

From hands to feet: Abstract response representations in distractor–response bindings



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ABSTRACT

Evidence suggests that, when people respond to target stimuli, distractors that accompany the target become integrated with the response, and can thus subsequently serve as a retrieval cue of that response—an example of *distractor–response binding*. In two experiments, we investigated whether the response codes that become part of such distractor–response bindings are effector-specific or abstract. In a prime–probe design, participants gave left and right responses with their hands or their feet. The required effector set was systematically varied between prime and probe responses. If participants executed each response immediately, effects of distractor–response binding were only observed for effector repetitions but not for effector changes. However, distractor–response binding was observed in effector-change trials if participants were keeping the prime-action plan active during probe–response execution. These results indicate that it is rather abstract response codes that are integrated with distractor stimuli and retrieved upon distractor repetition.

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1. Introduction

At any one moment, many objects in our environment are irrelevant for our current action goals and are thus better to be ignored. Interestingly, however, ignored stimuli have been shown to influence human actions by retrieving earlier responses (e.g., Frings & Rothermund, 2011; Hommel, 2005; Moeller & Frings, 2014). This influence can be accounted for in terms of the theory of event coding (TEC, Hommel, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001). The TEC proposes that the formation of an action plan leads to an integration of stimulus- and response features into the same episodic memory trace or *event file* (Hommel, 2004). Repetition of any of these features reactivates the entire event file, including the stimulus and the previous response to it. Thus, if the same response is required again, responding is facilitated due to the repetition of the stimulus. In contrast, if another response is required, stimulus repetition impedes the action. Importantly, it has been shown that actions can be influenced by ignored stimuli in a similar way (e.g., Frings, Rothermund, & Wentura, 2007). This *distractor–response binding* effect can be demonstrated in prime–probe designs that require responses to prime and probe targets accompanied by distractors. If the response has to be repeated from prime to probe, a repetition of the same distractor facilitates responding on the probe as compared to different prime and probe distractors. In contrast, if the

required response on the probe differs from that on the prime, distractor repetition hampers responding, leading to slow and/or inaccurate performance.

Response repetitions in previous studies of distractor-based stimulus–response retrieval involved a repetition of the exact motor response — e.g., pressing the same response key with the same finger as before (e.g., Frings & Moeller, 2010; Frings & Rothermund, 2011; Giesen & Rothermund, 2011, 2014; Moeller & Frings, 2011). However, under real-life conditions repeating an action does not necessarily involve the exact same muscle activations or involvement of the same effector: you may switch on the same light, and open the same door by using very different body parts. As actions have been defined in terms of both muscle activations (e.g., Barsalou, 2008) and more abstract codes such as the action goal (e.g., Prinz, 1997), it remains to be seen whether distractor–action bindings rely on the former or the latter.

On the one hand, it has been suggested that responses are represented in terms of their action goal rather than specific motor programs (e.g., Eder, Müsseler, & Hommel, 2012; Prinz, 1997; see also Rosenbaum, 1980; Schmidt, 1975; Stelmach, Mullins, & Teulings, 1984; Wright, 1990). It is therefore possible that it is relatively abstract action codes that become part of distractor–response bindings, and that such bindings are not overly sensitive to the particular effector used to execute an action. In line with this, several studies found that effects of stimulus–response compatibility are more or less insensitive to the anatomical status of the effector used to press a response key, so that a left stimulus, say, facilitates pressing a left key even if it is operated by the right hand (see, Simon, Hinrichs, & Craft, 1970; Wallace, 1971, 1972). Along the same lines, interference between concurrent action plans is equally pronounced

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between two plans involving the same hand and two plans with one involving a hand and another involving the ipsilateral foot (Stoet & Hommel, 1999). More specifically, regarding integration of distractor stimuli and responses, Frings, Bermeitinger, and Gibbons (2011) found that the repetition of the prime distractor as the probe target facilitated responses with the same hand as on the prime, even if the particular effector (i.e. the executing finger) changed. Even though alternative explanations (e.g., in terms of residual activation of the response hand) could not be ruled out entirely, this might be taken as a first indication that the response retrieved by distractor repetition is not restricted to exact muscle activation.

