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Action effect: An attentional boost of action regardless of medium and semantics*

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Previous research on the action effect had shown how simple action towards a stimulus can enhance the processing of that stimulus in subsequent visual search task (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). In four experiments, we investigated whether semantic representation of action word can induce the same attentional boost towards that stimulus and whether the type of action performed can modulate the action effect. In experiment 1, we replicated the same experimental paradigm displayed in previous studies. Participants were first shown an action word cue - “go” or “no”. When the action cue was “go”, participants were to press a designated key, but not to when the action cue was “no”. Next, participants performed a visual search task, in which they reported the orientation of a tilted bar. The target could appear on top of the previously shown prime object (valid), or not (invalid). Reaction times (RTs) to the search task were measure for analysis and comparison, and the action effect had been replicated. In experiment 2, participants were instructed to respond with the keyboard for the action task, and to respond with the joystick for the visual search task. In experiment 3, participants were instructed not to press any key on the onset of prime, and then perform the visual search task to isolate the effect of semantic representation. Lastly, in experiment 4, participants were instructed to press separate keys for “go” and “no” on the onset of prime, and then perform the visual search task. Results indicate that semantic representation alone did not modulate the action effect, regardless of type of action and medium of action.

Key words : attention, validity effect, action effect, semantic representation

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Introduction

Numerous models of visual attention had proposed several factors contributing to attentional allocation. Particularly, such elements have been studied in that they create biases to capture attention. For instance, it has been shown that spatially cueing a location in the search display creates attentional priority on the cued location in a subsequent search task (Remington, Johnston, & Yantis, 1992), and that attentional control settings can influence such capture effect (Folk, Remington, & Johnston, 1993), whereas visual context and probability of stimuli location can also affect attention implicitly (Chun & Jiang, 1998). Other cognitive factors have been demonstrated to affect attention in a top-down manner. Retaining mental representations in working memory is known to capture attention with cognitive control (Desimone & Duncan, 1995; Downing, 2000; Han & Kim, 2009), as well as unconsciously (Pan, Lin, Zhao, & Soto, 2013; Ji, Lee, & Kim, 2017).

Among such diverse factors contributing to attentional processing, motoric action has been shown to influence attentional allocation as well (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999; Deubel & Schneider, 1996; Wykowska, Schubö, & Hommel, 2009). Such action-based accounts had often utilized procedures inducing action planning among participants towards a given stimuli (Deubel & Schneider, 1996), or performed actions directly associated with the subsequent cognitive task, and measured compatibility effects to account for selection in attention (Wykowska et al., 2009). For instance, Deubel and Schneider (1996) instructed participants to perform planned saccadic movements before a visual search task. Such procedures led to faster reporting of target stimuli in the direction of the planned saccades than of those appearing in other locations. Wykowska and colleagues (2009) instructed participants to prepare a cued hand movement, but only to perform the action after a visual search task. Results displayed an attentional prioritization in the search task only to the stimuli related to the cued action than other neutral stimuli, showing faster reporting time. These action-based accounts of attention emphasize the role of pre-planned responses to the stimuli, in line with the action-specific perception account. The action-specific account dictates that what people perceive in the surrounding environment is ultimately according to their ability to interact with it (Witt, 2011). Such line of research was supported by Bloesch and colleagues (2012), who demonstrated that the individual reachability of an object can shape perceived proximity to that object (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012).

A recent series of research have been conducted on how a simple motor response to a presented stimulus can influence consequent attention allocation to the same stimulus in a later unrelated visual search task (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). Unlike in the aforementioned action pre-planning accounts, results of these studies emphasized that an unrelated physical action such as a simple keyboard press is enough to bias subsequent attention towards the acted-on object. In Buttaccio and Hahn's (2011) study , participants were first shown a color word, and then a colored shape stimulus, subsequently. Participants were instructed to perform a Go/No-go task, in which they pressed a designated key if the previous color word matched the color of the shape. If the color word did not match the color of the subsequent prime, participants were to just view the object. Participants then performed a visual search task, in which they searched for a target tilted bar and reported the orientation of the bar. The target could appear on top of the previously seen prime object (valid) or not (invalid). The target was always presented with three non-tilted, vertical distractor bars, which could appear on top of irrelevant-colored shapes in the valid conditions, and on top of the prime object in the invalid conditions. Attentional validity effect between the prime object was expected to be displayed, with faster RTs in valid trials than in invalid trials; however, results showed a discrepancy between the RT validity effects for go/no-go conditions, with differences in the amount of RT benefits for the two conditions indicating an additional facilitation effect of simple key-press response in the "go" trials. In other words, the amount of validity effect of RTs in go trials was significantly larger than in the no-go trials. The authors therefore argued for an "action effect" of attentional allocation to the specific property of the prime object (i.e., color), in that the physical action of pressing a designated key in the go trials contributed to strengthening the object's "trace". This notion of action effect was expanded in Weidler and Abrams's research (2014), in which they obtained the same kind of action effect with a more simplified series of experimental paradigms. The procedures of the experiments were similar to Buttaccio and Hahn's (2011), except that the semantics of the color words were eliminated and replaced with the words, "GO" and "NO". Participants performed action in the "GO" conditions, and only viewed the prime in "NO" conditions. The prime objects were simplified to a circular shape, and only two stimuli were displayed in the search array (see experiment 2). The authors simplified the experiment paradigm to investigate whether they can replicate the action effect even without having participants fully evaluate the features of the prime object. The same type of RT benefit was displayed in their results, supporting the originally reported action effect displayed in Buttaccio and Hahn's (2011) studies. Similar types of validity difference were displayed in various follow-up studies as well; action effect was displayed during pop-out visual search task (Weidler & Abrams, 2016), during unconscious visual processing in a breaking continuous flash suppression (b-CFS) paradigm (Suh & Abrams, 2018), and during priming of semantically related prime stimuli (Weidler & Abrams, 2018).

Such robust effect of action had been displayed through numerous replications mentioned above, yet the specific cognitive mechanisms to such facilitation have not been investigated in detail. One possible explanation that the original authors have continuously suggested is the event files account of attention (Hommel, 1998; see Hommel, 1998; 2004, for event file hypothesis). Event files are episodic memory traces that "link the current task context, codes of perceptual events, and the actions performed therein" (Hommel, 2004). Therefore, the event files generated with action and prime object may have created the attentional weight change in the subsequent visual search. However, this "Common Coding" view of perception focuses on the specificity of the link between the type of response (action) and the trace of features of stimuli. In Weidler and Abrams's (2014) case, the unrelated action is only mapped with the word "GO", and not with any features per se. Rather, the mapped action related with the feature of the stimuli would only be the response to the subsequent visual search task. Therefore, event files do not seem to entirely explain the attentional bias shifting in this case.

