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BRIEF REPORT

The Relationship Between Action-Effect Monitoring and Attention Capture

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Many recent findings suggest that stimuli that are perceived to be the consequence of one's own actions are processed with priority. According to the preactivation account of intentional binding, predicted consequences are preactivated and hence receive a temporal advantage in processing. The implications of the preactivation account are important for theories of attention capture, as temporal advantage often translates to attention capture. Hence, action might modulate attention capture by feature singletons. Experiment 1 showed that a motion onset and color change captured attention only when it was preceded by an action. Experiment 2 showed that the capture occurs only with predictable, but not with unpredictable, consequences of action. Experiment 3 showed that even when half the display changed color at display transition, they were all prioritized. The results suggest that action modulates attentional control.

Keywords: attention capture, action, action-effect monitoring, preactivation

Many recent studies have shown that a stimulus or event is processed differently when it is perceived as a consequence of one's action (Band, van Steenbergen, Ridderinkhof, Falkenstein, & Hommel, 2009; Hughes, Desantis, & Waszak, 2013; Hughes & Waszak, 2011; Kok, Brouwer, van Gerven, & de Lange, 2013; Kok, Jehee, & de Lange, 2012; Roussel, Hughes, & Waszak, 2013; Salomon, Szpiro-Grinberg, & Lamy, 2011; Waszak, Cardoso-Leite, & Hughes, 2012). For example, Waszak et al. (2012) showed that the threshold of detection of a stimulus is lowered when it is perceived as an action consequence. It was also shown that action effects that are predicted reach the threshold of awareness faster and give rise to more detailed stimulus representation (Kok et al., 2012). Similarly, Salomon et al. (2011) showed that a moving object gets priority in processing when the motion path is congruent with action. They argued that a congruent perceptual stimulus that follows an action would be perceived as the consequence of action, and would provide detailed temporal and kinetic information about the moving object, thus biasing selection.

Even though Salomon et al.'s (2011) findings suggest that action effects are prioritized based on congruence of perceptual stimulus with action outcomes, other studies have shown that even irrelevant action outcomes are automatically monitored. For example, Band et al. (2009) suggested that both task-relevant and task-irrelevant consequences of action are automatically monitored. Further, Elsner and Hommel (2001) showed that action-contingent sensory inputs are automatically integrated with the action they accompany.

The acquisition of action-effect associations does not depend on conscious perception or task relevance of the relationship between actions and effects (Hommel, Alonso, & Fuentes, 2003; Kunde, 2004). Indeed, ideomotor theory of action assumes that the acquisition of action-effect associations precedes the performance of outcome-eliciting action (Elsner & Hommel, 2001; Hommel, 1997), implying that the acquisition itself occurs rather automatically. Thus, it seems that automatic action-effect monitoring leads to improved stimulus representations as well as induces a selection bias.

It was previously shown that improved visual quality of an object can bias attentional selection (Gibson, 1996a; Sunny & von Mühlenen, 2014) by making it available to attentional processes earlier than the rest of the display. A similar temporal advantage might be received by the action-effect because of preactivated representations. This could bias attention in favor of the action-effect. Hence, in the present study, we test whether automatic action-effect monitoring also implies automatic attentional allocation to the action-effect. This is theoretically important because perceiving a sensory event as a consequence of your action could change how attention is allocated to that event even when there are no changes to its salience or relevance. If this is true, traditional attentional theories will need to include action as a factor that mediates selection. We used an irrelevant singleton paradigm with both color and motion singletons and tested whether they capture attention when preceded by an action.

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Experiments 1A and 1B

Experiments 1A and 1B aimed to test whether or not the visual outcomes of action are automatically monitored and lead to attention capture. Participants completed a visual search task, employing an irrelevant singleton paradigm (Yantis & Egeth, 1999) to test for attention capture. In both action and no-action conditions, the presentation of search display coincided with the appearance of a singleton (motion in Experiment 1A; color in Experiment 1B). If visual outcomes of action are automatically monitored, we would expect that feature singletons would capture attention in the action condition but not in the no-action condition.