On the other hand, there are reasons to consider that distractor–response bindings might involve effector-specific representations. Theories of cognitive embodiment claim that actions are represented through mental *simulations*, suggesting that action representation is body based (e.g., Barsalou, 2008; Wilson, 2002). If we assume an integration of such response representations, a distractor that has been bound to a left response with a hand would not retrieve a left response with a foot at repeated presentation. Consequently, changing the executing extremity from prime to probe should modulate the effect of distractor–response bindings. In fact, Eimer, Schubö, and Schlaghecken (2002) found response inhibition due to masked priming both for hand responses and for foot responses but no such inhibition if the effector pairs (hands or feet), associated with the prime and target, were different. In addition, Braem, Verguts, and Notebaert (2011) found better discrimination between tasks if participants used their hands to respond to one task and their feet to respond to the other, as compared to when participants used hand responses in both tasks to respond. These results also support a notion of action discrimination by extremities. Finally, manual probe responses were not influenced by retrieval of verbal prime responses when an auditory prime distractor was repeated as the probe target (Mayr & Buchner, 2010), further supporting the notion of effector specific bindings.

Taken together, different theories and past findings provide no clear picture as to what kind of response representation is likely to become integrated with a distractor stimulus. Particularly, in the one extreme, specific muscle activations might be integrated in distractor–response binding, resulting in the facilitation of very specific responses by repeated distractors. In the other extreme, it might be an abstract response code that is integrated with a distractor stimulus, resulting in the modulation of a range of responses by distractor repetition.

The present study was designed to pit these notions against each other. We used a prime–probe design and asked participants to categorize prime and probe targets by means of right and left responses, while ignoring flanking distractor stimuli. Left and right responses could be carried out with the hands or with the feet and the required effector pair (i.e., hands or feet) could repeat or change from prime to probe response. If distractor–response binding takes place at an abstract level of response coding the effect of distractor–response binding should survive changes of the effector set and thus be equally significant with effector-set repetitions and effector-set changes. For example, a left response executed with a hand on the prime should be integrated with the distractor and the repetition of this distractor should facilitate a left foot response on the probe. In contrast, if distractor–response binding is specific to the effector used to execute the response, we should only find a significant effect of distractor–response binding on trials with responses executed with the same effector set on the prime and the probe (i.e., either both with the hands or both with the feet). In two experiments we varied the effector-set relation (repetition vs. change) between prime and probe responses and measured effects of distractor–response binding on probe responses. In Experiment 1, we used a sequential distractor–priming paradigm that required participants to respond to the prime and the probe targets immediately. In Experiment 2, participants were required to delay the prime response and execute it only after completion of the probe response. The rationale of this requirement was that it would assure that the action plan

of the prime response was kept active during probe response execution (see Stoet & Hommel, 1999).

2. Experiment 1

2.1. Method

2.1.1. Participants

A total of 30 students (21 female) from the University of Trier took part in the experiment. The median age was 20 years with a range from 19 to 28 years. Two additional participants were replaced because of an extreme number of slow or incorrect responses (their error rates or mean response times were more than three interquartile ranges above the third quartile of the remaining sample; Tukey, 1977). All participants took part in exchange for partial course credit and had normal or corrected to normal vision.

2.1.2. Design

The design essentially comprised three within-subjects factors, namely response relation (repetition vs. change), distractor relation (repetition vs. change) and effector set relation (repeated vs. changed).

2.1.3. Materials

The experiment was conducted using the E-prime software (E-prime 2.0). Instructions and the fixation mark were shown in white on black background on a standard TFT screen. Target stimuli were colored ellipses that could be presented in red, yellow, green, or blue. Distractor stimuli were the white outlines of the shapes rectangle, triangle, ellipsis, and star. All stimuli had a horizontal visual angle of 1.5° and a vertical visual angle of 1.1°. A constant viewing distance of 50 cm was provided by asking participants to place their heads on a chin rest.

2.1.4. Procedure

Participants were tested individually in sound proof chambers. Instructions were given on the screen and summarized by the experimenter. Two foot pedals (Psychology Software Tools, Inc., Sharpsburg, USA) were placed in a comfortable position on the floor in front of the participants. The foot pedals were connected to the computer via a serial response box (PST, Inc., Sharpsburg, USA), providing a zero ms debounce period. Participants were instructed to place the index fingers of their hands on the far left and the far right key on a serial response box, respectively, and to place their feet on the foot pedals. Each participant worked through four blocks of the experiment: in one block they responded with their hands to both prime and probe, in one with their hands to the prime and with their feet to the probe, in one with their feet to the prime and with their hands to the probe, and in one with their feet to both the prime and the probe. In addition, before each prime and each probe display, a picture of a hand or a foot was presented in white on black background to indicate whether participants had to respond via hands or via feet to the next display. In each prime and each probe display a colored ellipsis was presented in the center of the screen and was flanked by two identical shapes. Participants' task was always to identify the color of the centered ellipse by pressing a key with the index finger on the side corresponding to the color or by pressing a foot pedal on the corresponding side with the left or right foot. To be able to vary response repetition independent of target repetition, each response could be indicated by two different target colors. Red and green stimuli were mapped to the right, and blue and yellow stimuli were mapped to the left responses. Participants were instructed to react as quickly and as correctly as possible.