Robinson, Clevenger, and Irwin (2018) refuted the action-based account of attentional selection by proposing the template matching account of attention. They suggested that the effects displayed are derived from enhanced goal processing, not from physical action per se. That is, participants would generate a template of the stimuli beforehand, in accordance with the experimental instructions; such mental template would then affect the subsequent visual search performance. For example, in Buttaccio and Hahn (2011), participants are to produce a response (action) whenever a color word matches a color stimulus. Robinson and colleagues' (2018) explanation is that when participants are shown the color word "red", they may generate a visual template of a "red circle". When the red circle is thus actually shown, processing of "red circle" is increased because of this strengthened template representation. Such increased processing carries over to the subsequent visual task, boosting the attention towards the stimulus. Robinson and colleagues argued that their visual template-related views are in line with priming studies and working memory template studies conducted in the past. That is, even though the action itself is not related, the visual template of the prime object shown is related to the subsequent visual search task. Indeed, the classical Desimone and Duncan's (1995) study had displayed the behavioral and neural evidence for the increased processing of templates retained in working memory in subsequent tasks; various related follow-up studies show similar results (i.e., Carlisle, Arita, Pardo, & Woodman, 2011; Eimer, 2014; Olivers, Peters, Houtkamp, & Roelfsema, 2011). Template matching does seem to explain the results obtained from Buttaccio and Hahn's (2011) studies ; however, the paradigms used in Weidler and Abrams's series of studies (2014; 2017; 2018) did not utilize the color word cues in the physical action task. Rather, they eliminated the possibility of color template generation by displaying action words (GO / NO), and the results still displayed the action effect. Although seemingly more parsimonious, the template matching account also does not entirely explain the action effect.

Reflecting on the affordance studies and action planning studies, the type of action made during the response to the prime and to the visual search task could be responsible for the action effect. That is, as aforementioned affordance studies had highlighted, the cognitive association between the type of action performed and the stimulus may come into play in this experimental setup. For instance, Handy, Grafton, Shroff, Ketay, and Gazzaniga (2003) had demonstrated that graspable objects can automatically capture spatial attention if participants realize the potential for action, also confirming the neural activations in the related regions of the brain. The task used in the action effect research requires participants to respond with a keypress, and this action is repeated in the visual search task as well via a keypress response, although with a different type of key. Nonetheless, it can be argued that the type of action is the same across all trials, priming participants not only with the displayed object but also with the keypress action. It can therefore be argued that the type of action may allocate participants' attention to the stimulus acted on, because participants may recognize the potential for the action in the subsequent visual search task. Could this same type of keypress be responsible for the faciliatory effect in action trials, thereby inducing the validity differences?

Another related theme in terms of explaining the mechanisms to the action effect seem to stand out: the concept of representation - trace of feature, as Buttaccio and Hahn (2011) pointed out - and attentional enhancing through such creation of the mental representation - template, as Robinson et al. (2018) pointed out. Although studies on representation of the stimulus acted on had been investigated in detail, studies on action-related representations have not been conducted in length. As action planning studies (Bloesch et al., 2012; Wykowska et al., 2009) elaborate, motoric representations can also affect attentional selection in visual search tasks. In this study, we focused on whether semantic representation of the action word cues could have biased attentional allocation to the prime object. Past models on semantic representations highlight the relationship between selective attention and semantic priming (Johnston & Dark, 1986; Meyer, Schvaneveldt, & Ruddy, 1975; Posner & Snyder, 1975). The core of semantic priming is that the processing of a word stimulus can speed up the processing of a semantically related prime word (Johnston & Dark, 1986). Such discrepancy in processing priorities via selection biases shows up in a number of classical studies such as the lexical categorization studies (Meyer, Schvaneveldt, & Ruddy, 1975) or matching latency studies (Posner & Snyder, 1975). From these classical concepts of semantic activations, recent studies revealed a neurological bases for specialized activations of motor areas when processing motor words. For example, action words related to actions of face, arm, or leg (i.e., talk, grab, walk) activate corresponding motor areas in the central cortex (Hauk, Johnsrude, & Pulvermüller, 2004; Pulvermüller, Shtyrov, & Ilmoniemi, 2005). Perhaps such automatic linguistic association between type of action and action word may have played a crucial role in the Go/No-go type task in inducing the action effect. Typically and intuitively, the words GO and NO convey facilitative and inhibitory connotations, respectively. Could these facilitative and inhibitory semantic representations of these word cues have modulated the relative validity effect in their respective conditions, ultimately leading to the validity differences?

In this study, we aimed to investigate three main factors regarding the action effect: first, whether having different medium of response during each task in the dual-task paradigm may influence the prioritization of the acted-on stimuli; second, whether the semantic representation of “GO” and “NO” alone would be sufficient to induce the differences in validity effect between the two conditions; third, to what extent the physical action plays a part in allocating participants’ attention onto the presented stimuli.

To preview, we investigated our hypothesis by using modified versions of experiment 3 of Weidler and Abrams’s (2014) study. In experiment 1, we aimed to replicate the original experiment to establish a baseline for comparative measures. In experiment 2, we separated the medium of response by instructing participants to respond with the keyboard for the action task and to respond with the joystick for the visual search task. Afterwards, we compared the results with experiment 1 to account for possible differences between the two experiments. In experiment 3, in order to isolate the possible effect of semantic representation, we eliminated the action task altogether. That is, we instructed the participants not to press any key on the onset of prime and then perform the visual search task. This way, if attentional boost to the prime was caused by the semantic activation of the word “GO”, then the same validity effect difference (action effect) would be displayed. Lastly, in experiment 4, we instructed participants to press separate keys for “GO” and “NO” on the onset of prime and perform the visual search task. This time, by having participants perform the same type of action for both “GO” and “NO” conditions, the action effect would also be displayed if attentional boost to the prime was caused by semantic activation of the word “GO”. By allocating the same type of action (pressing a certain key on the keyboard) for both action word cues, We would also be were able to compare the results between experiment 3 and experiment 4, since the only difference between the two was the presence of action. This way, we were able to account for the extent of attentional boosting effect of physical action in inducing the action effect. In other words, we were able to explore whether semantic activation alone could cause the attentional boost, whether physical action alone could cause the boost, or whether both were present in the attentional boost of action effect.