Method

Participants. Fourteen undergraduate students from the Indian Institute of Technology Gandhinagar participated in Experiments 1A (mean age = 20.4 years; 10 male), and another 14 participated in Experiment 1B (mean age = 20.8; 11 male). All gave prior consent to participate and were paid for their participation. They all reported normal or corrected-to-normal vision and were naïve to the purpose of the experiment.

Apparatus and stimuli. Participants were seated in a dimly lit room in front of an IBM PC compatible computer with a 19-in. LCD monitor. They used the left- and right-arrow keys on a standard keyboard for their responses to a visual search task. A fixation cross appeared on the center of the screen before each trial. The stimuli consisted of figure-8 placeholders and numbers, subtending a visual angle of 2° × 1° at approximately 57 cm. These were drawn in white (Experiment 1A), or in red or green (Experiment 1B), on a black background. The stimuli were placed randomly within an imaginary 9 × 9 matrix, with a random jitter between 1 and 100 pixels, so that they were not aligned either vertically or horizontally. The trials were divided into two blocks, depending on whether the critical manipulation of action was present or not. The blocks were counterbalanced in order to adjust for any order effects.

Procedure and design. Each trial began with a fixation cross in the center of the display for 500 ms, followed by either six or 12 placeholders. A 200-ms-long beep of 1,000 Hz was sounded 750 ms after the placeholders appeared. In the action condition, participants were asked to press the spacebar when they heard the tone. The placeholder display changed into the search display by shedding appropriate line segments from the figure 8. In the action condition, the search display appeared immediately after they pressed the spacebar, whereas in the no-action condition, it automatically appeared 250 ms after the beep (Figure 1).

Simultaneous with the search display, one of the items in the display started to move on a circular path (radius = 1.4°) in an anticlockwise direction (Experiment 1A) or change its color (Experiment 1B), from red to green, or vice versa, resulting in a motion or color singleton in the search display. Motion speed was of 8.6° per second. The singleton was equally likely to be any of the items in the display. That is, the motion onset or color singleton coincided with the target on only one sixth of the trials in displays with six items, and on one twelfth of the trials in displays with 12 items. Participants were instructed to look for the targets “5” or “2,” one of which would always be present in the search display consisting of other digits, and to respond with left- or right-arrow keys (counterbalanced). The search display remained visible until the participant responded. Visual feedback was given for every incorrect response, and participants had to press the spacebar to start the next trial.

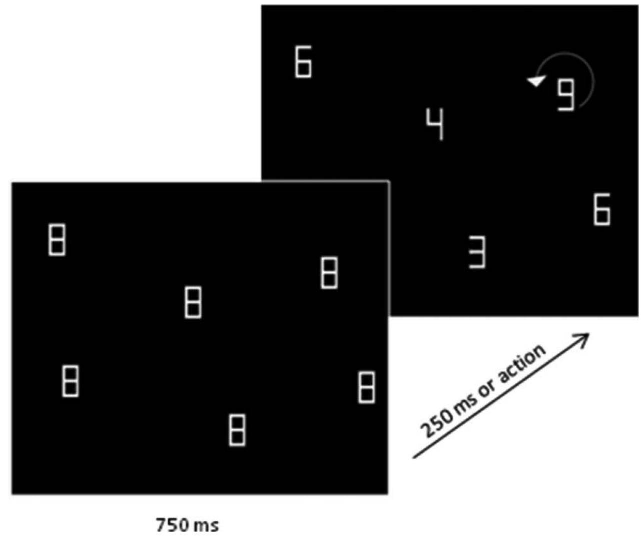

Figure 1. Example display showing the sequence of events in a trial in Experiment 1A. The placeholders were presented for 750 ms, after which a 1,000-Hz beep was sounded. In the action condition, participants pressed the spacebar after the beep. The figure eight changed to digits, either 250 ms after the beep (no-action condition) or immediately after the key press (action condition).

The experiments systematically manipulated four factors, with two levels each: Action (action or no-action), Display Size (6 or 12), Target (singleton or nonsingleton), and Target Identity (2 or 5). Target Identity was not considered during the analysis. Although Action was blocked, the other factors were presented randomly within each block in a factorial design. Each participant completed 48 practice trials, followed by 432 experimental trials (see Table 1). Reaction times (RTs) and errors were recorded for analysis.

