractor type

	Matching distractor	Nonmatching distractor	Distractor absent
RT	644 (84)	622 (75)	619 (77)
Interference effect	25	3	
PE	4.10 (4.40)	3.71 (3.77)	4.13 (3.65)

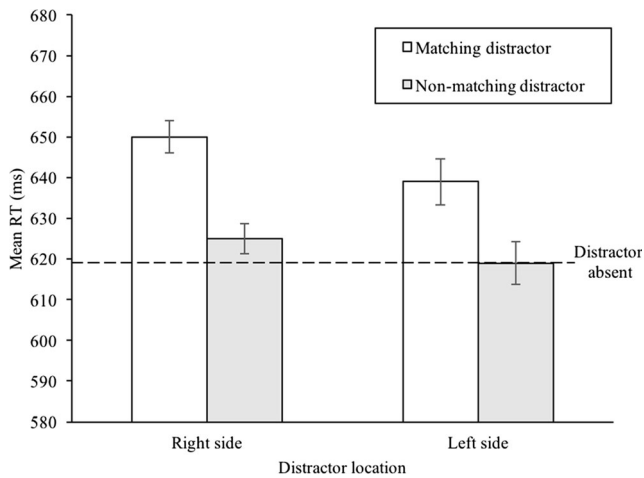


Fig. 4 Mean reaction times (RTs, in milliseconds) as a function of distractor location and distractor type in Experiment 1. Error bars show ± 1 within-subjects standard error of the mean (Cousineau, 2005)

might have maintained the dual ACSs asymmetrically in the training phase, the same amount of interference being exerted by the matching distractors at both locations reflects the existence of independent ACSs at specific locations.

Experiment 2

In Experiment 2 we aimed not only to generalize the findings of Experiment 1 with the spatial cueing paradigm, but also to examine the influence of cue–target repetition priming on the cue–validity effect. The existence of multiple ACSs at distinct locations was inferred indirectly on the basis of experience-driven attentional capture depending on the past ACSs. The

use of the spatial cueing paradigm allowed us to examine the possibility of multiple ACSs at separate locations directly, on the basis of the cue–validity effect depending on the current ACSs. To generate multiple ACSs at different locations, as in Experiment 1, the target was defined as a function of its color and location. Specifically, participants were to respond to the identity of the target letter L or T, which was colored in red, green, or blue. Importantly, different go/no-go task rules were applied to the red and green targets, called the “location-relevant targets.” For half of the participants, the go trials were designated to a red letter in a placeholder located on the right side and a green letter on the left side. The no-go trials were the opposite combinations of its color and location (e.g., a red letter on the left side and a green letter on the right side). For the other participants, the go and no-go targets were defined in the opposite way. A noninformative color cue was presented at the periphery of a placeholder before the onset of the target display, and its color was either red or green. When the color and location of the cue were matched with the ACSs on go trials (e.g., a red cue on the right side or a green cue on the left side), this cue was called the “ACS matching cue”; otherwise, it was called the “ACS nonmatching cue.”

Importantly, cue–target repetition priming had possibly been confounded with the cue–validity effects of the ACS matching and nonmatching cues in Adamo et al.’s (2008) experiments, as some researchers have argued (Becker et al., 2015; Parrott et al., 2010). That is, the difference in the cue–validity effects between the matching and nonmatching cues might have been due to the cue–target repetition-priming effect rather than to the local ACSs. However, this confounding effect has not yet been directly examined. In Experiment 2, to test this possibility, a *neutral target* was presented in half of

