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The influence of action on visual search: behavioral response toward stimuli modifies the selection process

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Abstract In five experiments, we investigated how simple actions (as assessed via a go/no-go task) influence visual search. In Experiments 1 and 2, participants responded (go) when a color name (cue) matched a colored shape (prime), and did not respond (no-go) when they mismatched. Participants then searched a visual array for a tilted line, either embedded within the prime (valid prime) or within a different shape of a different color (invalid prime). For go trials, but not for no-go trials, the validity of the prime influenced search behavior so that faster RTs were observed when the prime was valid as compared with when it was invalid. In Experiment 3, the go/no-go task was based on the shape of the prime. The color of the prime, but not the shape, was re-presented in the search array, and its validity produced a similar pattern as in Experiments 1–2. In Experiment 4, participants responded when the color name and prime mismatched. Reaction times indicated that attentional set had an influence on the validity differences in Experiments 1–3. In Experiment 5, the go/no-go task was based on whether a digit matched a digit appearing within the prime. Go trials produced similar validity effects as observed in Experiments 1–3.

Keywords Attention · Motor control · Priming

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Many of the tasks that we do on a daily basis involve using simple motoric actions to produce some desired result. Chances are, if you are reading this article, you spend much of your day in front of a computer. Your interaction with the computer (typically) consists of using a keyboard and mouse to introduce some sort of change, such as opening a folder to examine its contents. In the present research, we investigated whether these simple actions can influence the deployment of attention in a visual scene. To simplify the driving question of the article, does acting on an object (via an intermediary device such as a keyboard) direct attention toward that item that has been acted on?

Previous research has indicated that motoric action can have a strong influence on attention, enhancing the processing of stimuli that are congruent with the specific action that has been planned (e.g., Craighero, Fadiga, Rizzolatti, & Umiltà, 1998, 1999) and can bias attention in the early stages of visual processing in a visual search task (Wykowska, Schubö, & Hommel, 2009). The studies investigating the relationship between attention and action often have participants perform physical responses (e.g., grasping an oriented bar) to reveal the connection between attention and action. In the present study, we examined how a simple response (i.e., pressing a key on a keyboard) in response to stimuli presented on a computer screen can influence the deployment of attention in a visual scene toward the acted-on stimulus. Therefore, we are interested in how responses influence the deployment of attention and not in how action toward a stimulus elicits a particular response when the same or aspects of the same stimulus are re-presented (see Hommel, 1998, 2004).

Deubel and Schneider (1996) demonstrated that there is a coupling of action with attention such that planned actions involve a selection of the area to which the action is planned, providing empirical evidence for Allport's

(1987) selection for action hypothesis. In their task, participants were to make saccades to cued locations. Shortly after a location was cued, targets and distracters were presented. Participants were faster in reporting a target when it appeared where a planned saccade was directed than when the target appeared in a location other than that of the planned saccade. This work was later extended to show that there is a similar coupling of attention with planned hand movements (Deubel, Schnieder, & Paprotta, 1998). The behavioral evidence provided by Deubel et al. has been enhanced by a recent event related potential study by Gherri and Eimer (2009),which provided evidence of the inextricable relationship that exists between action and attention by showing that the two behaviors use similar neural structures.

Note that we view saccades, hand movements, and simple motoric movements as action. That is, the planning or execution of particular motoric movements requires similar processes (e.g., deciding when to perform an action). This is relevant for the present study since we are defining action by using simple motoric movements (by pressing a key on the keyboard). Although some may disagree with this claim (viewing action as a more active process such asreaching for and/or grasping objects [e.g., Bekkering & Neggers, 2002; Meegan & Tipper, 1999; Pavese & Buxbaum, 2002; Wykowska et al., 2009]), other researchers have used similar responses in their paradigms to examine action (e.g., Hommel, 1998; Loach, Frischen, Bruce, & Tsotsos, 2008; Tucker & Ellis, 1998).

The work by Deubel et al. (1996) and by other researchers examining the relationship between action and attention has focused on the preparatory nature of performing an action and its subsequent influence on the selection process (with the notable exception of Hommel (1998, 2004), but as was mentioned previously, he has been focused on how the re-presentation of a feature or object can elicit particular responses). To our knowledge, no one has examined how performing an action can subsequently influence the selection process in a visual search task. Other researchers have provided evidence that certain behaviors (e.g., selecting a target) that have just been carried out can have a strong influence on what is selected in a subsequent visual scene, despite the fact that it may hinder performance in a particular task.

Maljkovic and Nakayama (1994) demonstrated that the selection process itself subsequently influences future selection processes. In their paradigm, participants searched amongst diamond shapes for a color singleton and then reported whether the singleton had a cut on the left or on the right side of the diamond. Participants were faster in locating the target when the color of the target was repeated and were slower when it switched. Therefore, the selection of particular features within the environment subsequently leads to a deployment of attention toward the same feature. Other research has demonstrated that the information that is in working memory can have a strong influence on the selection process in subsequent visual scenes, such that the item in a visual scene that corresponds with the item in WM is selected (e.g., Downing, 2000; Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). The work by Maljkovic and Nakayama and the work showing that the contents of working memory drive attention suggest that the behaviors that we have just carried out can have a strong influence on cognitive processes in the future. That is, each visual scene does not drive the selection process toward bottom-up factors only (although see Theeuwes, 2010). Those behaviors that have been performed in the recent past (e.g., selection) can have a top-down influence on future selection.

On the basis of the work that has demonstrated the tight connection between attention and action (e.g., Deubel & Schneider, 1996) and how selection in a visual scene can be influenced by what has been recently selected (e.g., Maljkovic & Nakayama, 1994) or by what has been recently placed in working memory (e.g., Soto et al., 2005), we hypothesize that action can have a strong influence on selection. That is, an object (or feature) that is acted on will be selected in subsequent visual scenes. There can be a number of reasons that this may be the case, but if we make the assumption that an object in a visual scene that is processed to some extent (i.e., a decision is made regarding the stimulus) the strength of the trace of the object can vary. We propose action increases the strength of the trace of the object that has been acted on. This trace subsequently influences search when an object is presented in the visual field that matches the trace of the acted on object.. To test this idea, a novel experimental procedure was constructed in which a go/no-go task was employed to assess the degree of action on subsequent selection processes.

To help clarify the present paradigm, the basic experimental procedure for Experiments 1–5 is outlined. In all of the experiments, participants were first presented with a cue (e.g., "red"), followed by a prime of a particular shape and color. On half of the trials, the cue matched an aspect of the prime, and on the other half of the trials, they mismatched. The matching of the cue and a feature of the prime indicated to the participant whether a go (pressing the spacebar on the keyboard) or a no-go (not pressing anything) response was warranted (in Experiment 5, the cue was a digit, and the go/no-go task was based on the matching of the cue with a digit appearing within a prime). Following the go/no-go task, participants then performed a visual search task. The visual search array consisted of four different shapes, each of a different color. Embedded within each of the shapes was a line, with three shapes containing a vertical line (distracters) and one shape containing a tilted line (target). The directions for the go/no-go task (when to respond) and what was repeated from the prime presentation to the visual search display were manipulated in the different experiments to assess how action can influence the deployment of attention (i.e., selection).