Results

Experiment 1A. Mean correct RTs (after removing 1.4% error trials and 1.8% outliers [2.5 *SD* ± mean]) were calculated separately for each participant and factor combination (Figure 2A) and submitted to a 2 × 2 × 2 repeated measures ANOVA, with factors Set Size (6 and 12), Action (action and no-action)[1], and Target (singleton and nonsingleton). Results showed significant main effects for the following factors: Set Size, $F(1, 13) = 309.60$, $p < .001$, $\eta_p^2 = 0.96$, suggesting that, on average, search slowed down as the set size increased from 6 (1,139 ms) to 12 (1,485 ms); Action, $F(1, 13) = 131.27$, $p < .001$, $\eta_p^2 = 0.91$, suggesting that participants were, on average, faster in the action condition (1,223 ms) compared with the no-action condition (1,400 ms); and Target, $F(1, 13) = 78.60$, $p < .001$, $\eta_p^2 = 0.86$, suggesting that participants

[1] We also conducted an ANOVA to test whether the order in which participants completed the action and no-action condition had an effect. There was no main effect of order, and none of the interactions involving order were significant.

Table 1
Number of Trials in Experiments 1A, 1B, 2, and 3 Separately for Target Type and Set Size

Target type	Set size	Exp 1A	Exp 1B	Exp 2	Exp 3
Singleton/color change	6	24	24	24	80
	12	24	24	24	80
Nonsingleton/color unchanged	6	120	120	48	80
	12	264	264	120	80
Singleton absent	6	—	—	72	—
	12	—	—	144	—
Total		432	432	432	320

Note. The number of trials in each target type and set size were divided equally between the action and no-action conditions. Exp = experiment.

were, in general, faster in finding a singleton target (1,149 ms) compared with a nonsingleton target (1,474 ms).

The following two-way interactions were significant: Set Size × Action, $F(1, 13) = 56.42$, $p < .001$, $\eta_p^2 = 0.81$, in which RT slope was, overall, steeper in the no-action conditions (75 ms/item) compared with the action conditions (41 ms/item); Action × Target, $F(1, 13) = 128.38$, $p < .001$, $\eta_p^2 = 0.91$, with singleton targets found faster than nonsingleton targets only in the action condition; and Target × Set Size, $F(1, 13) = 43.00$, $p < .001$, $\eta_p^2 = 0.76$, with smaller slopes for singleton targets (43 ms/item) compared with nonsingleton targets (72 ms/item).

The full pattern of results is revealed by the significant three-way interaction between Action, Set Size, and Target, $F(1, 13) = 26.47$, $p < .001$, $\eta_p^2 = 0.67$. That is, there was a slope difference between singleton and nonsingleton targets in the action condition (59 ms/item), but not in the no-action condition (1.5 ms/item), suggesting that a singleton target captured attention only when preceded by action.

Experiment 1B. Mean correct RTs (after removing 1.4% error trials and 2.0% outliers [2.5 *SD* ± mean]) were calculated separately for each participant and factor combination (Figure 2B) and submitted to a 2 × 2 × 2 ANOVA. All main effects were significant: Set Size, $F(1, 13) = 387.85$, $p < .001$, $\eta_p^2 = 0.97$ (1,241 ms vs. 1,682 ms for 6 and 12, respectively); Action, $F(1, 13) = 66.93$, $p < .001$, $\eta_p^2 = 0.83$ (1,317 ms vs. 1,546 ms for action and no-action, respectively); and Target, $F(1, 13) = 194.87$, $p < .001$, $\eta_p^2 = 0.94$ (1,254 ms vs. 1,609 ms for singleton and nonsingleton, respectively).

There were also significant interactions between Set Size and Action, $F(1, 13) = 61.45$, $p < .001$, $\eta_p^2 = 0.82$ (44 ms/item vs. 83 ms/item for action and no-action, respectively); Action and Target, $F(1, 13) = 92.81$, $p < .001$, $\eta_p^2 = 0.88$, and Target and Set Size, $F(1, 13) = 48.35$, $p < .001$, $\eta_p^2 = 0.79$ (48 ms/item vs. 78 ms/item for singleton and nonsingleton targets, respectively).