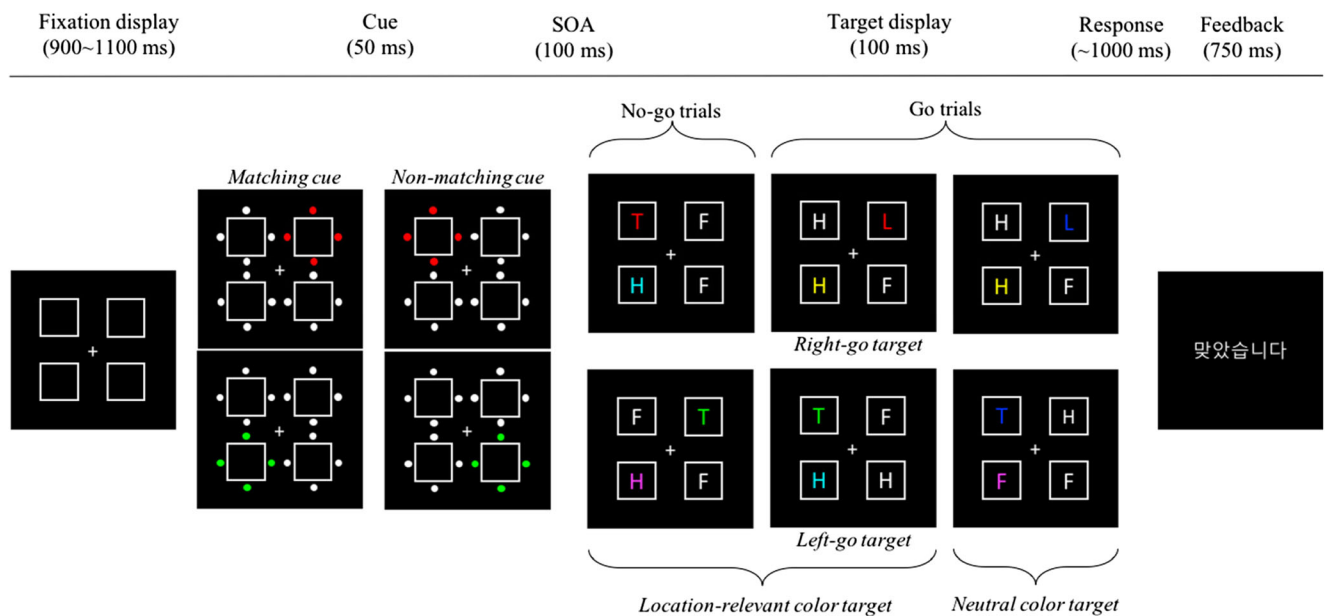


Fig. 5 Example of a trial sequence in Experiment 2

the go trials, which was colored blue so that the color of the target was never identical to that of the cue. Participants were instructed to identify a blue letter regardless of its location.

If the multiple ACSs for the two different colors were set but applied globally, regardless of whether the cue was matching or nonmatching, the color cue would capture attention. In addition, if the color and location of cue primed the target feature, the cue validity would be greater with the matching than with the nonmatching cue. However, the priming modulation would be evident only for the location-relevant targets and not for the neutral target, because of the lack of cue–target repetition. However, if multiple ACSs were formed as a conjunction of color and location, the matching cue would capture attention but the nonmatching cue would not, irrespective of target type.

Method

Participants A new group of 24 undergraduate students (mean age = 23.42, $SD = 2.48$; 15 male, nine female) from Korea University took part in Experiment 2 for a monetary reward of KRW 6,000 (about 5 USD).

Apparatus and stimuli The apparatus was identical to that used in Experiment 1. All stimuli were presented on a black background. Each trial consisted of a fixation display, a cue display, another fixation display, a target display, and a feedback display. The fixation display consisted of a fixation cross ($0.75^\circ \times 0.75^\circ$) at the center of the screen and four placeholders ($1.9^\circ \times 1.9^\circ$ each), located at the corners of an imaginary square ($3.6^\circ \times 3.6^\circ$). Each peripheral placeholder, drawn with a white line (0.08°), was equidistant from the central fixation cross (2.5° center to center) and from the adjacent placeholders (3.6° center to center). After the fixation display, the cue display was presented. The cue display consisted of the fixation display with the addition of four dots with a radius of 0.16° surrounding each placeholder, in a diamond pattern. One set of the dots was colored red or green, whereas the other three sets were white. The target display consisted of the fixation display with the addition of four letters inside of placeholders. The target was defined as the letter L or T colored red, green, or blue. The three nontarget stimuli were F or H, two among which were white and the other randomly selected from yellow, cyan, and magenta without replacement as distractors, to prevent singleton search mode (Bacon & Egeth, 1994). When a correct response was made, the feedback display informed participants that their response was correct by showing letter feedback: 맞습니다 (“Correct” in Korean). For an incorrect response, a 1000-Hz tone sounded for 500 ms.

