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Original Article

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Feature-based selective attention operates during visual search in the action effect paradigm

Sori Jung[1], Eunhee Ji[2†], Min-Shik Kim[1‡]

[1]Department of Psychology, Yonsei University

[2]Center for Neuroscience Imaging Research, Sungkyunkwan University

Previous research has demonstrated how a simple motoric response towards an object (the prime) can prioritize the allocation of attention to that same object in a subsequent unrelated visual search task (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). This phenomenon, known as the "action effect", results in faster reaction times (RT) only when the target is located within the object that was acted upon. To explore the attentional selection mechanism involved in the action effect, we examined how attention is allocated at the precise moment of action. Participants were instructed to respond (*go*) when the prime (a colored shape) appeared and withhold a response when "X" was displayed on the prime. Subsequently, participants were asked to search for a tilted line and report its orientation in the following visual search task. In valid trials, the target appeared on an object that shared a feature with the prime (either in terms of both-, color-, or shape-sharing), while in invalid trials, the target appeared on an object that did not share any features with the prime. The results revealed that visual features of the prime object guided visual attention to the location of the object that shared at least one feature with the prime. Therefore, the allocation of attention to specific features of the prime during the action task plays a critical role in inducing an attentional boost in the subsequent attentional selection process and it is suggested that this selection process occurs in a feature-based manner.

Keywords: Action effect, Feature-based attention, Visual attention, Validity effect

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Selective attention is a fundamental mechanism that serves to prioritize the processing of specific visual information in order for us to achieve efficient information processing (Posner, 1980; Posner & Petersen, 1990). When individuals engage in visual search tasks, their response selection is modulated by this mechanism. The nature of attentional mechanism in visual search has been extensively investigated across numerous visual search paradigms - whether it operates in a feature-based manner or object-based manner. It appears that the underlying mechanism of attentional guidance in visual search may vary depending on the specific search paradigm employed.

For a comprehensive understanding of how attention operates in visual search, it becomes imperative to

† 공동교신저자: 지은희, 성균관대학교 뇌과학이미징연구단, 경기도 수원시 장안구 서부로 2066, Tel: 031-299-4354,
E-mail: jieunhee01@gmail.com
‡ 공동교신저자: 김민식, 연세대학교 심리학과, 서울시 서대문구 연세로 50, Tel: 02-2123-4228, E-mail: kimm@yonsei.ac.kr

explore how these mechanisms interact and adapt to different task demands and contextual factors. On one hand, object-based visual attention has been observed in various visual search paradigms (e.g. two-rectangle paradigm; Chen, 2012; Egly, Driver, & Rafal, 1994; Marrara & Moore, 2003; Shomstein & Behrmann, 2008; Shomstein & Yantis, 2002). For instance, in the experiment conducted by Egly, Driver, and Rafal (1994), participants were presented with two rectangles, and a spatial cue briefly highlighted one end of a rectangle after a short delay. This study revealed that target detection time was fastest when the target appeared at the cued location (in 75% of the trials) compared to invalid locations (in 25% of the trials). Reaction times were faster when the target occurred at an invalid location of the same object than on the different object, suggesting that visual attention spreads within the cued object. Kristjánsson, Ingvarsdóttir, and Teitsdóttir (2008) provided additional evidence that priming can occur in an object-based manner when a single part of the presented stimulus is subject to change. Additionally, Luck and Vogel (1997) demonstrated that visual information could be stored as a conjunction of features in our working memory, reinforcing the role of object-based attention in visual processing.