There was also a significant three-way interaction between Action, Set Size, and Target, $F(1, 13) = 20.59$, $p = .001$, $\eta_p^2 = 0.61$. That is, there was a slope difference between a singleton and nonsingleton target in the action condition (59 ms/item), but not in the no-action condition (2.2 ms/item), suggesting that a singleton target captured attention only when preceded by action.

Discussion

The results suggest that a task-irrelevant feature singleton captures attention when it is preceded by an action compared with when it is not. This is an important finding for theories of attention capture. In both the action and no-action conditions, the bottom-up salience of the display, as well as the top-down goals of the observer, remain the same. Nevertheless, for both motion and color, singleton seems to capture attention when it is preceded by an action compared with when it is not.

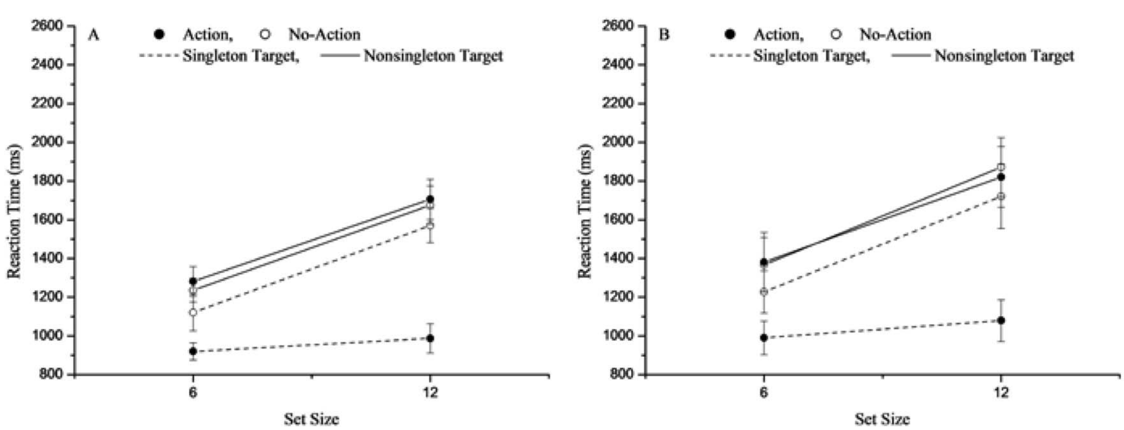

Figure 2. Mean correct reaction time as a function of display size, with separate lines for each factor combination in (A) Experiment 1A, and (B) Experiment 1B. The 95% confidence interval is plotted as error bars.

The capture by action can be sufficiently explained by the preactivation account of intentional binding. Many studies of attention capture have shown that a stimulus captures attention when it is available for processing earlier than the other items in the display (Gibson, 1996a, 1996b; Sunny & von Mühlenen, 2014; von Mühlenen, Rempel, & Enns, 2005), whereas, according to the preactivation account (Roussel et al., 2013; Waszak et al., 2012), events that are perceived to be the outcome of an action reach the threshold of awareness faster compared with events that are not. That is, when a feature singleton is preactivated, it might also cross the threshold of selection earlier than the nonsingletons, resulting in attention capture.

Experiment 2

It has been suggested that both control and prediction are critical for intentional binding to occur (Desantis, Hughes, & Waszak, 2012; Hughes et al., 2013)—that it is not just enough that the appearance of a singleton is preceded by participants pressing a key, but necessary that this happens in a more or less predictable manner (Moore & Haggard, 2008). In order to provide a more direct test of the role of preactivation in capture, we conducted Experiment 2, in which the relationship between the action and outcome was unpredictable. That is, in both the action and the no-action conditions, the feature singleton was presented only on 50% of the trials. Hence, there was no predictable relationship between action and the appearance of a feature singleton. Thus, if preactivation mediates attention capture by action, then there would be no capture when there is no preactivation, even though there is action.

Method

Fourteen students from IITGN participated in Experiment 2 (mean age 21.2 years; 11 male). The apparatus, stimuli, procedure, and design were the same as in Experiment 1A, except that now the singleton was present only in 50% of the trials in both the action and the no-action conditions.