Procedure Each participant performed 768 trials, which were preceded by 24 practice trials. Each trial began with the

fixation display for a random interval of 900, 1,000, or 1,100 ms. Then the cue display was presented for 50 ms. The fixation display then reappeared for 100 ms, followed by the target display for 100 ms. After the blank display, presented until a response within the time limit of 1,000 ms, the feedback display was presented for 750 ms.

Participants were asked to respond to the L or T depending on the go/no-go task rules formulated according to combinations of the target color and location. For the red or green target, participants were to make a response only when the red or green target (location-relevant target) was presented on a particular side of the display (e.g., a red letter on one of the two right placeholders or a green one on one of the two left placeholders; go trials), whereas they were not to make a response when a red or green letter was presented on the opposite side (e.g., red on one of the two left placeholders or green on one of the two right placeholders; no-go trials). Importantly, participants were to respond to the identity of a blue-colored target letter regardless of its location (neutral target). For go trials or a blue target, participants were instructed to respond by pressing the “f” key for the letter L and the “j” key for the letter T. The color–location combination and stimulus–response mapping were counterbalanced across participants (Fig. 5).

Design Cue type, cue location, target location, and target color were fully crossed, and trials were presented in a random order. Thus, a cue conveyed no information about the upcoming target location and color. Half of the trials were no-go trials, and the rest were go trials, half of which contained a red or a green target (location-relevant target: left-relevant or right-relevant target), whereas the others included a blue target (neutral target).

Results

With the same exclusion criteria as in Experiment 1, 3.85% of the trials were removed from the analyses. The mean correct RTs and PEs were calculated for each participant as a function of cue type (matching or nonmatching cue), target type (left-relevant, right-relevant, or neutral target), and cue validity (valid or invalid cue). Repeated measures ANOVAs were conducted on the mean RT and PE data, with those as within-subjects factors (Table 3).

RT The overall mean RT was 835 ms. The main effect of target type was significant, $F(2, 46) = 63.82$, $MSe = 7,518$, $p < .0001$, $\eta_p^2 = .7351$. Scheffé’s post-hoc analyses revealed that the mean RT for the neutral target ($M = 776$ ms) was the shortest among all target types, and that the mean RT for the left-relevant targets ($M = 851$ ms) was shorter than that for the right-relevant targets ($M = 918$ ms). The main effect of cue validity was

Table 3 Mean reaction times (RTs, in milliseconds, with standard deviations in parentheses) and percent errors in Experiment 2 as a function of target type, cue type, and validity

		Left go target		Right go target		Neutral target	
		Matching cue	Nonmatching cue	Matching cue	Nonmatching cue	Matching cue	Nonmatching cue
RT	Invalid	868 (96)	854 (104)	928 (108)	908 (125)	795 (82)	781 (82)
	Valid	816 (135)	864 (143)	902 (138)	933 (138)	761 (101)	769 (93)
	<i>Cue-validity effect</i>	52	- 10	26	- 25	34	12
PE	Invalid	4.42 (4.02)	4.86 (4.25)	3.82 (3.85)	5.13 (4.19)	2.61 (2.31)	3.31 (3.58)
	Valid	3.25 (4.95)	4.37 (6.39)	2.23 (4.68)	3.35 (7.37)	3.25 (3.68)	3.19 (3.61)

marginally significant, $F(1, 23) = 3.14$, $MSe = 4,954$, $p = .089$, reflecting that the responses in valid trials ($M = 841$ ms) were marginally faster than those in invalid trials ($M = 856$ ms). The main effect of cue type was not significant, $F(1, 23) = 2.83$, $MSe = 2,241$, $p = .106$. Neither the interaction of target type and cue type, $F(2, 46) = 1.41$, $MSe = 1,591$, $p = .254$, nor the interaction of target type and cue validity, $F(2, 46) = 2.22$, $MSe = 1,656$, $p = .120$, was significant. Importantly, the interaction of cue type and cue validity was significant, $F(1, 23) = 36.2$, $MSe = 1,039$, $p < .0001$, $\eta_p^2 = .6115$. Separate analyses confirmed that matching cues produced a significant cue-validity effect (38 ms), $F(1, 23) = 11.28$, $MSe = 4,499$, $p = .0027$, $\eta_p^2 = .3291$, whereas nonmatching cues did not (- 8 ms), $F(1, 23) = 1.61$, $MSe = 1,494$, $p = .2176$. The three-way interaction of target type, cue type, and cue validity was not significant, $F(2, 46) = 1.75$, $MSe = 1,454$, $p = .1851$, demonstrating that the interaction between cue type and cue validity was not modulated by target type. Indeed, a significant