On the other hand, feature-based visual attention has also been observed in numerous visual search paradigms (e.g. conjunction search paradigm; Egeth, Virzi, & Garbart, 1984; Kim & Cave, 1995; Treisman & Gelade, 1980; Wolfe & Horowitz, 2004; also see Carrasco, 2011 for a review). For instance, Kim and Cave (1995) explored how spatial attention operates in a conjunction search paradigm. In their study, the conjunction array consisted of one target and three distractors that shared certain features with the target or did not (e.g. same color, same shape, and neither). In 75% of the trials, participants were engaged in a memory task in which they reported the presence of a specific object. In 25% of trials, participants responded to a dot probe, which could appear in one of the array object's locations. When the probe appeared at the target location, reaction times were significantly faster. Generally, reaction times were faster when the probe appeared at the 'same color' or 'same shape' location compared to the 'neither' location. From these results, they concluded that feature-based spatial attention is manifested in conjunction search. Furthermore, Kristjánsson, Ingvarsdóttir, and Teitsdóttir (2008) demonstrated that feature-based priming could occur when two parts of the presented stimulus underwent changes, further highlighting the role of feature-based processing. As previous works demonstrated, whether selective attention operates in a feature-based or object-based manner in visual search can vary depending on the specific visual search paradigm employed.

While the nature of selective attention in visual search can vary based on the specific paradigm employed, recent research has brought attention to another intriguing aspect: the influence of motoric responses to objects on our attentional system and how it can prioritize the processing of the same object in subsequent visual search tasks (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). In experiment 1 of Buttaccio and Hahn (2011), participants were presented with a color word (cue) followed by a colored shape (prime). They were instructed to press the spacebar when the color word matched the color of the prime (*go*) and to not press it when the word did not match the color of the prime (*no-go*). Then, participants performed a visual search task, in which they searched for a tilted line among vertical lines presented within four colored shapes. The tilted line could either appear on the prime (valid) or on other objects (invalid). Overall reaction times (RT) for valid trials in the *go* condition were significantly faster compared to that of invalid trials. Buttaccio and Hahn (2011) proposed that an unrelated action toward a selected object might have strengthened the memory trace and enhanced attention allocation onto the same object in the subsequent visual search task, causing participants to respond faster (referred to as "RT benefits") in valid trials during the *go* condition. Building on this concept, Weidler and Abrams (2014) coined the term *action effect* and observed similar RT patterns when they simplified the action task by eliminating prime evaluation. In their study, participants responded to the prime in accordance with a previously seen action cue (e.g. *go* or *no-go*) or an action cue (e.g. X) embedded on the prime.

Previous research on the action effect has discovered that the object acted upon can influence the spatial bias of attention in subsequent visual search tasks. Furthermore, recent studies have demonstrated that a simple action can guide attention allocation through eye movements during visual search (Wang, Sun, Sun, Weidler, & Abrams, 2017; Weidler, Suh, & Abrams, 2018) and can induce attentional bias toward the color of prime, even when it is not consciously perceived (Suh & Abrams, 2018). However, what remains unknown is the specific mode of attentional allocation within the context of the action effect paradigm. It is unclear whether this allocation is driven by the trace of individual features or encompasses the entirety of the object itself. Wang, Weidler, Sun, and Abrams (2021) also addressed this issue, attempting to determine how prior actions can affect subsequent attention toward the feature of the acted-on object. Interestingly, their research finding indicated that among the features, color is unaffected by the attention demands of the task, while shape feature is influenced by the task's attention demand. However, it is worth noting that they did not investigate the effect of the prime stimulus on the object that shared all features. Discovering the nature of this attentional mechanism during visual search within the action effect paradigm, whether it operates in a feature-based or an object-based manner, would be a valuable addition to the current body of research.

EXPERIMENT

We examined which aspects of the prime contribute to selective attention during the visual search task within the action effect paradigm. To explore this question, we sought to ascertain whether selective attention operates in a feature-based or object-based manner by introducing a conjunction display to the visual search array. In this experiment, the search array comprised two objects: one that shared at least one feature with the prime (such as color-only, shape-only, or both) and another that shared none of the features with the prime (i.e. neither).

Two possible outcomes were anticipated. If the attention is directed in a feature-based manner during the visual search task within the action effect paradigm, we would expect to observe RT benefit when the target appears on the feature-sharing object (e.g. both, color-only, shape-only) in *go* trials. Conversely, if attention operates in an object-based manner, we would only anticipate RT benefit when the target appears on an object that shares both features with the prime in *go* trials. The latter would suggest that displaying an object identical to the prime is a necessary condition for inducing the action effect.