A single prime–probe sequence consisted of the following sequence of events (see Fig. 1): at the beginning of each trial, a plus sign was presented as a fixation mark for 1000 ms in the center of the screen and was followed by a blank screen that was presented for 200 ms. Then the cue (i.e., a picture of a hand or a foot) was presented for

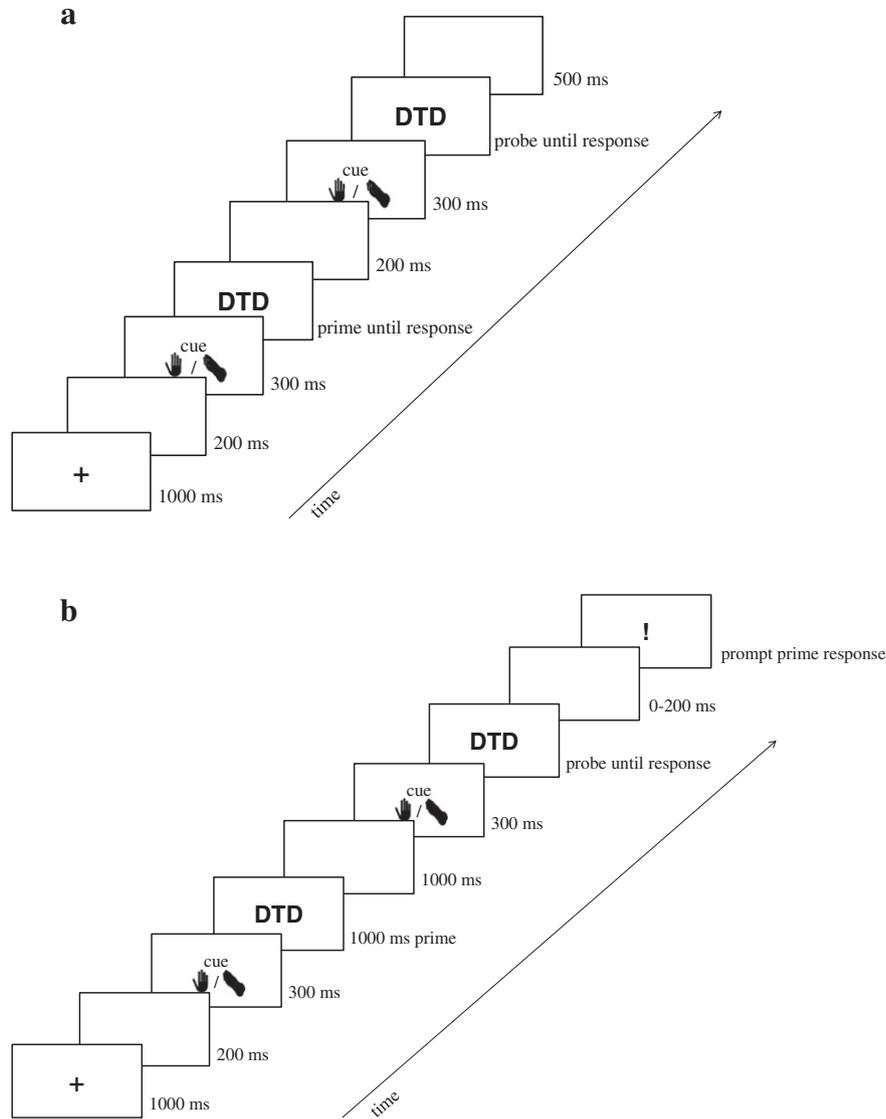


Fig. 1. a and b. Schematic sequence of events in one trial in Experiment 1 (upper panel) and Experiment 2 (bottom panel). T = target stimulus, D = distractor stimulus. Participants responded with a left or right key/pedal press to the targets and ignored the distractors. They received a cue before each prime and each probe display informing them whether they would have to respond with a hand or with a foot; for details, see procedures.

300 ms, indicating whether the participants had to respond via hands or via feet to the prime target. The prime display was then presented until participants' response. After 200 ms of a blank screen another cue, indicating the effector to be used for the probe response was presented for 300 ms. As on the prime, the probe display was then shown until participants' response. Finally, another blank screen was presented for 500 ms.