General Methods

Stimuli and Apparatus

All stimuli were presented on a 24-inch LED monitor with 60-Hz refresh rate with 1920×1080 resolution. The experiment was conducted on Intel quad-core level computers and operated via MATLAB equipped with Psychophysics Toolbox Extension 3.0 (Brainard, 1997). Distance from monitor to participants’ eyes was about 57 centimeters - 1 pixel was thus equivalent to 0.03°. Participants’ heads were each stabilized using chin-and-forehead rests.

All stimuli appeared in front of black-colored background with RGB = [0, 0, 0], and were of the same dimensions in all three experiments as described as following. Action words (GO / NO) appeared in Korean language (“출발” / “정지”), with fontsize of 2° in height at the center of the screen. Search stimuli were each 6°× 6° visual angle-wise in diameter, in one of six colors - red, yellow, green, blue, purple, and gray, and at one of five locations of equal distance and angle from the center of the screen. Search stimuli orientations were leaned to either left or right for targets, and vertical for distractors. Target tilt angle was determined by digitally drawing a line from either left top (-3°) or right top (3°) coordinates through the center of the circle stimulus. In our experimental settings, this put the tilt angle at about 31.53° angle from the center of the circle.

Experiment 1

Before manipulating the original Weidler and Abrams's (2014) experimental paradigm, we wanted to replicate the action effect with our own experimental apparatus. As Robinson and colleagues (2018) had not been able to replicate the action effect from using the same paradigm, we first wanted to confirm and set the baseline for the effect of action on attention. For the purposes of this replication, we utilized the experimental paradigm from the third experiment in Weidler and Abrams's (2014) studies, in which the acted-on stimulus did not offset before a set amount of interstimulus interval (ISI = 500ms), regardless of action. Such measures were taken to equate the exposure time of the stimulus regardless of action, and we sought to maintain the same conditions throughout our study. To replicate the results as close as possible to the original study, we also used the same analysis method as Buttaccio and Hahn (2011) and Weidler and Abrams (2014), by conducting a repeated measures analysis of variance (ANOVA) for median RTs only for trials with correct responses both to the action task and the visual search task. All stimuli were presented on a 24-inch LED monitor with 60-Hz refresh rate with 1920×1080 resolution. The experiment was conducted on Intel quad-core level computers and operated via MATLAB equipped with Psychophysics Toolbox Extension 3.0.

Methods

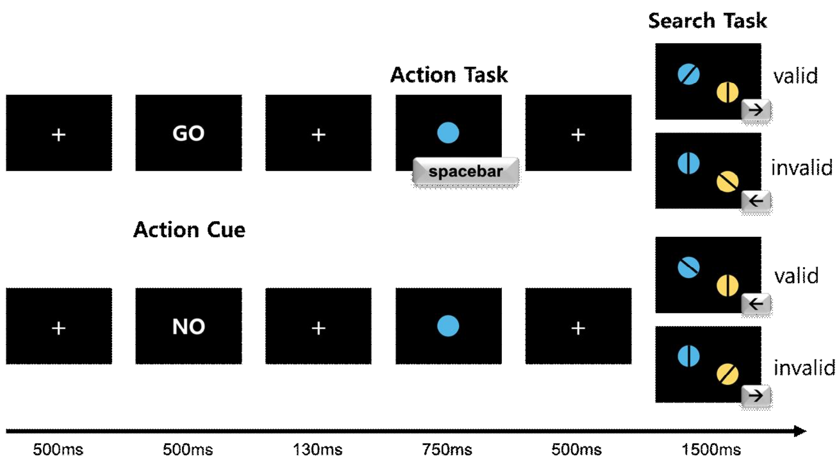
Participants

Nineteen students from Yonsei University (N=19) participated for course credit. All participants were of Korean nationality and had normal or corrected-to-normal vision. All participants were informed of their ethical rights and willingly signed consent forms before the experiment. The experiment was approved by the institutional review board (IRB) of Yonsei University.

Procedure and Design

At the beginning of each trial, participants were first presented with an action word cue - either

“GO” or “NO”, and sequentially presented with a colored circle (prime). They were instructed to press the “spacebar” key on the onset of the prime when the cue was “GO”, and not to press anything when the cue was “NO”. After 500ms, participants were presented with two different colored circles that could appear in two of the pre-allocated five locations equidistant from the center of the screen. One circle had the same color as the prime, and the other had a novel color. Of the two circles, one contained a vertical line (distractor) while the other contained a tilted line (target). Participants were instructed to search for the target and report the orientation of the target tilted bar by responding with the “left arrow” key or the “right arrow” key on the keyboard. The target could appear on top of the previously seen prime (valid condition), or on top of a novel colored circle (invalid condition). A total of 24 practice trials and 144 test trials were conducted, with half of all trials for valid conditions and the other half for invalid conditions (Fig. 1). Participants’ reaction times (RTs) and accuracy to both the action task and search task were recorded. An auditory feedback (beep sound) was given for responses that were too slow or incorrect, and the feedback differed in pitch for the action task and the search task. Participants were debriefed after the experiment.

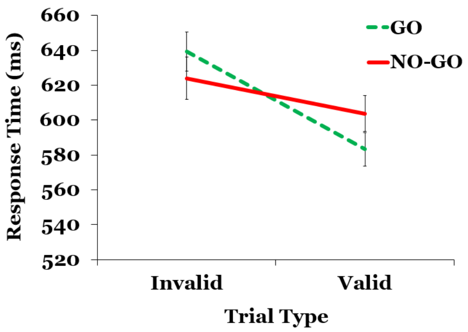


(Fig 1) Procedures for Experiment 1. In the action task, participants were instructed to press the “spacebar” after seeing “GO” and not to press any keys after seeing “NO”. In the subsequent search task, participants were instructed to find the target tilted bar and report the orientation of the bar with the respective arrow key. On valid trials, the tilted line was in the previously seen color; on invalid trials, that color contained a distractor. *Note that the action words cues given were displayed in Korean language. *Note that the action words cues given were displayed in Korean language.

Results

Mean accuracy for the action task was high at 98.13% (SE = .34). No significant differences were displayed for GO / NO conditions in terms of accuracy.