Results

Mean correct RTs (after removing 3.2% error trials and 2.01% outlier trials [2.5 *SD* ± mean]) were calculated separately for each participant and factor combination in Experiment 2 (see Figure 3) and submitted to a 2 × 2 × 3 repeated measures ANOVA, with factors Set Size (6 and 12), Action (action and no-action), and Target (singleton-absent, singleton, and nonsingleton).

Results showed a significant main effect of Set Size, $F(1, 13) = 591.92$, $p < .001$, $\eta_p^2 = 0.98$, and Target, $F(2, 26) = 11.94$, $p < .001$, $\eta_p^2 = 0.48$, but not Action, $F(1, 13) = 0.95$, *n.s.*, $\eta_p^2 = 0.07$. There was a significant interaction between Target and Set Size, $F(2, 26) = 6.05$, $p < .01$, $\eta_p^2 = 0.32$, suggesting that the targets were found more efficiently when it was a singleton (98 ms/item) compared with when it was a nonsingleton (125 ms/item), and when there was no singleton in the display (124 ms/item). Importantly, none of the interactions involving Action were significant (all $ps > .1$).

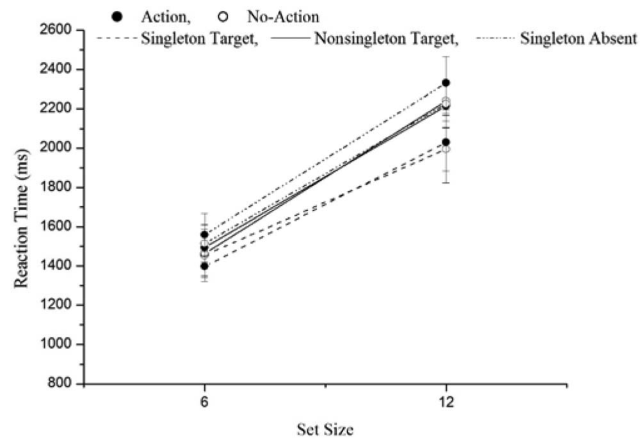

Figure 3. Mean correct reaction time as a function of display size, with separate lines for each factor combination, in Experiment 2. The 95% confidence interval is plotted as error bars.

Discussion

Experiment 2 provides more conclusive evidence for the role of preactivation in attention capture by action. The results suggest that action no longer captures attention when the probability of the action resulting in the appearance of a singleton is at chance level. If capture in Experiment 1 was because of other factors, such as changes in top-down control, working memory requirements, or temporal control between the action and no-action conditions, then we would still expect capture when an action results in the appearance of the singleton. In order to confirm that the capture effect is mediated by preactivation, we did an ANOVA across Experiments 1A and 2, with Experiment as a between-subject factor. The critical three-way interaction between Set Size, Action, and Experiment was significant, $F(1, 26) = 20.75$, $p < .001$, $\eta_p^2 = .44$, with action capturing attention in Experiment 1A but not in Experiment 2. That is, it is not action per se that captures attention, but the perception of the singleton as an action effect. Hence, overall, the results support the notion that capture is driven by the binding between the action and the singleton.

Experiment 3

In both Experiments 1 and 2, capture was mediated by the presence of a singleton. However, it is not clear whether binding will occur if more than one item changes as a consequence of action. In Experiment 3, instead of one item, half of the items in the display changed color at display transition. If binding occurs, all the changed items will be prioritized, resulting in a slope difference between the targets that change color compared with targets that do not. Otherwise, both color-change and no-change targets would have similar slopes.

Method

Fourteen students from IITGN participated in Experiment 3 (mean age 21.3; 9 male). The apparatus, stimuli, procedure, and design were the same as in Experiment 1B, except that instead of one item, half of the items in the display changed color.