METHOD

Participants

Twenty-five undergraduate students from Yonsei University with normal or corrected-to-normal visual acuity were recruited for course credit. Given sample size was derived from previous action effect studies, which generally range from twelve to twenty-four participants. Every participant provided written informed consent before taking part in the study. All procedures were approved by the Institutional Review Board (IRB) of Yonsei University.

Apparatus and Stimuli

An Intel quad-core level computer and a 24-inch LED monitor (resolution of 1920 X 1080 pixels, 120 Hz refresh rate) were used. The experiment was programmed via MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants' head positions were stabilized using a chin rest positioned approximately 57 cm away from the screen. Participants were instructed to respond as accurately and quickly as possible using instructed keys on a computer keyboard. All stimuli were presented on black background (RGB: 0,0,0). A fixation cross was always presented at the center of the screen in white (RGB: 255,255,255). Luminance was controlled for five colors used in the experiment: Red (RGB: 248,124,146), yellow (RGB: 188,162,12), green (RGB: 120,180,80), blue (RGB: 78,168,241), and purple (RGB:

148,153,235). The sizes of five shapes were controlled to occupy approximately the same surface area: circle (6° in diameter), square (5.12° × 5.47°), diamond (7.22° × 7.71°), hexagon (6.28° × 6.70°), and star (6.65° × 9.13°). The colored shape was always presented in 4° in visual angle and the action cue was always in 3° in visual angle.

Procedure

Each trial began with a fixation cross presented at the center of the screen for 500ms followed by an action task. The action task was displayed on the screen for a maximum of 750ms. After brief fixation (500ms), the visual search task was displayed for 1500ms, during which the participants were to identify the target (see Figure 1).

Action task. A colored shape (prime) was presented at the center of the screen. The color and the shape of the prime were randomly chosen from a set of five colors and five shapes, as mentioned earlier. The prime could appear alone or with an embedded action cue. The task was to respond accordingly to the previously instructed rule. Participants were instructed to passively view (*no-go*) the prime object when an action cue "X" appeared on the prime, and to press the spacebar (*go*) when the prime appeared alone.

Visual search task. The visual search array consisted of two colored shapes with a line embedded within it. The stimuli appeared randomly among five predetermined positions with the exception of neighboring positions that were set around an imaginary circle with a 12° radius. One of the colored shapes consistently shared either two features (both: e.g. color and shape), the color feature only (color only), or the shape feature only (shape only) with the prime. The other colored shape did not share any features with the prime. The target, a tilted line, could appear on the colored shape that shared at least one feature with the prime (valid) or on the colored shape that shared none of the features with the prime (invalid). Note that the tilted line was drawn either left (−3°) or right (3°) from the top center of each stimulus's coordinates (approximately −31.53° or 31.53° tilted from the vertical line). Participants were instructed to report the orientation of the tilted line using the left and right arrow keys on the keyboard.

Experimental design. Participants engaged in a practice phase, which consisted of 32 trials prior to the main experimental phase. The main experiment consisted of 600 trials (300 trials - 5 Colors × 5 Shapes × 2 Actions × 2 Validity × 3 Feature-Sharing Levels - with two repetitions) in counterbalanced order.