In response repetition trials (Rr) the same response side was indicated by the target on the prime and the probe. In response change trials (Rc) the response side changed from prime to probe. Orthogonally to the response relation, the distractor relation was varied. In distractor repetition trials (Dr) the same shape was presented as the distractor on the prime and the probe. In distractor change trials (Dc) the distractor shape differed between prime and probe.

Each participant worked through four experimental blocks of 80 prime–probe sequences that were presented in a random order. In two of the blocks (i.e., hand–hand block and foot–foot block), participants always responded to the prime and the probe displays with the same effector. In the other two blocks (i.e., hand–foot block and foot–hand block), participants always responded with different effectors to the prime and the probe display. The four trial types (RrDr, RrDc,

RcDr, and RcDc) were realized in 20 trials in each block. Each of the experimental blocks was preceded by four warm up trials. Prime and probe target colors as well as distractor shapes were randomly assigned in each trial, under the restriction that response relation and distractor relation of the current trial were given. For example, in distractor repetition trials the same shape was assigned to the prime distractor and the probe distractor. In half of the response repetition trials, the target color differed between prime and probe (for example, if the prime target was red, the probe target was green, with both colors mapped to the right response). In the other half of the response repetition trials the same color was presented as the target on the prime and the probe. Before the experimental blocks started, participants worked through four practice blocks (hand–hand, foot–foot, hand–foot, and foot–hand) of 16 prime–probe sequences each. During practice participants received feedback after each prime and each probe response. Other than that the practice blocks were identical to the experimental blocks.

2.2. Results

Only trials with correct answers to the prime and the probe were considered. Reaction times that were more than 1.5 interquartile ranges

Table 1

Mean reaction times (in ms) and mean error rates (in percentage) in Experiment 1 as a function of response-, distractor-, and effector set relation. Standard errors of the means in squared brackets.

| | Response Repetition | | Response Change | |
|----------------------------|---------------------|--------------|-----------------|-------------|
| | Response times | Error rates | Response times | Error rates |
| <i>Same effector</i> | | | | |
| Distractor repetition (Dr) | 475 [9] | 4.2 [0.8] | 527 [10] | 3.1 [0.6] |
| Distractor change (Dc) | 485 [11] | 3.9 [0.6] | 525 [11] | 1.7 [0.4] |
| Priming effect (Dc–Dr) | 10 [4] | –0.3 [0.6] | –2 [4] | –1.4 [0.7] |
| <i>Different effector</i> | | | | |
| Distractor repetition (Dr) | 587 [12] | 7.4 [0.7] | 574 [12] | 3.3 [0.8] |
| Distractor change (Dc) | 579 [12] | 6.7 [1.2] | 571 [11] | 3.2 [0.6] |
| Priming effect (Dc–Dr) | –8 [6] | –0.7 [0.1.1] | –3 [4] | –0.1 [0.8] |

above the third quartile of the RT distribution of the sample (Tukey, 1977), and those that were shorter than 200 ms were excluded from the analysis. Due to these constraints, 12.3% of all trials were discarded (probe error rate was 3.9%, prime error rate was 4.3%). Mean RTs and error rates for probe displays are depicted in Table 1.

In a repeated-measures ANOVA with effector set relation (repeated versus changed) \times distractor relation (repeated versus changed) \times response relation (repeated versus changed) as factors, the main effects of effector set relation, $F(1,29) = 152.70, p < .001, \eta_p^2 = .84$, and of response relation, $F(1,29) = 11.34, p = .002, \eta_p^2 = .28$, were significant. Responses were faster with response repetitions ($M = 529$ ms, $SD = 54$ ms) than response changes ($M = 548$ ms, $SD = 56$ ms), and if the effector set was the same on prime and probe ($M = 503$ ms, $SD = 52$ ms) than if the effector set changed ($M = 577$ ms, $SD = 61$ ms). The interaction of distractor relation and response relation was not significant, $F(1,29) = 0.73, p = .399, \eta_p^2 = .03$, while the three-way interaction of response relation, distractor relation and effector set relation was, $F(1,29) = 5.12, p = .031, \eta_p^2 = .15$.¹ Separate analyses revealed that response-by-distractor interaction (indicative of distractor–response binding) was significant with effector set repetitions, $F(1,29) = 4.74, p = .038, \eta_p^2 = .14$ (distractor–response binding effect in ms: $M = 12$ ms, $SD = 31$ ms), but not with effector set changes, $F(1,29) = 0.85, p = .364, \eta_p^2 = .03$ (distractor–response binding effect in ms: $M = -5$ ms, $SD = 32$ ms). This suggests that the repetition of a distractor retrieved a left (right) response only if the extremity executing this response was identical in prime and probe. Finally, the main effect of distractor relation was not significant, $F < 1, p > .8$, while the interaction of response relation and effector set relation was, $F(1,29) = 84.11, p < .001, \eta_p^2 = .74$, indicating a numerically reversed effect of response repetition in effector switch as compared to effector repetition trials. The interaction of distractor relation and effector set relation approached significance, $F(1,29) = 3.44, p = .074, \eta_p^2 = .11$.