Mean accuracy for the search task was also high at 97.6% (SE = .41). The main analysis of median RT means only included RTs for trials with correct responses to both the action task and the search task, as per the analysis rationale utilized in previous action effect studies (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014). A 2×2 repeated-measures ANOVA was conducted for mean RT scores, with validity (valid vs. invalid) and action type (GO vs. NO) as within-subject levels of factors. Graphic representation of the results is shown in Fig. 2. Analysis revealed that the main effect of validity was significant, $F(1,18) = 23.396$, $p < .001$, $\eta_p^2 = .565$, with significantly faster RTs for valid condition (M = 593.51ms, SE = 7.15) than invalid condition (M = 631.62ms, SE = 8.23). Interaction between action word cue and validity was also significant, $F(1,18) = 12.525$, $p = .002$, $\eta_p^2 = .410$, Main effect of action word cue was not significant, $F(1,18) = .257$, $p = .618$, $\eta_p^2 = .014$. Post-hoc analysis revealed that participants were slower to respond on invalid than valid conditions both in the action trials, $t(18) = 5.682$, $p < .001$, and in the no-action trials, $t(18) = 2.282$, $p = .035$. However, the mean RT difference between invalid and valid conditions was larger for action trials M = 56.05ms, SE = 12.86) than for no-action trials M = 20.18ms, SE = 4.63), contributing to the significant validity differences between the two conditions.



(Fig 2) Search task RT results for Experiment 1. Means of participants' median RT data were used for analysis as a function of action and validity. Interaction between GO trials and NO-GO trials were significant, successfully replicating the action effect. Error bars depict one standard error (SE).

Discussion

Results from Experiment 1 displayed a successful replication of the action effect shown in the previous studies, in which the RT differences between the invalid and valid conditions were larger for "GO" condition trials than for "NO" condition trials. Therefore, even when the physical action had been unrelated to the visual search task, the validity effect was modulated by the introduction of action.

Experiment 2

Now that the baseline effect has been established, we manipulated the experimental procedures to separate the type of action performed by the participants and compared the visual search task performance with those of the previous experiments. To elaborate, we distinguished the medium of response input from the action task and the visual search task. Participants still responded by pressing a key on the keyboard for the action task, but they responded via joystick input for the visual search task. In this way, participants could truly perform an "irrelevant keypress action" before the main visual search task. If physical action could enhance the priming effect regardless of response method and relevance to the main task, then we could expect the same type of action effect as displayed in the first experiment. However, if action type and relevance truly did matter, then we could expect an absence of the interaction between action and validity.

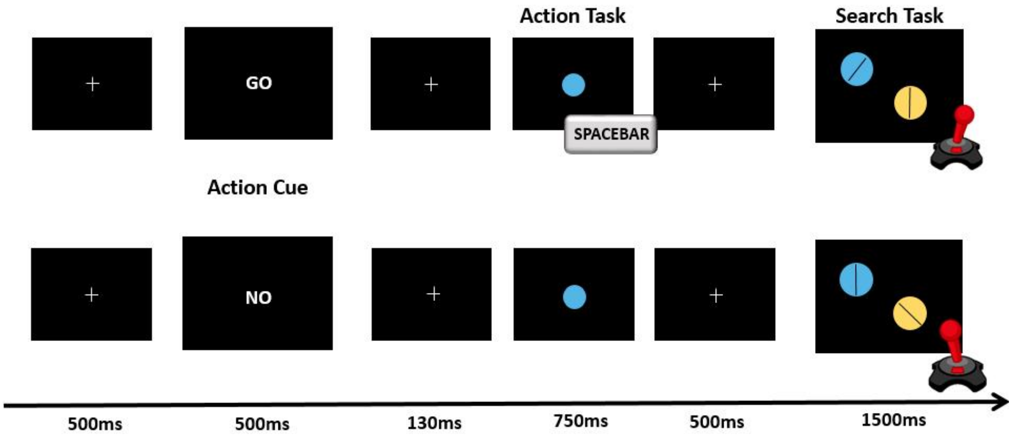
Methods

Participants

Nineteen undergraduate students from Yonsei University (N=19) participated for course credit. All participants were of Korean nationality and had normal or corrected-to-normal vision. All participants were informed of their ethical rights and willingly signed consent forms before the experiment. The experiment was approved by IRB of Yonsei University.

Procedure and Design

All procedures were identical to experiment 1 except for the following: participants were instructed to press “SPACEBAR” with their left hand on the onset of prime for “GO” condition trials and not to press any key for “NO” condition trials. In the subsequent visual search task, participants reported the orientation of the target with a joystick using their right hand, which the movements were coded into the experiment program file accordingly. The joystick device used in the experiment was the SAL-AJS-100 model manufactured by Ssaulabi (Ltd. Fatherfight), with approximate width and length of 32cm×22cm dimensions, respectively. Participants were instructed to use only the joystick portion of the device and not to press any other button on the device. RTs and accuracies were measured and recorded for both the action task and the search task. Participants were debriefed after the experiment (Fig. 3).

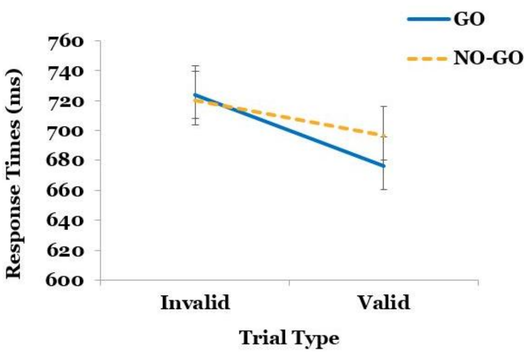


(Fig 3) Procedures for Experiment 2.Participants were instructed to perform the same kind of action task as in Experiment 1, but utilized a joystick device in the search task phase. Such measures were taken to ensure the distinction of type of action performed between the action task phase and the search task phase to induce a difference in potential for action.

Results

Mean accuracy for the action task was high at 98.46% (*SE* = .45). As with the other experiments, no significant difference was displayed for GO / NO conditions in terms of accuracy.