Experiment 1

Figure 1 provides a schematic illustration of the task and the different conditions that participants went through in Experiment 1. At the beginning of each trial, participants were presented with a color name (a cue) followed by a colored shape (prime). If the color name matched the prime, participants were instructed to press the spacebar on the keyboard (go). When the color name and prime mismatched, participants were instructed to refrain from responding (no-go). After responding or after 750 ms, participants were presented with four different types of shapes, each of a different color. Three of the shapes contained a vertical line, whereas one of the shapes contained a tilted line. Participants were instructed to locate the tilted line and to respond by pressing the spacebar. At the end of the trial, participants indicated the orientation (tilted left or right) of the target line.

The same key was used for both the go/no-go task and visual search task to emphasize speed in both tasks (i.e., arbitrary responses did not have to be learned) and because we are not interested in response compatibility effects (e.g., Hommel, 2004) in the present study. By using only one key, there would not be competition between different motoric responses. If a separate key were used for each type of a response (i.e., a key used for the go/no-go task, a key for when the line is tilted to the left, and a key for when the line is tilted to the right), participants would be using three separate keys. We simplified the go/no-go task and visual search task (where speed is important) by reducing the response mapping; therefore, participants could respond more quickly than they could if a separate key was used for the go/no-go task and the orientation discrimination. This methodology was used for all of the experiments throughout the study.

Note that the prime was always present in the visual search array. The probability that the prime would contain the target line was .25, and the probability that it would contain a distracter line was .75. A prime that later contains the target line in the visual search display is referred to as being valid, whereas a prime that contains a distracter line in the visual search display is referred to as being invalid. The low probability of the prime being valid was used for two reasons: (a) the low probability that the prime is the target ensures that participants are not using the prime itself to guide search, such as by storing the prime into WM and using that representation to guide search, which has been shown to guide visual attention (e.g., Soto et al., 2005); and (b) to allow for a comparison between go and no-go trials. If action does influence attention, as assessed through go trials, then this should be reflected in visual search reaction time (RT), depending upon the validity of the prime. For a go trial in which the prime is valid, participants should be faster in detecting the target line (because their attention will be directed toward the acted-on object that contains the target line) and slower when the prime is invalid. Moreover, the validity of the prime should not influence the deployment of attention following no-go trials, and there should be little or no difference between the invalid and valid conditions. Finally, we manipulated the interstimulus interval (ISI) between the offset of the prime (due to a response or after 750 ms) and the search array. This was done to assess whether there would be any time differences

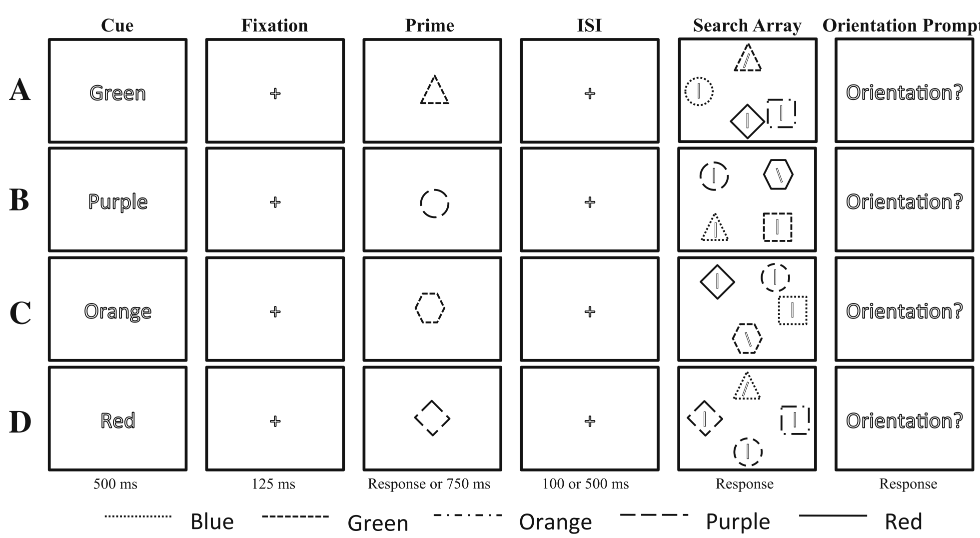

Fig. 1 Schematic illustration of the different conditions in Experiment 1. **a** Go valid trial. **b** Go invalid trial. **c** No-go valid trial. **d** No-go invalid trial. Note that the background was gray in the experiment with words and fixations in white

between acting on the prime and the prime's influence on visual search behavior (i.e., if the predicted effects were extremely transient or longer lasting).

Method

Participants Eighteen participants (12 females; M_{age} = 20.3) from the University of Oklahoma participated in Experiment 1 for course credit. All participants were right-handed and reported normal or corrected-to-normal vision.

Stimuli and apparatus Stimuli were presented on a 17-in. monitor, controlled by a Dell computer with a 3 GHz Pentium 4 processor. Distance to the monitor was approximately 60 cm. Stimulus presentation and data recording were controlled via E-Prime 2 by PST, Inc.

The colors used in the experiment were blue (RGB = 0, 0, 255), green (RGB = 0, 128, 0), orange (RGB = 255, 102, 0), purple (RGB = 102, 0, 102), and red (RGB = 255, 0, 0). The shapes used in the experiment were a circle (45 × 45 mm), diamond (50 × 50 mm), hexagon (45 × 55 mm), square (50 × 50 mm), and triangle (45 × 55 mm). The words presented at the beginning of each trial were presented in white font with a gray background. The words used were the same as the colors used (blue [10 × 25 mm], green [10 × 38 mm], orange [10 × 45 mm], purple [10 × 40 mm], and red [10 × 22 mm). In the visual search array, each shape contained a white line (15 × 2 mm) with three vertical lines. Two tilted lines (20° or −20°) were used as targets for the visual search task,with only one appearing in a given visual search scene.

In the visual search array, four different colored shapes were always presented. The shapes were presented around an imaginary circle (with a radius of 115 mm) with eight possible locations. Beginning with the first location (corresponding to 12 o'clock on a clockface), one shape was presented in location 1 or 2, 3 or 4, 5 or 6, and 7 or 8. All eight locations were equidistant from the center of the screen.

Procedure Each trial began with a fixation for 500 ms. Participants were then presented with a color name (cue), with the letters in white on a gray background. After a 125-ms fixation, participants were presented with a colored shape, which served as the prime. If the color of the prime mismatched the cue (e.g., the word "red" was presented and a green square was presented as the prime), participants were instructed to not respond (no-go). When the color of the shape matched the cue, participants were instructed to respond by pressing the spacebar as quickly as possible (go). After responding or 750 ms, a fixation was presented for either 100 or 500 ms (ISI). After the fixation, participants were presented with a visual search array. The visual search consisted of four different shapes of four different colors. It should be noted that for the no-go trials, the color name presented at the beginning of the trial never matched any of the colors in the visual search array. Three of the colored shapes contained a vertical line, whereas one of the colored shapes had a tilted line. The prime was always in the visual search array and contained the target line 25% of the time and a distracter line 75% of the time. After finding the tilted line, participants were instructed to press the spacebar. Participants were then prompted to indicate the orientation of the target line. At the beginning of the experiment, participants were instructed to keep their dominant hand on the spacebar and to respond to the orientation of the target line using their nondominant hand. Participants went through 32 practice trials and four blocks of 64 trials (see Fig. 1 for examples of the different conditions). For each trial, participants could potentially make three responses: (a) a go/no-go response, (b) a visual search response, and (c) an orientation response. Note that participants had to respond to the visual search array in order to continue with the experiment and could respond only one way. Due to this factor, no response errors could be made for the visual search array.