In the same ANOVA on error rates all main effects were significant: response relation, $F(1,29) = 20.55, p < .001, \eta_p^2 = .42$, effector relation, $F(1,29) = 15.70, p < .001, \eta_p^2 = .35$, and distractor relation $F(1,29) = 4.45, p = .044, \eta_p^2 = .13$. The interaction of response relation and effector set relation reached significance as well, $F(1,29) = 5.78, p = .023, \eta_p^2 = .17$. All other effects were not significant, all $F_s < 1, p_s > .4$.

2.3. Discussion

The results of Experiment 1 clearly revealed response retrieval due to distractor repetition as long as the same effectors were used to respond to the prime and to the probe display. Importantly, this effect vanished if the effector that executed the ‘left’ or ‘right’ response changed between

¹ The factor probe effector modality (hands vs. feet) did neither influence the binding effect, $F(1,29) < 1, p = .339, \eta_p^2 = .03$, nor the modulation of the binding effect by effector switch, $F(1,29) < 1, p = .792, \eta_p^2 < .01$.

prime and probe response. Hence, our results may be taken to suggest that distractor stimuli are integrated with the specific motor response rather than a more abstract response label. This would be in line with the finding that response modality switches from vocal to manual prevent retrieval of former responses due to distractor stimulus repetition (Mayr & Buchner, 2010). However, these results were possibly influenced by task switching effects. In particular, evidence exists that changing the response modality (e.g., between vocal, finger, and foot responses) functions as a task switch (Philipp & Koch, 2005, 2011). Supporting this notion, we observed response time (i.e., task switch²) costs if participants changed the effector set between prime and probe. In this case, any bindings involving distractor and response (regardless of effector specificity) could have been bound to the present task. Switching the task can then have suppressed or deactivated all bindings related to the previous task – including bindings between distractors and responses, which thus may have been too weak to affect performance. To test this possibility, it would be necessary to investigate bindings before the respective task set is discarded. Thus, we conducted a second experiment that required participants to keep the binding-related task active while responding to the probe stimulus.

3. Experiment 2

Experiment 2 was designed to analyze whether bindings related to an active task set include effector specific motor responses or more abstract response labels (e.g., ‘left’ and ‘right’). Therefore we implemented a design that was originally used to test whether active action plans prevent integrated response features from becoming part of a different action plan. The prime stimulus (A) always appeared before the probe stimulus (B), but the corresponding prime response only had to be executed after the response to the probe (ABBA design, see Stoet & Hommel, 1999). Hence, participants were forced to memorize the prime response while responding to the probe and probe responses were always executed while the bindings between prime stimulus- and response features were active. In the original study, stimuli and responses always differed between A and B. Therefore the repetition of a single response feature (in response B) that was already bound to action plan A would activate other features of action plan A, thus hampering the integration of that feature into action plan B. In contrast, in our Experiment 2 responses were repeated in half of the trials. That is, the effect of distractor-based response retrieval depends on the currently demanded probe response. For instance, if a distractor retrieves response A, it will facilitate responding if the same response is required at the prime and the probe whereas it will hamper responding if different responses are required. Similarly to the original study, impairment was thus expected for response (side) changes between A and B, while benefits should result for response (side) repetitions (see effector repetition blocks of Experiment 1). More importantly, if distractor stimuli are indeed integrated with an effector specific response, the same modulation of distractor response binding due to effector set relation as in Experiment 1 would be expected. Yet, if an abstract response code is integrated with the distractor stimulus, distractor–response binding effects should not be modulated by effector change between prime and probe.

3.1. Method

3.1.1. Participants

A total of 29 students (21 female) from the University of Trier took part in the experiment. The median age was 21 years with a range

² Note that in the present design, effector set repetition also involved repetition of the cue, and effector set switch trials included cue switch. Therefore, costs due to cognitive control processes involved in updating task sets (indicated by the main effect of effector set relation) were possibly also enhanced by priming effects due to cue repetition (see Jost, De Baene, Koch, & Brass, 2013).

from 18 to 32 years. One additional participant was replaced due to an extreme percentage of prime errors. All participants took part in exchange for partial course credit and had normal or corrected to normal vision.