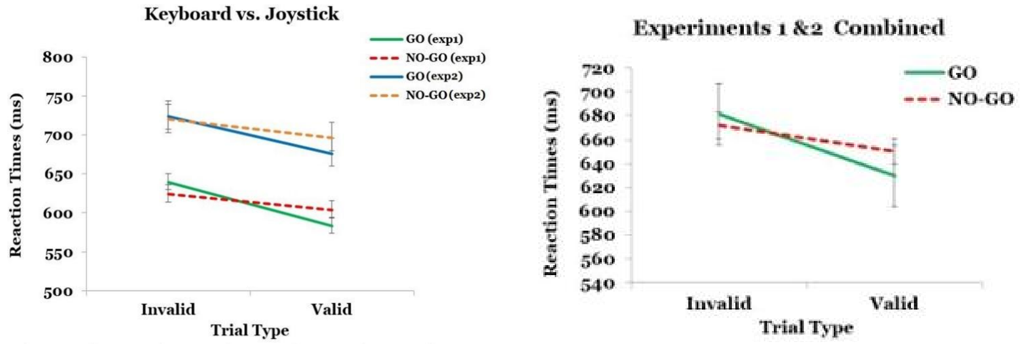
Mean accuracy for the search task was also high at 98.76% (*SE* = .28). Analysis of median RT means only included RTs for correct responses to both the action task and the search task. This time, no participant was in the range of accuracy lower than 2.5 standard deviations from the mean, and thus all 19 participants were included in the analysis. A 2×2 repeated-measures ANOVA was conducted for mean RT scores, with validity and action as within-subject levels of factors. Fig. 4 depicts the plotted results. Main effect of validity was significant, $F(1,18) = 18.178$, $p < .001$, $\eta_p^2 = .502$, with faster RTs for valid conditions (M = 686.37ms, SE = 16.03) than invalid conditions (M = 721.82ms, SE = 19.38). There was no main effect of action, $F(1,18) = 1.576$, $p < .225$, $\eta_p^2 = .081$. Most importantly, a significant interaction between action and validity was observed, $F(1,18) = 5.622$, $p = .029$, $\eta_p^2 = .238$, displaying the action effect. Post-hoc analysis of the interaction showed that participants were significantly faster to respond in the action trials than in the no-action trials for the valid trials, $t(18) = 2.298$, $p = .034$, with mean RT difference of M = 20.60ms, SE = 8.97. However, no significant RT difference was observed for invalid trials in both action and no-action trials, $t(18) = .462$, contributing to the interaction displayed.



(Fig 4) Search task RT results for Experiment 2. The main effect of validity was significant, with faster RTs for valid trials than invalid trials. Interaction of validity and action is also significant, displaying the action effect. Error bars depict one standard error (SE).

Discussion

The significant main effect of validity and the interaction between validity and action display an action effect regardless of the type of action performed. To see whether the medium of action may have had a modulatory effect on the action effect, we conducted an additional 2×2×2 repeated-measures ANOVA between experiment 1 and experiment 2, with validity and action as within-subjects factors and action medium (experiment type) as between-subjects factor. Analysis results displayed a significant main effect of validity, $F(1,36) = 41.240$, $p < .001$, $\eta_p^2 = .534$, and experiment type, $F(1,36) = 21.783$, $p < .001$, $\eta_p^2 = .377$. A significant interaction between action and validity was observed, $F(1,36) = 17.429$, $p < .001$, $\eta_p^2 = .326$, displaying the action effect (Fig. 5(a)). The significant main effect of experiment type may have been observed via task-switching costs, as previous studies had observed task-switch costs when having different response hands for different kinds of actions (Gladwin, Lindsen, & de Jong, 2005), or may have been due to the individual differences between participants. Nevertheless, the main effect of validity and the action effect even in the combined results of experiments 1 and 2 suggest that the action effect is shown independent of the type of action performed (Fig. 5(b)). Our results indicate that truly irrelevant physical action can modulate the priming effect of the given stimulus, even when there is no overlap between the action committed in the action task and the action performed in the visual search task.



(Fig 5) *(a)*. Comparison of experiment 1 results to experiment 2 results. *(b)*. RT results of experiment 1 and 2 combined, plotted accordingly. Interaction between validity and action was observed, as well as significant main effect of validity, and main effect of experiment type. The robust similarity between the two experiment results suggest an action effect independent from modality of action.

Experiment 3

With the baseline action effect established in experiment 1, we then manipulated the experimental procedures to isolate the semantic representations of action in participants. That is, with this experiment, we investigated if neither the processing of the relevant properties of the prime nor the physical action would be necessary to induce the action effect. Therefore, we instructed participants to only view the prime object during the action task phase, and then perform the visual search task. We predicted that if participants' attentional allocation can be affected by semantic representations of the action words, differences in validity effect during the subsequent visual search task would be modulated by the action words, thus displaying the action effect without physical action.

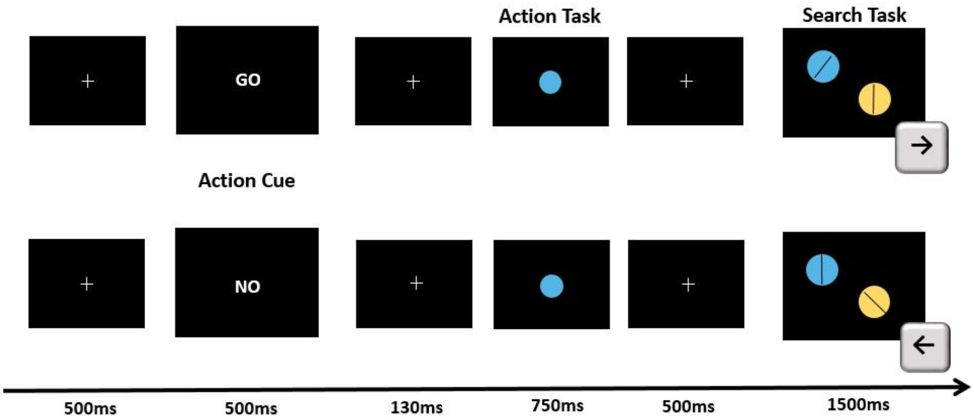
Methods

Participants

Sixteen undergraduate students from Yonsei University (N=16) participated for course credit. All participants were of Korean nationality and had normal or corrected-to-normal vision. All participants were informed of their ethical rights and willingly signed consent forms before the experiment. The experiment was approved by IRB of Yonsei University.

Procedure and Design

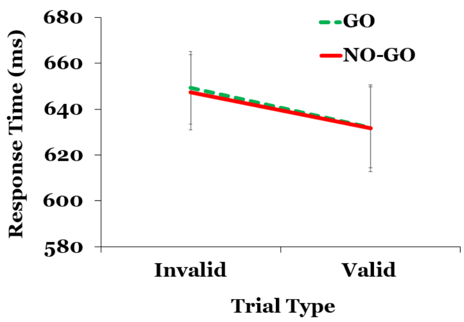
All procedures were identical to experiment 1 except for the following: participants were instructed not to perform any action during and after the presentation of the action cue and the prime. That is, participants were not to press any key until the visual search task (Fig. 6). RTs and accuracies were measured and recorded for only the search task, and the trials with any key press before the search task were excluded from analysis. Participants were debriefed after the experiment.