Results

The data from the practice trials were not analyzed. Errors for the go/no-go task occurred on 4.9% of the trials. Errors in reporting the orientation of the target line occurred on 1.4% of the trials. Conjunction errors for the go/no-go task and in reporting the orientation of the target line occurred on 0.3% of trials. Because the error rates were generally very low throughout the experiment, errors were not analyzed in any manner. For the visual search task, trials that were faster than 150 ms or slower than three standard deviations from the overall mean were removed from the analysis, resulting in a removal of roughly 1.3% of the data.

Overall median RTs were submitted to a repeated measures ANOVA, with go/no-go (go, no-go), ISI (100, 500), and prime validity (invalid, valid) as within-subjects variables. There was a main effect of ISI: The target line was detected faster at the longer ISI (500 ms) than at the shorter ISI (100 ms), $F(1,17) = 10.82$, $p < .01$, $\eta_p^2 = .39$. There was a main effect of prime validity: Responses were faster when a prime was valid as opposed to invalid, $F(1,17) = 109.82$, $p < .01$, $\eta_p^2 = .87$. There was a significant interaction between go/no-go and prime validity: Targets were detected faster following a go trial when the prime was valid as opposed to invalid, relative to the respective no-go conditions, $F(1,17) = 56.23$, $p < .01$, $\eta_p^2 = .77$ (see Fig. 2). A Bonferroni post-hoc analysis comparing go/no-go and prime validity further supported a significant

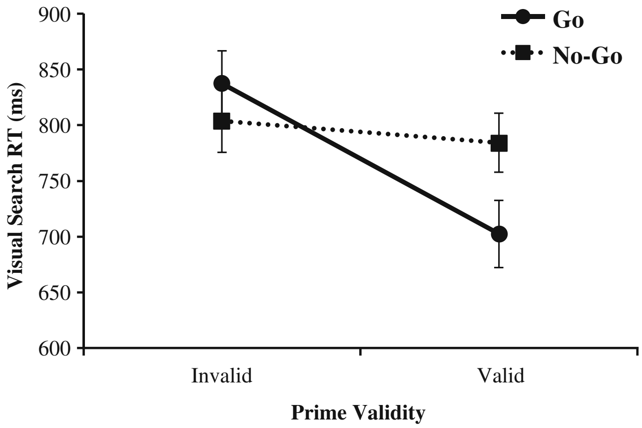

Fig. 2 Observed interaction between prime validity and go/no-go type in Experiment 1. *Error bars* represent one standard error

difference between valid (M = 837.4) and invalid (M = 702.4) conditions after a go trial ($p < .01$). There was no difference between the valid (M = 803.9) and invalid conditions (M = 784.2) following a no-go trial. The Bonferroni analysis was also used to examine whether differences existed in the invalid and valid conditions when comparing the go to the no-go trials. No difference was observed when comparing the go to the no-go trials when the prime was invalid. However, a difference was observed when the prime was valid between the go and no-go trials such that the target was detected faster on go trials than on no-go trials ($p < .01$).

Discussion

In Experiment 1, participants had two separate tasks: (a) to perform the go/no-go task, and (b) to find the target in the visual search array as quickly as possible. The go task carried over to the second task of searching for the target, even though the prime was unlikely to contain the target for the visual search task. The results from Experiment 1 provide evidence that an action performed on an object leads to a selection of the same object when it appears in subsequent visual scenes, providing another type of top-down influence on visual search behavior.

As was mentioned in the introduction, many researchers that have studied the relationship between attention and action have examined the role that preparatory actions have on subsequent selection processes (e.g., Deubel & Schneider, 1996). Experiment 1 provides evidence not only that preparatory actions can influence the selection process, but also that an action that has already been performed will influence the selection process. This evidence bolsters the claim made in the introduction that an acted-on item will lead to a stronger trace, and this trace leads to an influence on the selection process so that when the same object appears in the visual field that matches the trace, the item is selected. This selection occurs despite the fact that it is detrimental to do so given that the shapes are not related to the visual search task and provide no diagnostic information regarding the target (i.e., the prime was associated with the target only 25% of the time).

Note that participants' overall responses were not any faster in the visual search task if they had just previously executed a go response to a prime. This means that the results from Experiment 1 cannot be explained by a motoric priming account whereby participants are able to respond faster because they had previously just responded. This is because the motoric priming explanation would predict a general RT advantage after the go response. There was, however, a difference between the two valid conditions in which faster RTs were observed in the visual search task following a go response as compared with a no-go response. This difference was not observed between the go and no-go responses in the invalid condition. Although it would appear that the difference between the go and no-go valid trials indicates that participants are much faster in locating the target after a go trial than after a no-go trial, as will be shown, the results from Experiment 2 do not fully support this claim. Therefore, we will de-emphasize this difference in our explanation and will focus on validity differences for go and no-go trials since the interaction between go/no-go and prime validity is stable (i.e., a larger difference between invalid and valid conditions after a go response and a smaller difference after a no-go response).

In Experiment 1, we employed two different ISIs. The purpose of ISI as a variable in Experiment 1 was to assess whether the effect of action on an object would only be transitory, or would have more long lasting effects. Although participants were faster to detect the target in the visual search task at the longer ISI, there was a similar pattern of results for both ISIs. Even though participants had time between the prime and the visual search display, acting on the prime produced a bias toward the prime in the visual search display, suggesting the effect is not extremely transient (i.e., it lasts at least 500 ms).

In Experiment 1, the validity of the prime had a strong influence on visual search behavior following a go response but not following a no-go response. In Experiment 2, we further investigated this difference by examining RT distributions for the different conditions. If participants are more strongly influenced by a prime when it has been acted on than when it has not been acted on, then the RT distributions should reflect this difference. In Experiment 1, median values for each participant per condition were used to support this claim. The median values, however, do not provide much information about the nature of the response patterns. The differences of visual search performance driven by a go or no-go response could be due to changes in variance for the two conditions and not necessarily to a change in the fastest responses. Because our explanation of the results from Experiment 1 is based on the assumption that the faster RTs in the visual search task were influenced by the prime following go responses, Experiment 2 was conducted to ensure that this was the case.

Experiment 2

In order to further understand the nature of the visual search differences created by the validity of the prime following go responses, we conducted RT distribution analyses in Experiment 2. In Experiment 2, we employed the same experimental procedure as in Experiment 1, with the exception that a single ISI condition was used (500 ms), and we increased the number of trials per condition (since the RT distribution analysis requires more trials) while keeping the probability that the prime was valid the same as in Experiment 1. The ISI was not used as a variable because it did not interact significantly with go/no-go or prime validity in Experiment 1.

The ex-Gaussian analysis is a descriptive tool for RT distributions and has three values associated with it, μ, which describes the initial portion of the distribution, σ, which describes the amount of dispersion in the distribution, and τ, which describes the tail of the distribution. We predicted that the influence of the go/no-go task would change the nature of the response pattern. Following a go response, the faster responses (μ) should be influenced by the validity of the prime whereby a valid prime should lead to faster visual search RTs, and an invalid prime should lead to slower visual search RTs. The validity difference should not be observed following a no-go response. Because μ is a measure to reveal the fastest responses, we predict a significant difference between μ for the prime invalid and valid conditions following a go response (and not following a no-go response), without corresponding changes to σ or τ.