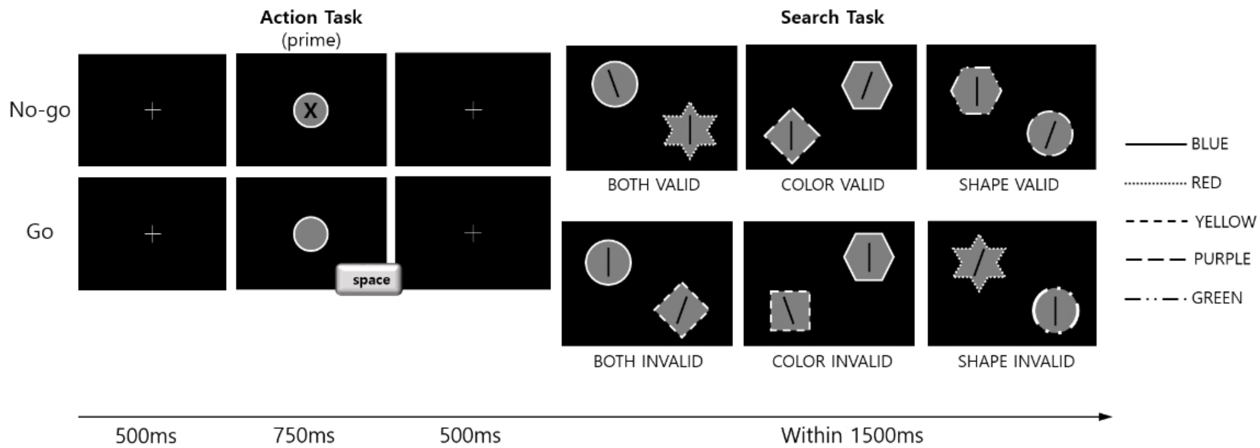

Figure 1. A conceptual example of an experiment. Participants were instructed to respond (go) when the prime (colored shape) appeared and not to respond (no-go) when "X" was presented on the prime. Subsequently, participants engaged in a visual search task, searching for a tilted line and reporting its orientation. Trials were considered valid when the target appeared on a feature-sharing object (either both-, color-, or shape-sharing) and they were considered invalid when the target appeared on a non-sharing object.

RESULTS

Overall, participants' accuracy was high at about 97.63% for the action task and about 97.27% for the visual search task. One participant with low accuracy was excluded from the analysis, for they scored four standard deviations below the overall mean accuracy of both the action task and visual search task. Additionally, trials with reaction times(RTs) faster than 150ms were excluded from the analysis, constituting an exclusion of about 0.99% of the collected data.

A repeated measures analysis of variance (ANOVA) was conducted for the mean RTs, using action (*go* vs. *no-go*), validity (valid vs. invalid), and feature-sharing level (both vs. color-only vs. shape-only) as within subject factors (see Figure 2). A significant main effect of validity was observed, $F(1,23) = 11.34$, $p = .003$, $\eta_p^2 = .326$, indicating significant difference between valid ($M = 656.33$) and invalid ($M = 667.39$) trials. There was no significant main effect of action, $F(1,23) = 0.07$, $p = .797$, $\eta_p^2 = .003$, nor feature-sharing level, $F(2,46) = 1.98$, $p = .15$, $\eta_p^2 = .079$, but there was a significant interaction between action and validity, $F(1,23) = 11.37$, $p = .003$, $\eta_p^2 = .331$, indicating that action performed toward the prime modulated the differences in validity. There was no significant interaction between action and feature-sharing level, $F(2,46) = 0.22$, $p = .804$, $\eta_p^2 = .009$. Furthermore, there was no significant three-way interaction between action, validity, and feature-sharing level, $F(2,46) = 0.51$, $p = .607$, $\eta_p^2 = .021$.

To further explore the interaction between action and validity, we conducted post-hoc comparisons using a Bonferroni correction. The results revealed that the target detection was significantly faster when the target appeared on the object that shared at least one feature with the prime (valid; $M = 650.41$) than when it appeared on the object that shared neither of the features with the prime (invalid, $M = 674.18$) - only when participants respond to the prime ($p = .0004$). However, there was no significant validity difference when participants did not respond to the prime ($p = .695$).

DISCUSSION

In the current experiment, a significant difference in reaction times(RTs) was observed between the feature-shared (valid) condition and the neither (invalid) condition. However, no significant RT difference was found between the both-feature condition and the one-feature-only conditions. This suggests that the action effect is induced when an object shares at least one feature with the prime, and this effect is more pronounced in go trials. The results support the idea that feature-based attentional guidance was evident exclusively in *go* trials, while *no-go* trials did not exhibit this effect.