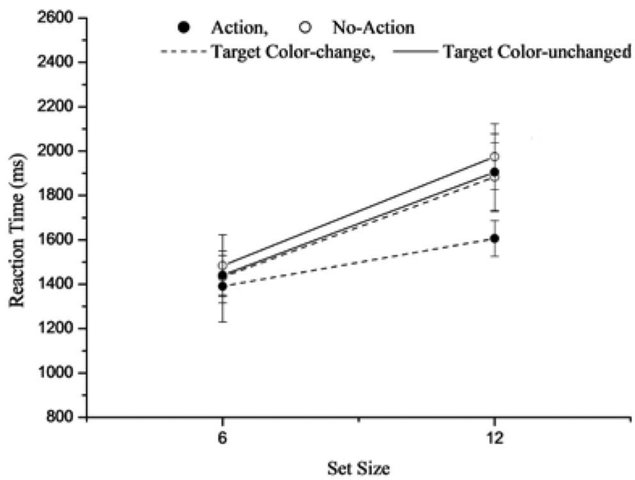

Figure 4. Mean correct reaction time as a function of display size, with separate lines for each factor combination, in Experiment 3. The 95% confidence interval is plotted as error bars.

Results

Mean correct RTs (after removing 2.29% error trials and 2.38% outlier trials [2.5 *SD* ± mean]) were calculated separately for each participant and factor combination in Experiment 3 (see Figure 4). The individual participants' means were submitted to a 2 × 2 × 2 repeated measures ANOVA, with factors Set Size (6 and 12), Action (action and no-action), and Target (color change and no-change).

Results showed a significant main effect of Set Size, $F(1, 13) = 283.85$, $p < .001$, $\eta_p^2 = 0.95$, Target, $F(1, 13) = 20.70$, $p < .001$, $\eta_p^2 = 0.61$, and Action, $F(1, 13) = 16.18$, $p < .01$, $\eta_p^2 = 0.55$. Critically, the three-way interaction was significant, $F(1, 13) = 6.02$, $p < .05$, $\eta_p^2 = 0.33$, suggesting that items that appeared in the changed color were prioritized over the items that did not change color, but only when they were preceded by action (42 ms/item vs. 7 ms/item).

Discussion

Experiment 3 showed that a feature change that is perceived as an action consequence is prioritized even when it does not result in a feature singleton. The results suggest that a feature change, not the presence of the singleton, triggered binding in Experiments 1A and 1B. In addition, it seems that a change in identity was not as important as a change in a basic feature in binding, suggesting that not all events associated with an action are equally prioritized. The results provide an indication that action-effect binding could be driven more by low-level sensory changes like color and motion compared with higher level changes to identity (Van Essen & Maunsell, 1983).

General Discussion

The current study reports three experiments that suggest that action interferes with attentional control settings (Experiment 1) and that this interference is mediated by intentional binding (Experiment 2). Experiment 3 suggests that more than the presence of a singleton, action-effect binding is mediated by a low-level feature change. Indeed, action effects have been shown to be monitored automatically because they bind with action (Band et al., 2009). Overall, the results suggest that stimuli that are perceived as action outcomes are automatically monitored and thus capture attention. The findings fit with the preactivation account of intentional binding, according to which action preparation or execution results in the activation of the sensory network that represents the sensory action effect, and increases its mean level of activity to some pedestal level, leading to better or more efficient processing of stimuli that are perceptual consequences of one's own action compared with stimuli that are not (Kühn, Seurinck, Fias, & Waszak, 2010; Roussel et al., 2013; SanMiguel, Widmann, Bendixen, Trujillo-Barreto, & Schröger, 2013; Waszak et al., 2012).

More importantly, the results are in line with the studies that show that capture occurs when an object is available for processing earlier than other objects in the display. For example, Gibson (1996a, 1996b) showed that abrupt onsets capture attention when the other objects in the display are masked by the preceding placeholders. Similarly, Sunny and von Mühlenen (2014) showed that motion onsets, as well as abrupt displacements, captured attention only when the objects escaped forward masking by the preceding figure-8 placeholders. Capture by action is similar to these previous studies, in that the object that captures attention is available earlier for processing compared with the other objects in the display. However, the physical salience of the singleton is the same in both the action and no-action conditions. Hence, capture by action cannot be fully explained by a bottom-up model of attention capture. Moreover, it is also problematic to argue that capture is caused by a change in the top-down goals, as this, too, remains unchanged between the action and the no-action conditions. The findings from the current study suggest that action could modulate how top-down and bottom-up factors determine selection.

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