Method

Participants Twenty new participants (7 females; M_{age} = 19.4) from the University of Oklahoma participated in Experiment 2 for either course credit or monetary compensation ($10). All participants were right-handed and reported normal or corrected-to-normal vision.

Procedure The same procedure as in Experiment 1 was used except for the following. Only the 500 ISI was used between the prime presentation and the search display. Participants went through 400 experimental trials, with 200 go trials and 200 no-go trials. The prime was valid 25% of the time, just as it was in Experiment 1.

Results

The data from the practice trials were not analyzed. Errors in the go/no-go task occurred on 7.5% of the trials. Errors in reporting the orientation of the target line occurred on 1.7% of the trials. Conjunction go/no-go errors and reporting the orientation of the target line errors occurred on 1.2% of trials. Errors were not analyzed in any manner. For the target detection task, responses faster than 150 ms were removed from analysis, and this removed three trials overall. All responses that were above three standard deviations of the overall mean, for the target detection response, were removed from the analysis, which resulted in a removal of roughly 1.7% of the data.

Overall median RTs were submitted to a repeated measures ANOVA, with go/no-go (go, no-go) and prime–target validity (invalid, valid) as within-subjects variables. There was a main effect of prime validity: Responses were faster when a prime was valid as opposed to invalid, $F(1,19) = 42.51$, $p < .01$, $\eta_p^2 = .69$. There was also a significant interaction between go/no-go and prime validity: The target was detected faster following a go response when the prime was valid as opposed to invalid, as compared with the respective no-go conditions, $F(1,19) = 16.41$, $p < .01$, $\eta_p^2 = .46$. A Bonferroni post-hoc test examined the differences in validity for both go and no-go. Participants were significantly faster to find the target when the prime was valid (M = 827.5) than when it was invalid (M = 959.3) following a go response ($p < .01$). No difference was observed between the valid (M = 880.6) and invalid (M = 910.7) conditions following a no-go response.

Ex-Gaussian analysis For the ex-Gaussian analysis, a μ, σ, and τ value was obtained for each participant for each condition using the same data set that was used to obtain the medians for each condition for the previous results. The quantile maximum-likelihood procedure was used to run the analysis (Cousineau, Brown, & Heathcote, 2004; Heathcote, Brown, & Mewhort, 2002). Each part of the distribution (i.e., μ, σ, and τ) was run through a repeated measures ANOVA. There was a significant main effect of prime validity for μ:Participants were faster in detecting the target when the prime was valid as opposed to invalid, $F(1, 19) = 15.01$, $p < .01$, $\eta_p^2 = .44$. There was also a significant interaction between prime validity and go/no-go: Following a go response,the target was detected faster when the prime was valid as opposed to invalid, $F(1,19) = 7.32$, $p < .02$, $\eta_p^2 = .28$ (see Fig. 3). A Bonferroni post-hoc test revealed a significant difference between valid (M = 641.3) and invalid (M = 749.8) trials following a go response ($p < .01$). A significant difference was not detected between valid (M = 695.4) and invalid (M = 675.2) trials following a

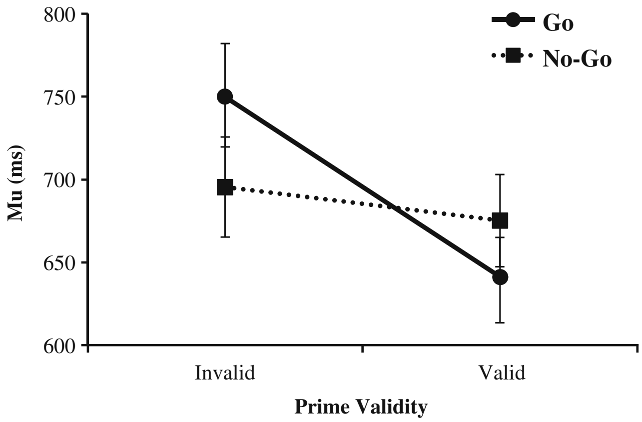

Fig. 3 Observed interaction between prime validity and go/no-go for μ. *Error bars* represent one standard error

no-go response. The only other significant difference occurred with σ, with less dispersion when the prime was valid as opposed to when it was invalid, $F(1, 19) = 4.94$, $p < .04$, $\eta_p^2 = .21$.

As was mentioned in the Results section for Experiment 1, the significant difference found between the go and no-go trials when the prime was valid was not a true difference based on the analysis from Experiment 2: This difference was not found when examining the μ values and therefore does not support the claim that there is a significant change in the distribution between the two conditions. Therefore, for the rest of the study, these differences are not examined (because we will be using median RTs for our analyses and will not be using the ex-Gaussian for the other experiments). We will focus on whether visual search RTs are influenced by the validity of a prime following a go or a no-go response.

Discussion

Consistent with Experiment 1, we observed that following a go response, participants were faster to find the target line in the visual search task when the prime was valid and that they were slower when it was invalid, with no such difference observed following a no-go response. We also found that the differences in the validity conditions were due to entire shifts of the distribution as opposed to variation within the RT distribution. The ex-Gaussian analysis provides additional support to the claim that the trace that has formed of the prime following a go response is stronger than the trace formed following a no-go response, due tothe finding that the μ values shifted from the valid to invalid conditions following go responses, but that the μ values for the invalid and valid trials did not differ significantly following a no-go response. Although there was a difference with σ when the prime was valid as opposed to invalid, there were no other significant differences. The solid shift of μ values due to validity suggests that the initial responses are strongly biased by the validity of the prime following go responses.

In Experiments 1 and 2, participants executed a go response when the prime matched the color name (cue) presented at the beginning of the trial and did not respond (no-go) when the prime and color name did not match one another. For instance, the no-go valid condition indicates that the color name did not match the color of the prime stimulus shape, but the prime shape was used for the visual search display and contained the target. On the other hand, when the color name matched the color of the prime shape, participants pressed the spacebar. In other words, participants acted on the stimulus when they were primed repeatedly. Thus, it is possible that the action-connected validity effect we observed in Experiments 1 and 2 might have been produced by the double priming as opposed to either acting or not acting on the prime. That is, participants are being double primed, by the color name and the prime. The argument that visual search is being influenced by the repetition of the color name and a prime of the same color in Experiments 1 and 2 can be explained in terms of the attentional set hypothesis (Folk, Remington, & Johnston, 1992), and action may not be need to explain the findings for the first two experiments.

The attentional set hypothesis (Folk et al., 1992) states that the attunement of the cognitive system to particular dimensions (e.g., color) will influence the processing and subsequent deployment of attention to features within that dimension that appear in the visual field. For instance, if there is an expectation of a colored target, then the cognitive system will be adjusted to expect a colored object to appear, which will lead to facilitation in the processing of a color when it appears in the visual field. This processing facilitation has two main consequences: (a) dimensions other than the expected one (e.g., an abrupt onset) will not capture attention, and (b) features within a dimension will capture attention, even if it is irrelevant for the task. The attunement to a particular dimension will have a strong influence on the deployment of attention. Within the present study, the cue for Experiments 1 and 2 may be defining the attentional set for participants. That is, the color name attunes the system for a particular feature. The subsequent presentation of the prime that matches the cue makes the attunement stronger and more specific, because the actual color is presented and the color is selected. The selection of the color, then, could be driving attention toward the selected item in the visual search array. Therefore, it may not be action that is influencing the deployment of attention in the visual search display, but rather the adjustment of the attentional system based on the matching of the prime with the cue. To investigate this possibility, Experiments 3 and 4 were conducted.