Interestingly, in Weidler and Abrams' (2014) Experiment 4, there was an opposite prime stimulus effect in the

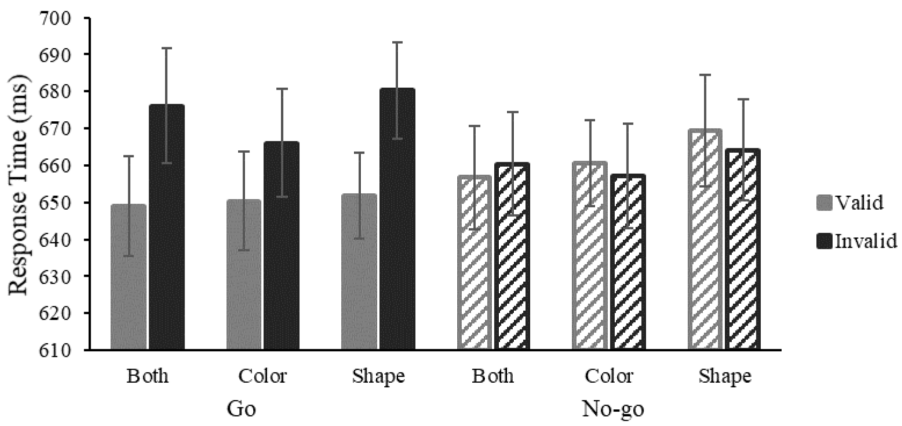

Figure 2. Results of experiment. Reaction times (RTs) were analyzed in relation to action, validity, and feature-sharing levels. Solid-colored bars represent go trials, while shaded bars represent no-go trials. A lighter shade indicates valid trials, while a darker shade indicates invalid trials.

no-go trials compared to the *go* trials. However, in the current experiment, despite the similar conditions between the both-feature and *no-go* conditions, there was no observed slowing of reaction times in the *no-go* trials. One possible hypothesis for this difference could be that previous research used uniform shapes as stimuli, whereas in the current study, a variety of features, such as color and shape, were combined in different ways. It is possible that when performing the action with simplified stimuli and not engaging in action, inhibition effects carried over into subsequent attentional processing in Weidler and Abrams' study. However, in our experiment, which utilized diverse features, it is likely that these effects operated more weakly and did not lead to RT benefits, and may have even resulted in opposite effects.

Despite the fact that our visual search was not inherently a conjunction search, several factors suggest that a feature-based search mode could have been a relevant strategy, since participants were instructed to find a tilted line and report its orientation (Bacon & Egeth, 1994; Lamy & Egeth 2003; Pashler, 1988). Additionally, since the objects to which each line was embedded were irrelevant to the visual search task, the results demonstrated that feature-based attentional selection can influence the guidance of attention to the target tilted line. Such patterns of behavior would be expected from a conjunction search task. In fact, previous studies on conjunction search have suggested that the pre-attentive stage of visual search screens and selects sets of stimuli that share at least one of the target's features (Egeth, Virzi, & Garbart, 1984; Wolfe & Horowitz, 2004; also see Carrasco, 2011 for a review). Even though the properties of the prime were irrelevant to the target feature in the visual search task, they still captured participants' attention.

Previously, Buttaccio and Hahn (2011; e.g. experiment 3) suggested the existence of an "independent trace" of prime features. In their experiment, the name of a stimulus shape served as the action cue, and participants were required to make a motoric response when the shape's name matched the actual shape of the prime object. Subsequently, in the visual search task, the valid object shared only the color with the prime, but the search array never contained the cued shape. In Wang et al. (2021)'s Experiment 2a, the search array could share either color or shape with the prime. However, depending on whether color or shape names were used as action cues, different attention capture effects were observed. When we reconsidered the fact that in our experiment, the action cue "X" was entirely unrelated to color or shape, our results provide supporting evidence that the properties of an acted-on object can facilitate a validity effect in the subsequent visual search task, even when evaluating the property of the prime is not necessary.

Treisman and Sato (1990) demonstrated that each feature dimension contributes additively in conjunction search. Furthermore, it appears that even within a feature dimension, each layer modulates the amount of attention in an additive manner. For instance, a priming effect can be observed as an additive function of reaction times when presenting stimuli with two changing parts compared to stimuli with only one changing part (Kristjánsson, Ingvarsdóttir, & Teitsdóttir, 2008). While previous studies primarily focused on the impact of task-relevant features, we did not observe a significant RT benefit in the two-feature valid condition over the one-feature valid condition in our visual search task. These results might be limited by the nature of our visual search task, which presented only two objects in the search array, potentially making it too easy to observe the conjunction effect of features. Due to the simplicity of the task, it is possible that salient features played a dominant role in influencing selective attention during the visual search in the action effect. Future experiments will be necessary to address this matter and further expand our understanding in this area of research.