(Fig 6) Procedures for Experiment 3. Participants were instructed not to press any key for the action task phase and perform the subsequent visual search task.

Results

Mean accuracy for the search task was high at 97.92% (*SE* = .60), excluding the one low-accuracy participant. The main analysis of median RT means only included RTs for trials with correct responses to the search task and excluded trials with action taken during the onset of prime or the action word cue. One participant with lower accuracy than 2.5 standard deviations of the mean was excluded from data analysis, and a 2×2 repeated-measures ANOVA was conducted for



(Fig 7) Search task RT results for Experiment 3. Only the main effect of validity was significant, with faster RTs for valid trials than invalid trials. Error bars depict one standard error (SE).

mean RT scores with validity and action word cue as within-subject levels of factors. Fig. 7 shows the plotted results of the analysis. Main effect of validity was significant, $F(1,14) = 6.776$, $p = .021$, $\eta_p^2 = .326$, with faster RTs for valid condition (M = 631.77ms, SE = 17.96) than invalid condition (M = 648.31ms, SE = 15.80). However, there was no interaction between action word cue and validity, $F(1,14) = .017$, $p = .899$, $\eta_p^2 = .001$, and no main effect for action word cue, $F(1,14) = .070$, $p = .795$, $\eta_p^2 = .005$.

Discussion

Unlike experiment 1, results showed an absence of interaction between action word and validity, not yielding the action effect. However, one thing to note is that even with removing the physical action on the prime, the main effect of validity was significant. Such results resembled a cueing effect or repetition priming effect, in which previously seen features of stimuli are known to be selected more readily when presented again in a subsequent visual task (Maljkovic & Nakayama, 1994). In a similar fashion, the fact that such validity effect is shown even without action in experiment 3 may highlight the role of physical action in capturing or boosting attention to the same feature in a subsequent visual task in experiment 1. After all, in experiment 1, the validity effect in the no-action trials was also significant, but the existence of an interaction between action and validity may indicate a boosting effect of action in the action trials. Moreover, the absence of interaction may have been resulted from absence of attention to the action word cue. That is, participants may have allocated their attention to the prime, but not to the action word cue, since the words did not serve as a predictive cue to the subsequent search task. Therefore, we conducted experiment 4 to account for the extent of how physical action boosts such attentional prioritization by using displaying the same type of action word cues yet instructing participants to perform action in both action word cue conditions.

Experiment 4

In this experiment, we instructed participants to perform physical action on the prime object in both action word cue conditions, and then engage the visual search task. That is, participants were to press a designated key for each action word cue. This way, we could maintain the same amount of exposure to the semantic representation cues as well as allow participants to allocate attention to the action word cues. Also, to observe the effect of physical action on modulating the validity effect, we compared the results of experiment 4 to the results of experiment 3.

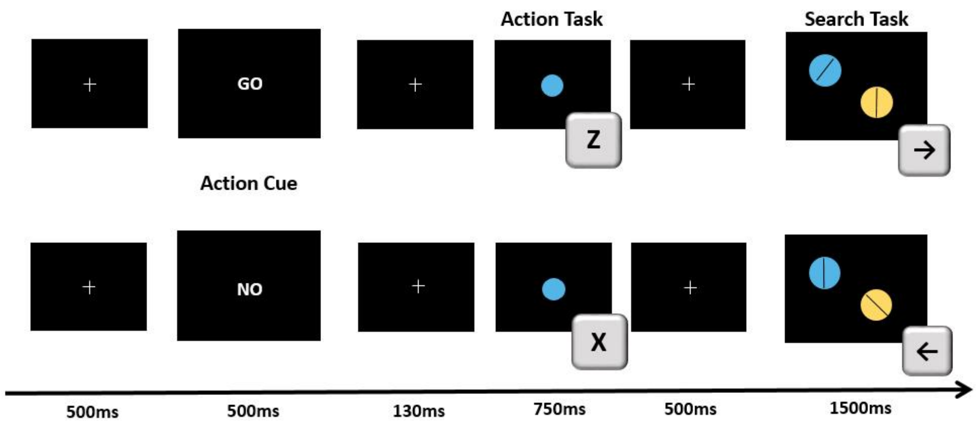
Methods

Participants

Sixteen undergraduate students from Yonsei University (N=16) participated for course credit. All participants were of Korean nationality and had normal or corrected-to-normal vision. All participants were informed of their ethical rights and willingly signed consent forms before the experiment. The experiment was approved by IRB of Yonsei University.

Procedure and Design

All procedures were identical to experiment 1 except for the following: participants were instructed



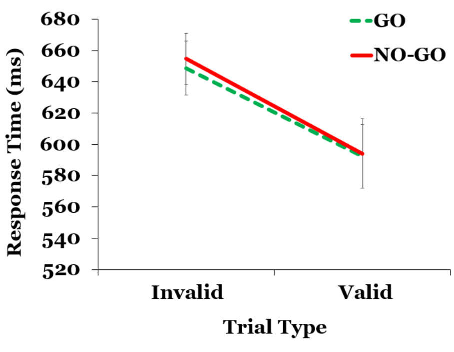
(Fig 8) Procedures for Experiment 4. Participants were instructed to press separate keys ("z" or "x") in the action task phase and perform the subsequent visual search task. The keys were counterbalanced between participants and the RT data were collated.

to press a designated key on the onset of prime for “GO” condition trials and press another key for “NO” condition trials as well (Fig. 8). Keys designated for the action words were counterbalanced between subjects. RTs and accuracies were measured and recorded for both the action task and the search task. Participants were debriefed after the experiment.

Results

Mean accuracy for the action task was high at 97.70% (*SE* = .58). Again, no significant difference was displayed for GO / NO conditions in terms of accuracy.

Mean accuracy for the search task was also high at 96.35% (*SE* = .63). Analysis of median RT means only included RTs for correct responses to both the action task and the search task. Two participants with lower accuracy than 2.5 standard deviations, one in the action task and one in the search task, were excluded from analysis. A 2×2 repeated-measures ANOVA was conducted for mean RT scores, with validity and action word cue as within-subject levels of factors. Fig. 9 depicts the plotted results. Main effect of validity was significant, $F(1,13) = 20.921$, $p = .001$, $\eta_p^2 = .617$, with faster RTs for valid condition (M = 593.22ms, SE = 20.90) than invalid condition (M = 651.74ms, SE = 16.55). However, there was no interaction between action word cue and validity, $F(1,13) = .157$, $p = .698$, $\eta_p^2 = .012$, and no main effect for action word cue, $F(1,13) = .379$, $p = .549$, $\eta_p^2 = .028$.