Experiment 3

To determine whether it is responding toward the prime or merely the attentional set of the participant that is biasing attention in Experiments 1 and 2, the attentional set of the participant needs to be directed toward a feature of the prime that is dissociable from the object in visual search scene (i.e., the feature is not repeated). If a non-relevant feature for the go/no-go task is repeated in the visual search task, then the influence of responding to the prime should be able to be determined depending on the validity of the non-relevant feature of the prime. However, if the attentional set of the participants is the principal influencing factor in the visual search process, than either responding or not responding to the prime should have little influence on visual search behavior.

In Experiment 3, participants were first presented with a shape name followed by a prime. When the shape name and prime matched, participants responded (go); they did not respond when the shape name and prime mismatched (no-go). Participants then performed a visual search task in which the prime shape was never present. However, the color of the prime was always associated with a different shape than the prime. For instance, if an orange square were presented as the prime in a trial, the visual search array would not contain a square, but would always contain a different shape that was orange, such as an orange triangle. If a response toward the prime is important in the deployment of attention, prime validity differences should be observed following a go response and not following a no-go response, as was observed in Experiments 1 and 2.

Another important hypothesis that was tested (other than testing the veracity of the attentional set hypothesis for the current paradigm) in Experiment 3 was whether action leads to an increase in the strength of the prime trace only for the feature that was responded to (color in Experiments 1 and 2) or whether all of the features of the prime's trace are strengthened. If the different features of the prime trace are strengthened when a go response is executed, then the color of the prime should influence visual search behavior so that responses are faster when the color of the prime is valid and slower when the color of the prime is invalid. However, if only the trace for the feature of the prime that is responded to (shape in Experiment 3) is strengthened, then the validity of the color of the prime should have no influence on visual search RTs in Experiment 3 because the responded-to feature will not be repeated in the visual search array.

Method

Participants Nineteen participants (15 females; $M_{age} = 18.6$) from the University of Oklahoma participated in Experiment 3 for course credit. All but one participant were right handed, and all participants reported normal or corrected-to-normal vision.

Stimuli and apparatus Pentagons (45 × 55 mm) were introduced into Experiment 3. Also, shape names were presented at the beginning of each trial, and were the same as the shapes used in the previous experiment, with the addition of the pentagon (circle [10 × 30 mm), diamond [10 × 48 mm], hexagon [10 × 46 mm], pentagon [10 × 50 mm], square [10 × 38 mm], and triangle [10 × 42 mm]). The shape names were presented in white on a gray background.

Procedure Experiment 3 was similar to Experiment 2 except for the following elements: At the beginning of each trial, participants were presented with a shape name (500 ms), followed by a prime. Participants were instructed to press the spacebar when the shape name (cue) and the prime matched (go), and to not respond when they mismatched (no-go). After responding or after 750 ms, a fixation was displayed for 500 ms, followed by the visual search array. In the visual search array, a shape was always present that was the same color as the prime, but a different shape. For instance, if a red square was the prime, a red pentagon may have been in the visual search array. The visual search array never contained the prime shape or the shape that was indicated at the beginning of the trial. If participants were presented with "triangle" at the beginning of a trial followed by a red square, neither a triangle nor a square would be present in the visual search display, although a different shape (e.g., pentagon) would be red. Thus, the color of the prime was either valid (associated with the target line in the visual search display) or invalid (associated with a distracter line in the visual search display). The prime color was valid on 25% of the trials and invalid on 75% of the trials. Participants went through 16 practice trials and 128 experimental trials.

Results

One participant was removed from the analysis because of an odd data pattern; this will be discussed later but is mentioned here because this influences the reported error rate. The data from the practice trials were not analyzed. Errors in the go/no-go task occurred on 13.8% of the trials. Errors in reporting the orientation of the target line occurred on 1.1% of the trials. Go/no-go response errors in conjunction with errors in reporting the orientation of the target line occurred on 0.4% of trials. Errors were not analyzed in any manner. For the target detection task, two trials were removed before calculating the cutoff point for data that should be excluded from the analysis because of their being extreme outliers. After their removal, all responses that were above three standard deviations of the overall mean, for the target detection response, were removed from the analysis, which resulted in a removal of roughly 1.8% of the data.

Overall median RTs were submitted to a repeated measures ANOVA, with go/no-go (go, no-go) and prime–target validity (invalid, valid) as within-subjects variables. There were no main effects; however, there was a significant interaction between prime validity and go/no-go, $F(1, 17) = 17.12$, $p < .01$, $\eta_p^2 = .5$ (see Fig. 4). A Bonferroni post-hoc test examined the differences in validity for both go and no-go. Following a go response, there was a significant difference between the invalid (M = 1133.6) and valid (M = 1035.5) conditions whereby participants were faster in the visual search task when the prime was valid than when it was invalid (p = .01). Following a no-go response, there was not a significant difference between the invalid (M = 1063.55) and valid (M = 1117.5) conditions (p = .32). As was mentioned earlier the previously presented results have one caveat: One participant was removed due to his being an outlier. This participant significantly changed the results: With his inclusion, the difference between the invalid and valid conditions was not significant following a go response (p = .12), but was approaching significance following a no-go response (p = .08). The average difference between the invalid and valid conditions (difference = invalid − valid) following a go response was 98.13 ms (without the outliers inclusion), whereas the average for the outlier was −498.5 ms. The corresponding differences following a no-go response was −54.19 ms for the group and −402 ms for outlier. The exclusion of any other participant did not qualitatively alter the results reported previously (i.e., a significant difference between valid and invalid conditions were obtained following a go response (all p values < .05) but not following a no-go response).

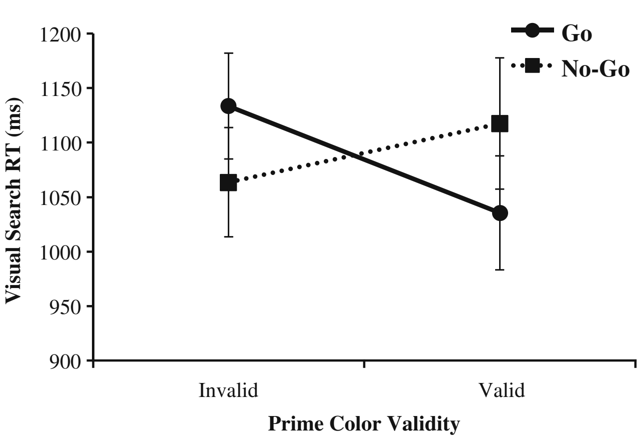

Fig. 4 Observed interaction between prime validity and go/no-go in Experiment 3. *Error bars* represent one standard error

Because of the large RTs in Experiment 3, we performed an analysis comparing the different experiments in the present study (Experiments 1–5). For each experiment, medians for each participant were used for the four main conditions (go invalid, go valid, no-go invalid, and no-go valid) while collapsing across ISI for those experiments that had ISI as a variable. This analysis revealed a main effect of experiment: The RTs in Experiment 3 were significantly slower than in the other experiments (all p values < .01), whereas none of the other experiments differed from each other significantly. We hypothesize that this difference is due to participants responding to the shape of the stimulus, which is likely to be a more difficult task than responding to its color (Experiments 1, 2, and 4) or to a digit within the prime (Experiment 5). This difficulty could then carry over to the visual search task, delaying the speed with which participants are able to identify the target. Because this does not deal with the driving question of the present study, we do not pursue this result further.