interaction between cue type and cue validity was found not only for a right-relevant target, $F(1, 23) = 11.50$, $MSe = 2,029$, $p = .0025$, $\eta_p^2 = .3333$, or a left-relevant target, $F(1, 23) = 11.51$, $MSe = 1,414$, $p = .0025$, $\eta_p^2 = .3336$, but also for a neutral target, $F(1, 23) = 6.13$, $MSe = 503$, $p = .021$, $\eta_p^2 = .2105$ (Fig. 6). Thus, these findings indicate that the evidence of attentional capture by the matching cue was constantly obtained, regardless of target location (e.g., left or right) and cue-target repetition (e.g., location-relevant or neutral).

PE The overall PE, including both go and no-go trials, was 3.85%. The mean hit rate of go trials was 96.4% ($SD = 2.5$), and the mean false alarm rate of no-go trials was 3.39% ($SD = 1.8$). A significant main effect of cue validity was observed, $F(1, 23) = 5.75$, $MSe = .00071$, $p = .025$, $\eta_p^2 = .2001$, indicating that more errors were committed on invalid trials ($M = 4.0\%$) than on valid trials ($M = 3.3\%$). No other main effect or interaction was significant.

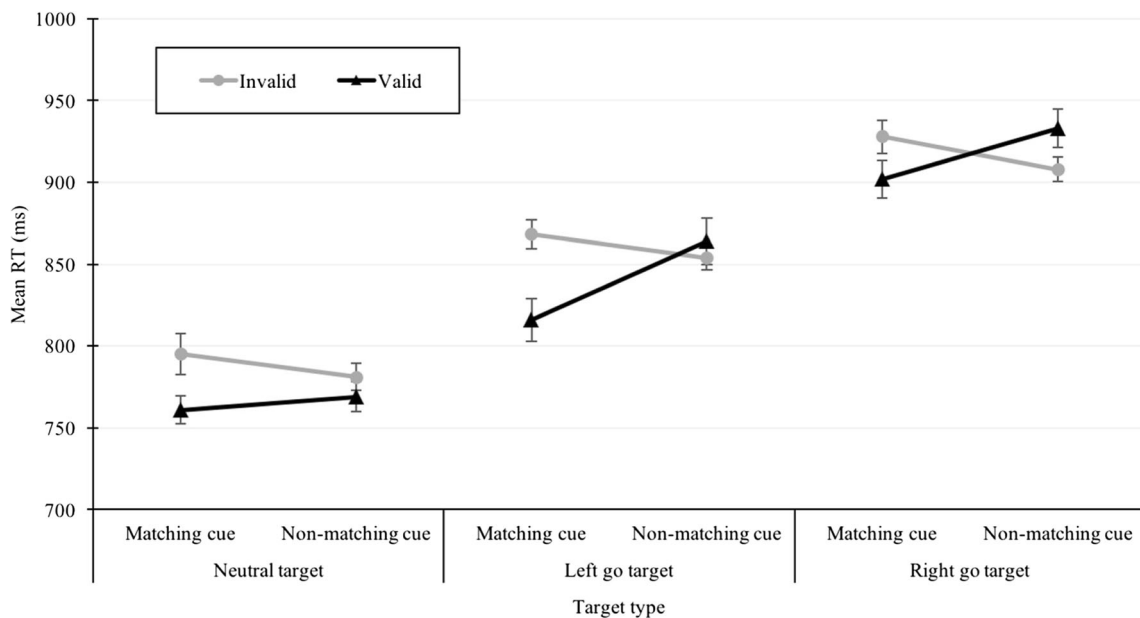


Fig. 6 Mean reaction times (RTs, in milliseconds) as a function of target type, cue type, and validity in Experiment 2. Error bars show ± 1 within-subjects standard error of the mean (Cousineau, 2005)