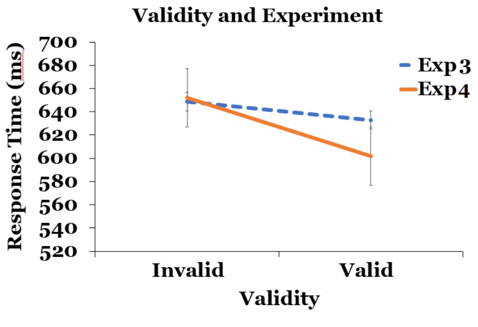


(Fig 9) Search task RT results for Experiment 4. Again, only the main effect of validity was significant, with faster RTs for valid trials than invalid trials. Error bars depict one standard error (SE).

Discussion

Similar to the results of experiment 3, no main effect of action word cue was observed and no interaction between action word and validity was observed. However, the main effect of validity was significant, showing a priming effect of the object. We compared the results between no-action trials (experiment 3) and all-action trials (experiment 4) to account for the enhancing effect of physical action, maintaining the same amount of semantic representation. We conducted a 2×2×2 repeated-measures ANOVA, with validity and action word cue as within-subject factors, and physical action (experiment type) added as the between-subjects factor. Results revealed a significant main effect of validity, $F(1,27) = 28.784$, $p < .001$, $\eta_p^2 = .516$, with faster RTs for valid trials (M = 618.43ms, SE = 13.69) than for invalid trials (M = 650.09ms, SE = 11.55). More importantly, there was a significant interaction between experiment type and validity, $F(1,27) = 9.002$, $p = .006$, $\eta_p^2 = .250$ (Fig. 10). Post-hoc analysis of the interaction reveals a significant difference between valid conditions in experiment 3 and experiment 4, with faster RT for valid conditions in experiment 4 (M = 601.07ms, SE = 19.89) than in experiment 3 (M = 631.77ms, SE = 18.52).

This validity difference resembles the action effect observed in Weidler and Abrams's (2014) studies and in our replication experiment as well. Controlling for possible effects of semantic representation of action words, we were able to replicate the action effect via physical action. Therefore, as per the intentions of this experiment, the cross-examination results may highlight the facilitation effect of physical action in deploying attention to the object acted on.



(Fig 10) Observed interaction between experiment and validity. Post-hoc analysis revealed that participants responded faster in valid trials of Experiment 4 than in valid trials of Experiment 3. The interaction provides evidence for a faciliatory effect of physical action in terms of priming.

General Discussion

In four experiments, we investigated the role of the type of physical action and the role of semantic representations in inducing the action effect. Through experiment 1, we successfully replicated the action effect, using the experimental apparatus from previous studies. In experiment 2, we investigated whether the type of action performed in each task could modulate the attentional deployment to the displayed prime stimulus. Results still demonstrated a significant action effect, even when the type of action and medium of response were both separate between each task, showing a faciliatory effect of a truly irrelevant physical action. In experiment 3, we attempted to find out whether differences in semantic associations to the action word cues can induce the validity difference. We found no evidence of such differences between conditions but found that view-only conditions can also induce the priming of object. In experiment 4, we verified whether physical action can boost the priming effect displayed in experiment 3. The cross-analysis results between experiment 3 and experiment 4 showed that physical action was responsible for inducing the difference in validity effect, regardless of the semantic associations to the action words, and further specified the boosting of attentional deployment onto the object acted on.

Our results are in line with previous studies (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014) that an unrelated physical action enhances the "trace" of the object acted on, affecting subsequent visual search task performance. In our research, we attempted to explain the specific mechanisms to the action effect by separating the semantic representation of the action words from physical action and demonstrated the sole effect of physical action on deployment of attention. Our experimental paradigms differed from those of the attentional set account (Folk, Remington, & Johnston, 1992; Robinson et al., 2018) in that the specific property (color) of the prime object was never provided until the actual onset of the prime. Participants therefore would not have been biased towards creating a template of the expected prime object, since there would be no association to begin with.

Although semantic representation alone could not induce the enhancement of the priming mechanisms in this paradigm, perhaps physical action could have been more directly involved in the lower-level aspects in capturing attention in this case. Indeed, a follow-up research on the action effect by Weidler and Abrams (2016) provides support for action's effect even on the most efficient parallel search. The authors argued that physical action is not limited to affecting decision-level processes, as shown from the conjunction search paradigms; even visual search driven by physical salience can be affected by physical action. Possibly, semantic associations between action words and action may not have been salient enough to be generated within the participants to induce the relative expected difference, giving more weight to the bottom-up salience of the prime object associated with the response. Hence, the effect of action could have been larger for the participants, overshadowing any possible effect of semantic representation.

It is also possible that the perhaps semantic representations may not have been formed at all, due to the limitations in the experimental paradigm. Although we have taken measures to separate the semantics of the action word cue from the actual physical action, this manipulation itself could have caused the semantics of action to completely dissipate. After all, participants may have not attended to the meaning of the action words in experiments 2 and 3; the words “go” and “no” may have served only as meaningless cues to press a designated key on the keyboard. In this context, additional manipulations to encourage the participants to create a semantic representation of the action cue words (i.e., working memory test of the semantic cues after the visual search task) may be necessary to fully control for the effect of semantic cues.

Nevertheless, our results indicate the significance of physical action. Why, then, does physical action provide a boost to attentional deployment to the object acted on? Priming mechanisms tends to manifest on stimuli with relevance to subsequent visual tasks, but it has been demonstrated that priming of pop-out (PoP) targets may guide attention towards an irrelevant stimulus (Brascamp, Blake, & Kristjánsson, 2011). The core idea of the PoP account is that the pop-out of stimulus can steer where to orient attention. Such capture of attention was more intensified when pop-out objects were actively searched and responded to, than in just viewing conditions (Kristjánsson, Saevarsson, & Driver, 2013). Expanding on this notion, the priming effect towards the prime object may have been boosted in our experiments as well, because participants actively responded to the popped-out prime object in a similar fashion. Such active response made could have steered participants’ attention towards the valid stimulus in the subsequent visual search task, thus contributing to the validity difference shown. This notion had been also discussed in the previous studies of Weidler and Abrams (2014), and our results also seem to be in line with their discussion.