Discussion

The most relevant finding from Experiment 3 for the present study is that the validity of the prime color influenced how participants deployed attention in the visual search scene. Following a go response, participants were faster in finding the target in the visual search task when the target in the visual search array was contained within the shape that had the same color as the prime from the same trial. However, participants were slower to respond to the target in the visual search array when the shape that was the same color as the prime contained the distracter line. Therefore, participants are influenced by the color of the prime even though it was not needed for either the go/no-go task, or for the visual search task.

The results from Experiment 3 cannot be fully explained by the attentional set hypothesis. Participants should be attuned to a particular shape according to the cue presented at the beginning of the trial. By acting on the shape, however, the attunement of the system was adjusted to the features of the prime. This selection process then subsequently influenced performance in the visual search task. This provides evidence that the different features of the prime (independently) leave a trace that subsequently influences the selection process. That is, even though participants were responding to a particular feature of the prime for the go/no-go task, responding to the trace of the other feature of the prime (a different dimension than the responded to feature) influenced behavior in the visual search task.

Although the attentional set explanation in the introduction to Experiment 3 did not predict the results from Experiment 3, the results from Experiments 1–3 can be explained through a modified version of the attentional set hypothesis. If participants are attuned to a particular feature (a feature of the prime in this case) and a stimulus is presented that has that feature, then the item is going to be selected, including the different features of the stimulus (e.g., the specific color and shape). Since all of the features of the object are selected, the selection process then influences the visual search behavior in a priming of a pop-out-type effect (e.g., Maljkovic & Nakayama, 1994). In order to determine whether action has a unique contribution to the effects observed in Experiments 1–3, participants must act on the prime on the basis of the fact that it contains a feature that is different than the cue. For instance, if participants are presented with the cue “red,” then they would make a go response when the prime is some other color than red. This issue was explored in Experiment 4.

Experiment 4

In Experiments 1–3, participants responded to the prime according to the match between the word (cue) presented at the beginning of the trial with the prime. In Experiments 1 and 2, participants responded when the color name and prime matched, and in Experiment 3, participants responded when the shape name and prime matched. As was discussed, a modified version of the attentional set hypothesis can explain the results from Experiments 1–3. Thus, Experiment 4 was designed to test whether this modified version of the attentional set hypothesis is driving the results from Experiments 1–3 or whether action in itself modifies attentional deployment. In Experiment 4, participants were instructed to respond when the color name and the prime color did not match (go) and to not make any response if the color name and the prime color matched (no-go). We aimed to understand the degree of response action’s role in modifying the subsequent visual search performance. To allow for a comparison between Experiments 1 and 4, all aspects of Experiment 1 were included in Experiment 4 with the exception of when a go or no-go response was warranted.

Method

Participants Fourteen participants (12 females; M_{age} = 19.1) from the University of Oklahoma participated in the experiment for course credit. Twelve of the participants were right handed, and all participants reported normal or corrected-to-normal vision.

Stimuli and apparatus The same stimuli and apparatus as in Experiment 1 were used in Experiment 4.

Procedure A similar procedure used in Experiment 1 was used in Experiment 4, with the exception that participants were instructed to press the spacebar when the color name and the prime matched (go) and to not press anything when the color name and prime mismatched (no-go). Participants completed 32 practice trials andfour blocks of 64 experimental trials.

Results

Go/no-go errors occurred on 5.5% of trials,and the target identification error rate was 0.8%. Go/no-go errors in conjunction with target identification errors occurred on roughly 0.2% of trials. Trials with error responses and practice trials were not analyzed. In addition, one trial was removed due to a target detection response being faster than 150 ms. Finally, trials more than three standard deviations above the overall mean were removed (1.5% of trials).

Median RTs were submitted to a repeated measures ANOVA with go/no-gotype (go, no-go), ISI (100, 500 ms), and the prime–target validity (invalid, valid) as within-subjects variables. We found a significant main effect of ISI, $F(1, 13) = 6.25$, $p < .03$, $\eta_p^2 = .33$. Participants were faster to detect a target at the longer ISI than at the shorter ISI. We also obtained a main effect of prime validity: Participants were faster to respond when the prime was valid as opposed to invalid, $F(1, 13) = 16.3$, $p < .01$, $\eta_p^2 = .56$. There was a significant interaction between go/no-go type and ISI, $F(1, 13) = 10.14$, $p < .01$, $\eta_p^2 = .44$. Participants were slower to find the target after a go response at the shorter ISI than at the longer ISI, but ISI did not make a difference following a no-go response. The interaction between ISI and prime validity approached significance, $F(1, 13) = 4.24$, $p = .06$, $\eta_p^2 = .24$. When the prime was invalid, participants’ RTs were equivalent; however, when the prime was valid, participants were faster to respond at the longer ISI than at the shorter ISI. Unlike in Experiments 1 and 2, however, we did not find the significant interaction between go/no-go and validity.

We also obtained a significant three-way interaction among the go/no-go, ISI, and prime–target validity, $F(1, 13) = 7.4$ $p < 0.02$, $\eta_p^2 = .36$ (see Fig. 5). We conducted a post-hoc Bonferroni analysis, which revealed some differences between the invalid and valid conditions, depending on whether a go or a no-go response preceded the visual search task. Relevant to the present study, following a go response, we obtained a significant interaction for ISI and prime validity: For the shorter ISI condition, there was no RT difference between the invalid (M = 836.8) and valid (M = 821.7) conditions, but for the longer ISI condition, participants were faster at detecting the target when the prime was valid (M = 828.6) than when it was invalid (M = 733.21) ($p < .01$). Following a

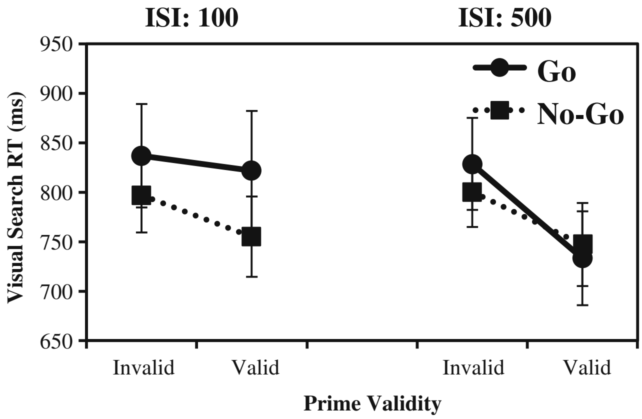

Fig. 5 Observed interaction between go/no-go, ISI, and prime validity in Experiment 4. *Error bars* represent one standard error

no-go response, the opposite was true, with a significant difference occurring at the shorter ISI ($p < .03$) between the invalid ($M = 796.8$) and valid ($M = 755.1$) conditions, but not a significant difference at the longer ISI between the invalid ($M = 800.3$) and valid ($M = 747.1$) conditions.