Discussion

As in Experiment 1, a spatial cue captured attention only when its color and location were identical with those of the target of go trials, resulting in a significant cue-validity effect for the matching cue (38 ms) but not for the nonmatching cue (− 8 ms). Thus, for conjunctive targets defined as a combination of color and location, the ACSs for different colors could be maintained simultaneously at particular locations, consistent with the results of previous studies (Adamo, Pun, & Ferber, 2010; Adamo et al., 2008; Adamo, Wozny, et al., 2010). In particular, even with the neutral target, a significant cue-validity effect was obtained with the matching cue (34 ms), $F(1, 23) = 14.23$, $MSe = 980$, $p = .001$, $r_p^2 = .3822$, but not with the nonmatching cue (12 ms), $F(1, 23) = 2.19$, $MSe = 710$, $p = .152$, suggesting attentional capture by the matching cue without any confounding effect of cue–target repetition priming. Furthermore, the lack of a three-way interaction of target type, cue type, and cue validity indicates that the sizes of the cue-validity effect for different types of targets were similar, although a red or green target was possibly primed by the color of the cue, whereas the neutral target (e.g., blue) was not. Thus, cue–target repetition priming failed to modulate the cue-validity effect in the present experiment, which is inconsistent with the idea that the cue-validity effect varies as a function of color and location as a result of cue–target repetition priming (Becker et al., 2015; Parrott et al., 2010). In sum, when multiple targets were defined depending on a specific color in a limited area, the ACSs for different color targets were applied to restricted locations independently and simultaneously, and this was not due to cue–target repetition priming.

Consistent with the target type effect in the training phase of Experiment 1, a significant target type effect was obtained in Experiment 2, suggesting that the mean RT for the left-relevant target ($M = 851$ ms) was shorter than that for the right-relevant target ($M = 918$ ms). It is assumed that two factors could cause this left-prioritized processing. First, the instructions for the targets were given in a form such as “You should search for a green stimulus on the left side and a red stimulus on the right side.” Thus, the sequence of the targets’ introduction in the instructions might have prioritized the production of ACSs for the left side, consistent with the previous findings that the instructions play an important role in the top-down strategy (e.g., Klink, Jentgens, & Lorteije, 2014). In addition, visual field asymmetries in attentional processing has been reported for targets (Asanowicz, Śmigasiewicz, & Verleger, 2013), spatial cues (Śmigasiewicz, Asanowicz, Westphal, & Verleger, 2015; Śmigasiewicz, Westphal, & Verleger, 2017), and distractors (Burnham, Rozell, Kasper, Bianco, & Dellituri, 2011; Du & Abrams, 2010), suggesting that stimuli on the left side of the visual field were given

processing priority, as compared to those on the right side. This phenomenon has been hypothesized to be a reflection of asymmetrical abilities of an attentional mechanism in the different hemispheres of the brain.

General discussion

In the present study, the possibility of maintaining multiple ACSs at separate locations was examined with two different experimental paradigms. In Experiment 1, a visual search task was used in which participants were to search for one of two targets defined as conjunctions of color and location, to prompt the formation of multiple ACSs at separate locations in the training phase. In the subsequent test phase, in which the target was defined as a diamond, the interference effect was significant only when the color and location of the distractor were compatible with the conjunctions of the target-defining features in the training phase, but not when they were incompatible. Thus, this result indicates that dual ACSs at different locations were formed in accordance with the target definitions. The spatial cueing paradigm was used in Experiment 2 to generalize the possibility of multiple simultaneous ACSs and to control the influence of cue–target repetition priming on cue validity depending on the cue types. Consistent with previous reports (Adamo, Pun, & Ferber, 2010; Adamo et al., 2008; Adamo, Wozny, et al., 2010), the cue-validity effect depended on whether the color and location of the cue were matched with the target-defining features in the ACSs. For example, a significant cue-validity effect was obtained with a matching cue whose features were suited with the target definition, whereas no effect was obtained with a nonmatching cue. Of importance, this contingent capture by the matching cue was obtained even when the colors of the matching cue and the target were not repeated. Additionally, the size of the cue-validity effect did not change depending on the target type. These results indicate that attentional capture occurs on the basis of the compatibility between the cue and the ACS, independent of cue–target repetition priming.