In a more physiological context, number of studies highlight the relationship between attention and readiness for action. Brunia (1993) suggested that the motor system utilizes a gating mechanism for transmitting motor information similarly to the attentional gating mechanisms and recorded the potentials during motor preparation. Stemming from this notion, Baker, Mattingley, Chambers, and

Cunnington (2011) showed that movement preparatory processes may involve cognitive control mechanisms that share resources with selective attention processes in an electroencephalogram (EEG) study. Applying this idea to our experimental design, the motor response in the action task may have increased the level of response readiness for the visual search task, thereby facilitating the selective attention mechanisms in processing the displayed prime object. Such concept of action readiness may help interpret the results of experiment 2, where action effect was shown not to be action type-specific. Rather, the general readiness for physical action may have facilitated the attention to that specific prime object. Such “action readiness potentials”, so to speak, could be investigated in future research by utilizing EEG or fMRI methods.

In continuation from the motor-attentional relationship, one limitation of our stream of studies is that the experimental procedures our predecessors (Buttaccio & Hahn, 2011; Weidler & Abrams, 2014) and we used thus cannot discriminate physical action from the planning of action. Apart from the priming account of physical action, it may be possible that the deployment of attention depends on the “thought of performing the action”. That is, the representation of action could be of importance within the current framework of the research paradigms. After all, the action task demands participants to anticipate a given condition (“GO”) and plan a response accordingly. Such measures require participants to maintain a type of planned action – pressing a designated key on the keyboard. As past stream of studies had outlined, planned action can bias selection in visual search tasks, priming action-related stimulus dimensions (Fagioli, Hommel, & Schubotz, 2007; Wykowska et al., 2009). Perhaps the maintenance of representation of action could have been the main difference between the GO/NO conditions, enhancing the processing of action-related (keypress-related) stimulus, thus yielding the relative validity difference between conditions. Further research is needed to investigate the role of this “action representation”, with modifications to the experimental paradigm.

Investigating the temporality of action performed may also be a future direction in this stream of research, given that all types action in this line of experimental paradigms are performed within a set time frame. One possible question may be whether the physical action must be performed at the precise moment of the onset of the object for the trace of the prime to be strengthened. In fact, a study conducted by Sergent, Wyart, Babo-Rebeleo, Cohen, Naccache, and Tallon-Baudry (2013) had demonstrated that cueing attention after stimulus offset could enhance attention towards that stimulus. Related studies have also shown that such retrospective cueing may trigger a boost in conscious perception (Thibault, van den Berg, Cavanagh, & Sergent, 2016; Xia, Morimoto, & Noguchi, 2016). Moreover, a recent study showed that simple action planning can influence the allocation of attention in subsequent visual searches (Han et al., 2020). In this context, the boosting effect of action may linger to boost the perceptual trace of the stimulus when performed at the offset of prime. Conversely, action could be performed previously to the onset of the stimulus in a similar fashion to pre-cueing. Numerous studies have demonstrated the pre-cueing attentional capture effect, ultimately resulting in the same type of validity difference in reaction times, as mentioned in the introduction (Desimone & Duncan, 1995; Folk, Remington, & Johnston, 1992; Remington, Johnston, & Yantis, 1992). In this context, action could serve as a pre-cue in predicting the target stimulus, resulting in the boost in trace of prime. Either way, manipulating the temporality of action may be of worth in further investigating the role of physical action in directing attention.

Throughout our experimental paradigm, we were able to explore the importance of physical action in inducing the boost of attention deployed onto the stimulus acted upon. Since a large portion of, if not all, psychological studies depend on the participants' physical responses, further research should be conducted on how our responses in one task can shape future responses, expanding even more to the domains of implicit and unconscious processing (e.g., Hong, Jeong, & Kim, 2022; Hwang & Kim, 2016). As Awh, Belopolsky, and Theeuwes (2012) had pointed out, various cognitive factors may affect attentional control, and the simple top-down and bottom-up distinction may not be the case in our studies, too. Rather, our studies show that physical actions may affect our cognitive processes more than we think.

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(요 약)

의미적 표상 및 매개체와 무관한 단순 행동의 주의력 증진 효과

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행동 효과(action effect)란, 특정 자극에 대한 단순한 행동이 이후의 시각 탐색 과제에서 해당 자극의 인지적 처리를 향상시키는 효과를 말한다. 본 연구는 행동을 지시하는 단어의 의미적 표상과 실제로 수행하는 행동의 종류가 행동 효과에 미치는 영향을 알아보고자 시행되었다. 실험 1은 선행 연구의 실험 패러다임을 반복 검증하였다. 참가자는 화면을 통해 제시되는 “출발” 또는 “정지”의 행동 지시어를 보고 뒤이어 나타나는 원형 자극에 대하여 키보드를 이용해 응답하거나(출발 조건) 응답하지 않았다(정지 조건). 다음으로, 참가자는 한쪽으로 기울어진 선분을 찾아 기울어진 방향을 보고하는 시각 탐색 과제를 수행하였다. 이때 표적 자극은 이전에 제시되었던 원형 자극 위에 나타나거나(타당 조건) 다른 자극 위에 나타날 수 있었다(비타당 조건). 시각 탐색 과제의 반응 속도를 분석한 결과, 선행연구와 동일한 행동 효과(행동 조건과 타당도 조건의 상호작용)를 관찰할 수 있었다. 실험 2에서는 반응 도구 및 물리적 행동의 종류가 상이한 경우에도 행동 효과가 유지되는지 알아보고자 진행되었다. 참가자는 제시되는 행동 지시어에 대하여 키보드를 이용해 응답하였으나, 시각 탐색 과제에서는 조이스틱 방향을 조정함으로써 반응을 보고하였다. 그 결과, 타당도에 따른 주효과 및 행동 효과 모두 유의한 것으로 나타났다. 단어의 의미적 표상이 행동 효과에 미치는 영향을 알아보기 위하여, 실험 3에서는 두 행동 조건 모두 반응을 하지 않게 하였고, 실험 4에서는 두 행동 조건 모두 각기 다른 키를 사용하여 반응하게 하였다. 그 결과, 두 실험 모두 타당도에 따른 주효과만 유의미했으며 행동 효과는 관측되지 않았다. 실험 3과 실험 4의 결과를 비교 분석한 결과, 실험 유형과 타당도 간의 상호작용이 관찰되었다. 본 연구는 행동 지시어의 의미적 표상만으로는 행동 효과를 야기할 수 없으며, 이중과제 패러다임에서 물리적 반응의 도구 및 종류와 상관없이 행동 효과가 관찰될 수 있다는 점을 시사한다.

주제어 : 주의, 타당도 효과, 행동 효과, 의미적 표상