Combined analyses for matching and mismatching go/no-go trials One goal of Experiment 4 was to examine whether the matching of the cue with the prime itself could explain the prime–target validity effect without resorting to action as a possible explanation. In Experiments 1–3, participants acted when the cue matched the prime. In Experiment 4, participants acted on the prime when the cue mismatched the prime. The results from Experiment 4 are not as straightforward as those in Experiments 1–3. Thus, we decided to further examine the role of matching and action on visual search by running an additional analysis.

For the analysis, we combined Experiments 1 and 4 and treated go/no-go (go [Experiment 1], no-go [Experiment 4]) as a between-subjects variable and prime validity (invalid, valid) as a within-subjects variable, while collapsing across ISI. There was a significant main effect of prime validity: Participants were faster in detecting a target when the prime was valid as opposed to invalid, $F(1, 30) = 85.49$, $p < .01$, $\eta_p^2 = .74$. There was also a significant interaction between go/no-go and prime validity: Participants were faster to respond when the prime was valid than when it was invalid for the go condition, with a smaller difference between the respective no-go conditions, $F(1, 30) = 19.69$, $p < .01$, $\eta_p^2 = .4$ (see Fig. 6). A Bonferroni post-hoc analysis revealed a significant difference between the valid ($M = 702.4$) and invalid ($M = 837.4$) conditions after a go response ($p < .01$). No difference was observed between valid ($M = 751.1$) and invalid ($M = 798.6$) trials following a no-go response. The same test was performed when comparing the respective ISIs (i.e., invalid and valid differences for go and no-go at 100 ISI and 500 ISI), with the same results for both.

Discussion

The average difference between the invalid and valid conditions for a no-go response (when the cue and prime matched) was 48 ms in Experiment 4. This contrasts with the 135 ms difference between the invalid and valid conditions in Experiment 1 following a go response, with similar standard error values (the standard errors in Experiment 1 were slightly smaller than those in Experiment 4). Our additional analysis of directly comparing Experiments 1 (go) and 4 (no-go) further confirmed the significant differences for these two conditions. The invalid–valid differences for prime stimuli were significantly larger for Experiment 1.

Another important aspect of Experiment 4 was that it revealed time differences in the influence of the prime on visual search depending upon whether a go or no-go response was executed. At the shorter ISI, there was a significant difference between the invalid and valid conditions for the no-go condition (when the cue and prime matched). This difference was not present at the longer ISI, however. This relationship was flipped for the go response (when the cue and the prime mismatched), with no difference between validity occurring at the shorter ISI, but with a significant difference occurring at the longer ISI. This result suggests that the attentional set hypothesis, as was argued previously, does have an influence, but this influence rapidly dissipates (i.e., it does not last for 500 ms). The influence that action has may strengthen the trace of the prime and subsequently influence the selection process when the cue and the prime match, leading to a stronger influence of the prime at both the short and longer ISIs (as shown in the differences, the comparison of Experiment 1 with Experiment 4) in the visual search task,

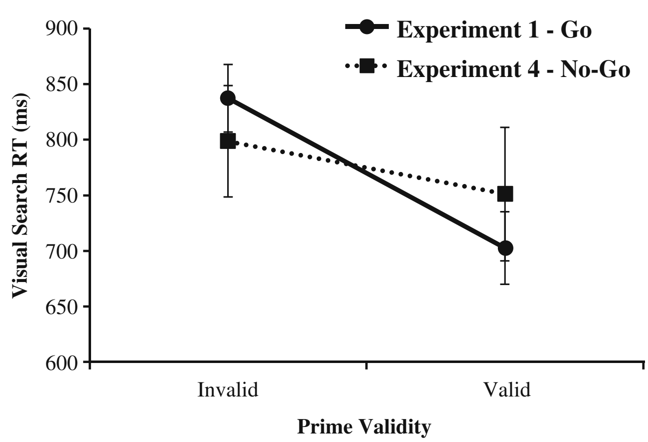

Fig. 6 The observed interaction when comparing Experiments 1 and 3 for trials when the cue matched the prime. In Experiment 1, participants responded (go) when the cue matched the prime, whereas in Experiment 3, participants did not respond (no-go) when the cue matched the prime. The interaction provides evidence for a unique contribution of action for the observed validity effects. *Error bars* represent one standard error

but is not able to be untangled with the present set of experiments. Acting on an object may also have a strong influence on the selection process, but takes longer to have an influence when the object is acted on because of the absence of a feature (i.e., not being red). Therefore, the strength of the trace of the prime depends on a number of factors, including the attentional set of the participant, whether a response was made, and the amount of time after responding that a similar feature that matches the trace appears in the visual field. The specific time course of these different processes is an important issue but is outside of the scope of the present study.

Experiment 5

In Experiments 1–4, participants made a go/no-go response on the basis of some feature of the prime. For instance, in Experiment 1, participants responded on the basis of whether the prime contained a particular feature (i.e., the prime color matched the cue), and in Experiment 4, participants responded when the prime lacked a particular feature. For the most part, these experiments revealed that action can have a strong influence on what is selected in subsequent visual scenes. We have interpreted these findings as indicating that the trace of the prime is being strengthened (Experiments 1 and 2), including the individual features of the prime (Experiment 3). In Experiment 5, we examined whether a response that is made to a feature other than an aspect of the prime can strengthen the trace of the prime and also influence the selection process. Specifically, this was examined by having participants respond to the matching of a digit (cue) presented at the beginning of each trial with a digit that appeared briefly in a subsequent visual screen and always appeared within a prime. Although participants are responding to the digit, the validity of the prime may have an influence on visual search behavior. If action does indeed strengthen the trace of the prime, then the validity of the prime should have an influence following a go response and should not have an influence following a no-go response.

Method

Participants Nineteen participants (16 females; M_{age} = 18.9) from the University of Oklahoma participated in Experiment 5 for course credit. All participants were right-handed and reported normal or corrected-to-normal vision.

Stimuli and apparatus In Experiment 5, digits (1–9) were presented within the primes (roughly 10 × 10 mm). All other stimuli in the experiment were the same as those appearing in the other experiments.

Procedure Each trial began with the presentation of a digit (cue) for 500 ms, followed by a fixation for 150 ms. After the fixation, the prime appeared, and after a brief period (400 ms), a digit appeared within the shape for 200 ms, followed by the same prime being presented for an additional 400 ms. When the digit within the prime matched the one at the beginning of the trial, participants were told to respond by pressing the spacebar (go). When the number within the prime mismatched the cue, participants were told to not respond (no-go). For 25% of the trials, the prime was valid and contained the target line, and for 75% of the trials, the prime was invalid and contained a distracter line. The prime was always in the visual search display. Participants went through 16 practice trials and then went through four blocks of 64 experimental trials each (see Fig. 7 for a schematic illustration of a go valid trial).

Results

For go/no-go, the average error rate was 4.7%. For reporting the orientation of the target, the error rate was 2.0%. Conjunction errors in reporting the orientation of the target and responding to the prime occurred on 0.3% of trials. One trial was removed because of an RT to the visual search array that was faster than 150 ms. RTs beyond three standard deviations from the mean were removed from the analysis, resulting in 1.8% of the data being removed. Trials with errors and practice trials were not further analyzed.