3.1.2. Design

The design essentially comprised three within-subjects factors, namely response relation (repetition vs. change), distractor relation (repetition vs. change) and effector set relation (repeated vs. changed).

3.1.3. Materials and procedure

Materials and procedure were the same as in Experiment 1 with the following exceptions. We replaced the shapes and colors used in Experiment 1 by letter stimuli, which were likely to be more familiar to the participants. The letters D, F, J, and K were used as targets and the letters S, G, H, and L were used as distractors. D and F were mapped to a left response and J and K were mapped to a right response. Each letter had a horizontal visual angle of 0.9° to 1.1° and a vertical visual angle of 1.1° . The target letter was always presented in the center of the screen and was flanked by two identical distractor letters. Importantly, in contrast to Experiment 1, participants were instructed to memorize the prime response and execute it only after their response to the probe. Effector-set relation between prime and probe responses (hand–hand, foot–foot, hand–foot, foot–hand) was again varied blockwise. A single trial included the following events (see Fig. 1b): at the beginning of each trial, a plus sign was presented as a fixation mark for 1000 ms in the center of the screen and was followed by a blank screen that was presented for 200 ms. Then the cue (i.e., a picture of a hand or a foot) was presented for 300 ms, reminding the participants whether they had to respond via hands or via feet to the prime target. The prime display was then presented for 1000 ms, followed by blank display of another 1000 ms. Then a cue, reminding the participants of the effector for the probe was presented for 300 ms. The probe display was then shown until participants' response to the probe target. After a random interval of zero to 200 ms, an exclamation mark was presented that prompted the participant to execute the memorized prime response.

In response repetition trials (Rr) the same response side was indicated by the target on the prime and the probe display. In response change trials (Rc) the response side changed between prime (i.e., the delayed response) and probe (i.e., the immediately executed response). Orthogonally to the response relation, the distractor relation was varied. In distractor repetition trials (Dr) the same letter was presented as the distractor on the prime display and the probe display. In distractor change trials (Dc) the distractor letter differed between prime display and probe display. In turn, four different conditions for effector repetition and effector change, as well as the four practice and four experimental blocks were realized as in Experiment 1.

3.2. Results

Applying the same criteria as in Experiment 1, 12.2% of all trials were discarded (probe error rate was 3.6%, prime error rate was 2.1%). Mean RTs and error rates for probe displays are depicted in Table 2.

In a repeated-measures ANOVA on probe response times with effector set relation (repeated versus changed) \times distractor relation (repeated versus changed) \times response relation (repeated versus changed) as factors, the main effects of effector set relation, $F(1,28) = 13.33$, $p = .001$, $\eta_p^2 = .32$, and of response relation, $F(1,28) = 8.22$, $p = .008$, $\eta_p^2 = .23$, were significant, while the effect of distractor relation approached significance, $F(1,28) = 3.0$, $p = .094$, $\eta_p^2 = .10$. Responses were faster with response repetitions ($M = 726$ ms, $SD = 117$ ms) than with response changes ($M = 748$ ms, $SD = 128$ ms), if the effector set was the same on prime and probe ($M = 721$ ms, $SD = 114$ ms) than if it changed ($M = 753$ ms, $SD = 133$ ms), and if the distractor was the same on prime and probe ($M = 732$ ms, $SD = 119$ ms) than if it changed ($M = 741$ ms, $SD = 123$ ms). Importantly, the interaction of distractor

Table 2

Mean reaction times (in ms) and mean error rates (in percentage) in Experiment 2 as a function of response-, distractor-, and effector set relation. Standard errors of the means in squared brackets.