Attentional processing of the nonmatching stimuli

Interestingly, no significant interference by a distractor was obtained in the test phase of Experiment 1 when the distractor’s features were not completely matched with the target definition in the previous training phase, whereas previous studies had shown that significant attentional interference by a stimulus was obtained even when the features of the stimulus only partially matched the features of the target (Becker et al., 2015; Irons & Remington, 2013; Parrott et al.,

2010). This discrepancy may be attributed to a critical difference in terms of the task relevance of the distractor features. Specifically, in the present study the distractors were completely irrelevant in the test phase, in which the target was defined as a shape singleton independent of its color. In contrast, attentional interference by a nonmatching distractor was obtained when the distractor shared a relevant feature with the “current” targets, such as either color or location. For example, in Becker et al.’s Experiments 1 and 2, the distractors were colored green or blue, which was identical to the colors of the targets, but the distractors were presented at a location mismatched with the target definition for the color. In the same vein, Irons and Remington used an RSVP task to test local ACSs in their experiments, in which the color of the distractor was the same as the target color, but its location was different from the target definition. In both studies, although the distractors did not completely share the features of the target, the distractors did capture attention.

According to Adamo, Pun, and Ferber’s (2010) ERP study, in which the mechanism of the multiple ACSs was examined using a method similar to that in Adamo et al.’s (2008) study, the operation of local ACSs is based on the interplay of two attentional mechanisms, *feature-* and *space-*based attention. The RT data in their study showed a significant cue-validity effect for matching cues but not for nonmatching cues. However, they found that the amplitude of the N2pc was modulated by cue validity regardless of cue color, indicating space-based attention, whereas the amplitude of the P3 depended on the compatibility between the cue and target colors, irrespective of their locations, indicating feature-based attention. In this view, as regards feature-based attention, which is one of the mechanisms for the construction of multiple ACSs, a stimulus containing the currently relevant color, such as nonmatching distractors, might draw attention (Becker et al., 2015; Irons & Remington, 2013). In contrast, if the task was changed so that the maintenance of the previous ACSs was not necessary, the impact of the past ACSs might not be as powerful. In short, the *relevant* distractors in the previous studies could elicit stronger attentional slippage than did the *irrelevant* distractors in the present study, even though both distractors were nonmatching stimuli.

Importantly, the nonmatching cue did not capture attention in Experiment 2, although other studies had shown significant cue-validity effects with nonmatching cues in ERP data (Adamo, Pun, & Ferber, 2010) and behavioral data (Parrott et al., 2010, Exp. 2). One possible reason for this inconsistency is a difference in the available search strategies. In the latter studies, since no distractor was presented in the target display, a color singleton search mode was possibly utilized to search for the target (Bacon & Egeth, 1994), resulting in a significant cue-validity effect being caused by any color cue. On the contrary, since an irrelevant color distractor was always presented with the target in Experiment 2, a feature search mode

was more likely to be utilized (Folk & Remington, 1998; Grubert & Eimer, 2016; Irons et al., 2012), resulting in a significant cue-validity effect only by the target-matching cue. Remarkably, Grubert and Eimer reported that behavioral measures showed an attentional capture effect only for the target-matching cue but not for an irrelevant color cue, while N2pc components were obtained for both cue types, as in Adamo, Pun, and Ferber’s experiment. However, when different color distractors were included in the target display, an N2pc component was elicited only by the target-matching cue, but not by the nonmatching cue. Overall, even though Adamo, Pun, and Ferber concluded that the conjunctive ACSs did not rely on early attentional processing, it is still unclear whether nonmatching stimuli can be successfully rejected by an early attentional filter when top-down demands for feature-specific search settings are sufficiently met, as in the present study.