Overall median RT's for the visual search task were submitted to a repeated measures ANOVA, with go/no-go (go, no-go), ISI (100, 500), and prime validity (invalid, valid) as within-subjects variables. Participants were faster in detecting the target in the visual search array when the prime was valid as opposed to invalid, $F(1, 20) = 17.16$, $p < .01$, $\eta_p^2 = .46$. There was a main effect of ISI: The target item was detected faster at the longer ISI (500 ms) than at the shorter ISI (100 ms), $F(1, 20) = 8.18$, $p = .01$, $\eta_p^2 = .29$. There was also a main effect of go/no-go: Participants were slower to respond following a gotrial than following a no-go trial, $F(1, 20) = 5.5$, $p = .03$, $\eta_p^2 = .22$. Finally, there was a significant interaction between go/no-go and prime validity, $F(1, 20) = 29.98$, $p < .01$, $\eta_p^2 = .6$ (see Fig. 8). A post-hoc Bonferroni analysis test confirmed that participants were faster when the prime was valid (M = 755.1) than when it was invalid (M = 846.8) following a go response ($p < .01$). No such difference was present between the valid (M = 767.6) and invalid (M = 779.9) trials following a no-go response.

Discussion

In Experiment 5, participants performed either a go or a no-go response on the basis of whether a digit presented with a

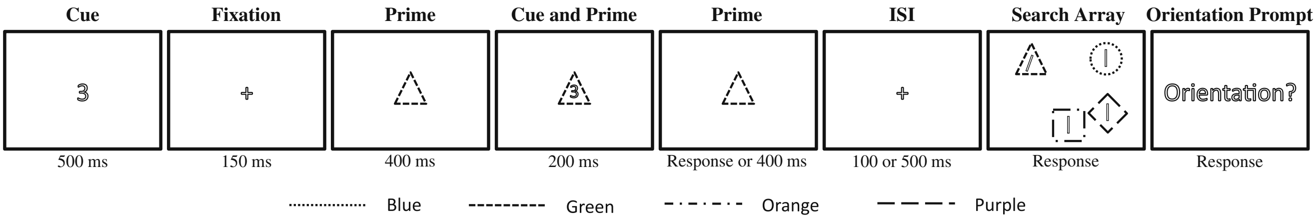

Fig. 7 Schematic illustration of a go trial with the prime being valid Experiment 5

prime matched a digit that was presented at the beginning of a trial. Following a go response, the validity of the prime influenced search such that participants were faster in detecting the target when the prime was valid and slower when the prime was invalid. Even though the go response was only based on temporal co-occurrence of the events, we still observed that it resulted in an attentional bias during the visual search task.

The results of Experiment 5 provide evidence that action can indeed have an influence on visual search behavior even when the action-object association is merely temporal. These results suggest that the trace of the prime was strengthened even though participants were not responding to a feature of the prime. The results also show that participants' visual search performance was slower overall in the action condition than in the no-action condition. One would expect that making a motoric response during the prime trial would facilitate response during visual search. We considered that the indirect association between the action and the feature of the prime object would have caused the general slowing for the go condition as compared with the no-go condition.

General discussion

In five experiments, we investigated how acting on a prime influenced visual search behavior with an invalid or valid

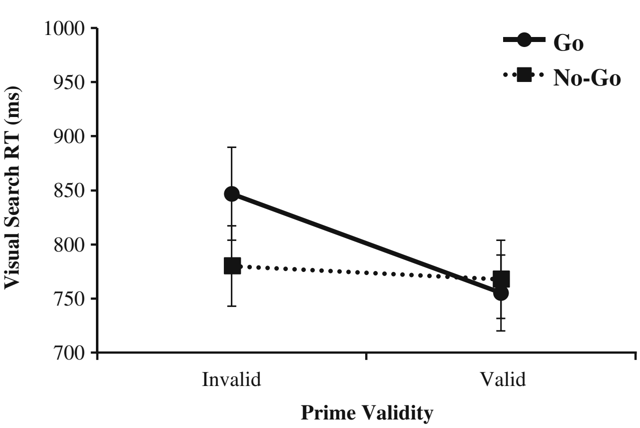

Fig. 8 Observed interaction between go/no-go and prime validity in Experiment 5. *Error bars* represent one standard error

prime. In Experiments 1 and 2, we demonstrated that the validity of a prime can strongly influence visual search behavior, but only when the prime has been acted on. In Experiment 3, we provided further evidence for this claim, demonstrating that even when a prime is acted on because of its containing a feature that is not in the visual search display (shape), the feature of the prime that is not important for the task (color) can still have an influence on visual search behavior when the prime has been acted on. The results from Experiment 3 suggest that when an object is acted on, the trace of the individual features is strengthened as compared with when the object is not acted on.

The matching of the cue with the prime does have an influence on visual search behavior (as was demonstrated in Experiment 4), as would have been predicted by a modified version of the attentional set hypothesis. However, action does indeed have a unique contribution, as demonstrated by the comparison of the Experiment 1 go condition (in which the prime matched the cue) with the Experiment 4 no-go condition (in which the prime matched the cue as well). This claim is also bolstered by the finding that at the longer ISI in Experiment 4, there were validity differences for the go condition but not for the no-go condition. Finally, in Experiment 5, we provided evidence that action while a prime is presented can have an influence on visual search behavior even when the reason for acting (the matching of the cue with the digit) is only temporally and spatially connected.

The results from the present study suggest that action can have a strong influence on the deployment of what is selected in a visual scene after the action behavior has already taken place. As was discussed in the introduction, many studies have investigated the role of how preparing an action can influence what is selected in a visual scene (e.g., Craighero et al., 1998). We suggest that another important aspect in the relationship is how attention is deployed after an action has already occurred. When considering this relationship however, it is important to consider a number of different variables, including (a) why an object is being responded to (e.g., because an object has or does not have a particular feature), (b) whether or not a response is made, and (c) the time frame between viewing an object and when the same object or a feature of the object is repeated. Future research may wish to examine these different variables to provide tighter constraints on when these different variables have an influence on visual search behavior.

Throughout the present article, we have suggested that the strength of the trace of the prime is being manipulated on the basis of several different factors. Important to the present study, we hypothesize that this trace is strengthened when an object is acted on, biasing the selection process in subsequent visual scenes. We suggest that the trace modifies the attentional weight of specific features in subsequent visual scenes. When the visual search array is presented, the top-down goal of searching for the target line competes with the trace of the prime as well as with bottom-up influences; however, we did not examine bottom-up influences in the present study. Following an action toward an object (given the conditions specified previously, such as time interval), the trace of the prime biases attention toward the same object (or feature, as demonstrated in Experiment 3) in the visual array and wins the competition for selection regardless of whether it is the object that is important for current task goals (e.g., a visual search task).

Neuropsychological research has demonstrated the importance of action in cognitive processing. The dorsal stream of the visual pathways is known to perform the sensorimotor transformations required for visually guided actions, such as grasping a specific object (Jeannerod, Arbib, Rizzolatti, & Sakata, 1995; Goodale & Milner, 1992; Rizzolatti, Riggio, & Sheliga, 1994). Each region within the posterior parietal cortex projects to separate regions within the premotor areas of the frontal lobes, where movements are programmed. We assume that just as similar cortical structures are involved in planned motor movements and attention (e.g., Gherri & Eimer, 2009), similar cortical structures are involved in the execution of a response toward an object (or feature) and subsequent influence on attention, even for simple motoric responses.

In sum, the results of the present study demonstrate that a simple action performed on an object or feature can modify a subsequent visual search task. The direct link between the trace of an object and the action performed on the object provides a source of reconfiguration as we dynamically interact with the environment.

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