| | Response repetition | | Response change | |
|----------------------------|---------------------|-------------|-----------------|-------------|
| | Response times | Error rates | Response times | Error rates |
| <i>Same effector</i> | | | | |
| Distractor repetition (Dr) | 683 [21] | 1.8 [0.5] | 741 [23] | 5.3 [1.1] |
| Distractor change (Dc) | 700 [18] | 2.0 [0.5] | 732 [22] | 5.0 [0.8] |
| Priming effect (Dc–Dr) | 16 [9] | 0.2 [0.6] | –10 [9] | –0.3 [1.0] |
| <i>Different effector</i> | | | | |
| Distractor repetition (Dr) | 734 [23] | 4.1 [0.6] | 744 [24] | 3.1 [0.6] |
| Distractor change (Dc) | 758 [24] | 4.8 [0.9] | 739 [25] | 2.6 [0.5] |
| Priming effect (Dc–Dr) | 25 [7] | 0.7 [0.8] | –5 [8] | –0.5 [0.6] |

relation and response relation was significant, $F(1,28) = 8.05$, $p = .008$, $\eta_p^2 = .22$, indicating distractor–response binding, while the three-way interaction of response relation, distractor relation and effector relation was not, $F(1,28) = 0.04$, $p = .845$, $\eta_p^2 = .001$.³ Thus, there was no evidence that distractor–response binding was any different in the two effector-set conditions (distractor–response binding effect $M = 26$ ms, $SD = 83$ ms for effector repetition and $M = 29$ ms, $SD = 58$ ms for effector change). Finally, the interaction of response relation and effector set relation, $F(1,28) = 22.62$, $p < .001$, $\eta_p^2 = .45$, was significant, indicating a numerically reversed effect of response repetition in effector switch as compared to effector repetition trials, while the interaction of distractor relation and effector set relation was not significant, $F(1,28) = .117$, $p = .289$, $\eta_p^2 = .04$.

The ANOVA on error rates showed only a significant interaction between response relation and effector set relation, $F(1,28) = 23.24$, $p < .001$, $\eta_p^2 = .45$.

3.3. Discussion

The results of Experiment 2 were clear cut: effects of distractor–response binding influenced performance in a paradigm that required responding while keeping a different action plan active. That is, distractors facilitated execution of responses that were currently integrated with them in the same active action plan. Importantly, there was no evidence that this process was any different for effector repetition and effector change, suggesting that the specificity of the response code does not matter for integration.

4. General discussion

We investigated what kind of response representation becomes integrated with distractor stimuli. In Experiment 1, in which participants responded to each display, we found evidence of response retrieval due to distractor repetition only if both prime and probe responses were executed with the same effectors. However, if participants kept the prime action plan active while responding to the probe (Experiment 2), distractor–response binding effects influenced probe responses both if the effectors repeated and if they changed from prime to probe. This means that, say, if a manual ‘left’ response was integrated with a distractor stimulus, the repeated presentation of this distractor also facilitated a left foot response. Thus, we can conclude that the response code that is integrated with a distractor stimulus representation represents the action goal rather than the particular motor program.

The modulation of distractor–response binding by effector repetition in Experiment 1 might be the result of a perceived task switch if the effector set differed between prime and probe responses (see,

³ The factor probe effector modality (hands vs. feet) did neither influence the binding effect, $F(1,28) < 1$, $p = .720$, $\eta_p^2 = .01$, nor the modulation of the binding effect by effector switch, $F(1,29) < 1$, $p = .452$, $\eta_p^2 = .02$.

Philipp & Koch, 2005, 2011). Apparently the current task was also integrated with the action plan. In turn, switching to another task may have led to inhibition of the associated action plan together with the former task. However, it should be noted that distractor–response binding effects have been shown to influence responding even if participants' task (color- vs. grammatical classification) and response mode (verbal vs. manual) changed between prime and probe (Rothermund, Wentura, & De Houwer, 2005). Yet, it is still possible that participants in the study of Rothermund et al. covertly prepared both vocal and manual responses, which then enabled retrieval effects (see Mayr & Buchner, 2010). In addition, in the experiments of Rothermund et al. (2005) the 'distractor' was part of the target object and hence stronger retrieval effects could be expected (Ihrke, Behrendt, Schrobdsdorff, Herrmann, & Hasselhorn, 2011; Moeller & Frings, 2014) which in turn might have hedged against diminishing influences of the task switch.

At first sight, the results of Experiment 1 might be taken to contrast with a study by Schuch and Koch (2004). These authors asked participants, in each trial, to categorize two number stimuli of which one appeared shortly before the other (PRP-design). The effector changed (from verbal to manual) from the first to the second response. If participants performed the same categorization (e.g. odd/even) on both stimuli, response repetition was beneficial even though effectors switched. In contrast, in our Experiment 1 response repetition benefits turned into costs for effector change blocks. An important difference between the two experiments is the manipulation of SOA that Schuch and Koch used. Participants were instructed to respond to each of the two stimuli as soon as they appeared and SOA varied between 100 and 1700 ms. That is, at least for the shorter SOAs, action plans for the first response were not yet carried out and could thus not be discarded at the time of S2 presentation. This setup might have generally counteracted disregard of the first task set at presentation of the second response (i.e., at effector change).