Attentional inhibition on the no-go target features

Irons and Remington (2013) explored the possibility that inhibitory attentional processing for nonmatching distractors operates in a color–location-specific manner. They used an RSVP task in which the target was defined as a set for a specific colored stimulus at a certain location. In their Experiment 3, to explore whether participants could suppress the nonmatching distractor, the cue containing the upcoming distractor’s features was previewed early in each given trial. Interestingly, the interference effect by the distractor was reduced when the distractor-matching cue was previewed. This suggests that the inhibitory processing on the distractor could operate on the basis of the distractor’s features as the conjunction of its color and location. Note that, in their study, the distractor was a no-go stimulus, in that participants were not to respond to it, although its color was identical to the target color. In this view, it was consistent with the previous findings that the no-go target color was actively suppressed in their experiment, resulting in a negative cue-validity effect in the spatial cueing paradigm (Anderson & Folk, 2012; Belopolsky, Schreij, & Theeuwes, 2010).

Likewise, in Experiment 2 of the present study, in which a go/no-go task rule was applied as a function of features to produce the local ACSs, the nonmatching cue tended to elicit a negative cue-validity effect for the right (e.g., – 25 ms) and left (e.g., – 10 ms) go targets. This finding might reflect attentional suppression of the nonmatching stimuli, since the cues contained the features of the no-go targets. However, because these negative cue-validity effects were not statistically reliable, it is not clear whether multiple ACSs based on dual inhibitory attentional processing were in operation. Furthermore, in Experiment 1 no evidence of attentional suppression, such as a negative distracting effect by a nonmatching distractor, was found. On the other hand,

facilitative attentional processing was reliably obtained with the go target, resulting in attentional capture by a matching distractor (Exp. 1) or spatial cue (Exp. 2). Participants seemed to employ attentional controls that facilitated attentional engagement with the target-defining features as a primary strategy, and inhibited the to-be-neglected stimuli as a secondary strategy. The cooperation of the primary and secondary strategies implies that participants could optimize their top-down control when facing complicated task goals.

The impact of repetition priming on cue validity

As we mentioned earlier, Becker et al. (2015) and Parrott et al. (2010) suggested that the findings of attentional capture by a cue matching the ACS but not by an ACS nonmatching cue in Adamo et al.'s (2008) experiments was due to cue–target repetition priming. For example, Parrott et al. replicated the results of Adamo et al.'s (2008) Experiment 1, in which a rectangular stimulus colored blue or green was used as a cue and a target. Thus, the color and shape of the cue could prime the target representation. However, in their Experiment 2, in which the cues were colored peripheral lines of a placeholder and the targets were letters, the compatibility between the features of the cue and target did not modulate the size of the cue-validity effect. Parrott et al. concluded that the interaction of cue type and cue validity in their Experiment 1, as well as in Adamo et al.'s (2008) experiments, was mainly due to target representation priming based on the perceptual similarity between the cue and target. However, it is difficult to make a conclusion based on the difference in results of these two experiments, because the ACSs were generated as a function of color and shape in their Experiment 1, but as a function of color and location in their Experiment 2.

The present study, however, replicated the result of location-specific ACSs without such repetition priming. In Experiment 1, because, instead of a cue, a distractor was used to monitor the specificity of ACSs, the repetition-priming effect was not expected to occur. In addition, in the test phase, the target color was selected randomly but was never the same as the distractor colors. Thus, it was fundamentally impossible that the asymmetrical interference by the distractors, depending on the compatibility of the ACS with their features, could be affected by any sort of priming effect by a cue or target. More importantly, in Experiment 2 the cue–target repetition-priming effect was examined directly. Specifically, not only was the red or green target only restrictedly valid as the target color, but also a blue target was used that was to be searched for regardless of its location. Importantly, a location-specific cue-validity effect was obtained with a red or green color cue when the neutral target was presented, although in this case the color of the target was always different from the color of any cue. Moreover, the cue-validity effects for the matching cues were of comparable size, regardless of whether the color

of the target was the same as the color of the cue. Therefore, these results imply that the existence of ACSs for multiple colors at specific locations concurrently was confirmed by the exclusion of any bottom-up impact from repetition priming.

Conclusion

The converging evidence in the present study has generalized the fact that performers searching for more than one target can flexibly set attentional controls based on the given task demands. Additionally, by dissociating the possibility of repetition priming, we confirmed that these lines of evidence reflect selective attentional control that depends on a specific feature of a stimulus at a certain spatial location. These findings shed light on how our attentional system promotes the efficiency of top-down control in order to achieve complicated task goals.

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