Given that previous action effect research has predominantly focused on color, our studies can open up new avenues in this research area. Recent studies examining attention effects related to visual features (Wang et al., 2021) did not thoroughly investigate the degree of feature-sharing. Future research could explore whether different types of features can induce the action effect. As suggested by earlier studies, if the action effect is indeed a specialized form of priming (Huffman & Pratt, 2017; Weidler & Abrams, 2014), it should be replicable when employing features commonly studied in typical priming research, such as orientation and spatial frequency, in addition to color (e.g., Kristjánsson, 2006). Furthermore, based on the pattern observed in our results, the attentional mechanism in visual search seemed to operate as if it were engaged in a conjunction search. This suggests that features like size and orientation, often employed in typical conjunction search tasks, may also be relevant in the action effect paradigm (e.g., Wolfe, Cave, & Franzel, 1989).

Taken together, our findings suggest that the action effect arises from the interplay between attentional mechanism and action. Furthermore, attention and actions directed toward the prime object may facilitate feature-based attentional guidance toward task-irrelevant stimuli. Prior research on attention has primarily focused on attentional guidance toward task-relevant stimuli (e.g., Brascamp, Blake, & Kristjánsson, 2011; Kristjánsson, 2006; Kristjánsson, Saevarsson, & Driver, 2013; Maljkovic & Nakayama, 1994; 1996) or task-relevant actions (e.g., Craighero et al., 1999). Our current research design extends this concept of attention to a broader context, encompassing the unintentional guidance of attention based on irrelevant action. Our studies contribute to this relatively new area of research by demonstrating that the mode of attention deployment can be in accordance with established principles of feature-guided visual search.

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행동효과에서 주의 유도의 역할: 특징 기반의 선택적 주의를 중심으로

정소리[1], 지은희[2], 김민식[1]

[1]심리학과 연세대학교, [2]뇌과학이미징연구단 성균관대학교

행동 효과(action effect)란 선행자극(prime)에 대한 반응 이후 시각 탐색 과제에서 선행자극과 동일한 자극 위에 제시되는 표적에 대하여 반응시간이 빨라지는 현상을 이야기한다(Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). 본 연구는 선행자극에 대한 주의가 행동 효과에 미치는 영향을 알아보기 위하여 진행되었다. Weidler와 Abrams(2014)는 행동 효과에 대한 설명으로, 선행자극에 대한 주의나 평가 없이 물리적인 행위를 하는 것만으로 이후 시각 탐색 과제에서 선행자극과 동일한 자극이 우선적으로 처리될 수 있다고 제안하였다. 이에 착안하여, 본 연구에서는 선행자극에 대해 행위하는 동안의 주의 효과가 특징 기반으로 작동하는지, 혹은 객체 기반으로 작동하는지 여부를 탐구하였다. 실험 자극은 조도를 통제한 다섯 가지 색과 면적을 통제한 다섯 가지 도형으로 구성되었다. 반응 과제에서 참가자들은 키보드를 사용하여 색 도형(선행자극)이 반응하되(행동 조건), 선행자극 위에 단서가 함께 제시되면 반응하지 않도록(비행동 조건) 지시받았다. 시각 탐색 과제에서 참가자들은 제시되는 선분 중에서 기울어진 선분을 찾아 방향을 판단하는 과제를 수행하였다. 표적이 선행자극과 특징을 공유하는 자극 위에 나타나는 타당(valid) 조건과 특징을 공유하지 않는 자극 중 한 곳에 위치하는 비타당(invalid) 조건의 반응 속도 차이를 분석하였다. 실험 결과, 행동 조건에서의 타당도 효과가 비행동 조건에서의 타당도 효과보다 더 강한 것을 확인할 수 있었다. 이러한 결과는 행동효과에서 선행자극에 대한 주의가 중요한 요소이며, 이러한 주의가 이후 시각 탐색 과제에서 특징 기반으로 작용함을 시사한다.

주제어: 행동효과, 특징기반주의, 시각 주의, 타당도 효과