The present results also shed light on the role of distractor–response bindings across the formation, existence and disintegration of action plans. Stoet and Hommel (1999) propose a differentiation between action code integration and action code activation. During response preparation, action codes are first activated and then integrated to action plans. Before response execution the integration is kept active and effects of action code occupation influence performance. After response execution, action plans quickly disintegrate, while action codes show residual activation for up to 1 s. The results of Experiment 2 indicate that abstract action codes are integrated with distractors in action plans. This finding is in line with the former results. If an action plan was kept active in the present study (i.e., in Experiment 2), integrated responses were facilitated by distractor repetition regardless of the effector that was used to execute the response. Moreover, the results of our Experiment 1 might indicate that any residual distractor–response binding is effector specific.

It should be mentioned that task requirements in our Experiment 2 were rather different from those in Experiment 1. In particular, participants had to remember the response to the prime stimulus after the display had been out of sight for about 2000 ms. One could argue that this might have encouraged or even forced participants to create explicit, semantic response codes, which might be easier to keep in mind. Hence, our task might have more or less artificially produced particularly abstract representations, which would render it less surprising that we were able to demonstrate them. Moreover, one may wonder what the term 'abstract' means if it comes to response coding. For one, it could mean that people code their actions by means of semantic labels, such as the concept or verbal representation 'left' or 'right'. While this is a logical possibility, it is inconsistent with the available evidence. Previous research has shown that code occupation through action planning does not only affect the planning of actions with overlapping features, as investigated in the present study, but also the perception of events with overlapping features. For instance, planning a left or right hand movement for later execution effectively prevents participants from

perceiving a masked arrow if it points to the side at which the action is to be carried out (Müsseler & Hommel, 1997). Interestingly, however, planning a manual action 'blinds' participants to compatible left- and right-pointing arrowheads but not to the words 'left' and 'right', while planning a vocal action has the opposite effect (Hommel & Müsseler, 2006). If planning for later execution would encourage or force participants to re-code their action plan in terms of abstract features, both kinds of actions should affect both kinds of stimuli equally. The fact that they don't, effectively rules out the semantic-coding argument.

The other possibility for response codes being abstract has been discussed by Hommel et al. (2001). They have suggested that codes are concrete with respect to their distal reference (i.e., to the external event they refer to) but abstract with respect to their proximal reference (i.e., to the sensory modality providing the information about a perceptual event or the muscles involved in producing a particular action). The code 'left', say, would be the same for a hand movement or a foot movement, if they only produce a change on the same side, which makes the code abstract in the sense that we suggest in this article. And yet, this does not imply any semantic labeling or higher order categorization, so that the 'left' reference of a motor action and the meaning of the word 'left' would indeed be different. One might argue that even this non-semantic abstractness might have been artificially produced by introducing longer delays between planning and execution in Experiment 2. However, there is evidence that planning for later execution does not change the nature of the codes. Stoet and Hommel (1999: Experiment 3) compared a condition in which participants planned an action before executing another (the same design that we used in Experiment 2) with a condition in which participants were presented with irrelevant response-compatible cues but were not required or encouraged to plan an action before executing the other. This turned the negative feature-overlap effect into a positive feature-overlap effect. Apparently, the cues activated the cue-compatible action, which again facilitated to-be-executed actions if they were sharing the same features. This was only possible if the format of the features was the same as in the planning condition, suggesting that cue-triggered, immediate action activation is using the same codes as planning for later execution.

In any case, the observed result pattern seems to reflect very adaptive processes regarding distractor–response binding. After response execution, changing the effector that is used to manipulate the environment would typically be a good indicator that bindings from previous action plans are no longer relevant. In this sense, an effector switch might facilitate current flexible behavior. On the other hand, as long as an action has not been executed, binding between distractor stimuli and response codes rather than muscle specific responses might contribute to keeping active the action-goal that can still be accomplished using different effectors. Thus, before response execution, effector unspecific binding between distractors and responses would contribute to flexibility in eventually accomplishing the current goal.

In conclusion, we investigated what kind of action code is integrated with distractor stimuli. The present results suggest that distractors are integrated with rather abstract action goals and that they can principally survive an effector switch. However, the particular task context has a modulating influence on the effect. Response codes of executed actions that belonged to a different effector do not influence current actions. Taken together, binding seems to have a very general effect on behavior that may help responding across various kinds of responses. But at the same time, these effects are restricted to specific tasks, preventing maladaptive response modulations.

Author notes

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