

Multi-Level Response Coding in Stimulus-Response Bindings: Irrelevant Distractors Retrieve Both Semantic and Motor Response Codes

Carina Giesen and Klaus Rothermund
Friedrich-Schiller-Universität Jena

Stimulus-response (S-R) episodes are formed whenever a response is executed in close temporal proximity to a stimulus. Subsequent stimulus repetition will retrieve the episode from memory, reactivating the previous response. Whereas many research findings attest to the flexibility of representing stimulus features, only little is known about the way responses are coded within transient S-R episodes, that is, whether the retrieved response is represented in terms of specific motor codes, abstract/semantic codes, or both. To differentiate between these accounts, we used an approach/avoidance task in which semantic meanings (i.e., moving a word “towards” or “away from” a manikin on screen) and motor codes of responses (i.e., pulling or pushing a joystick) were manipulated orthogonally. Results of 2 experiments indicated that stimulus repetitions retrieve both, semantic as well as motor code representations, indicating multiple and independent levels of response coding. We conclude that response representation in S-R episodes follows similar binding principles as are known from stimulus integration.

Keywords: stimulus-response binding, event files, stimulus-action associations, stimulus-classification associations, repetition priming

Stimulus-response (S-R) bindings indicate that, whenever a response is executed in close temporal proximity to a perceived stimulus, a transient association of their mental codes is created and stored in memory (i.e., an *event file*; Hommel, 1998). If the stimulus is repeated on a later occasion, the associated response will be retrieved from memory. Such a stimulus-based response retrieval is of merit if the same response is appropriate in the new situation and will produce facilitation effects. However, if a different response is required, the retrieved response is inappropriate and will lead to response interference. Processes of S-R binding and retrieval allow for an efficient way of stimulus-based behavior regulation (Logan, 1988) and apply to a broad scope of stimuli, modalities, and responses (for an overview, see Henson, Eckstein, Waszak, Frings, & Horner, 2014). Attesting to the generality of this binding mechanism, evidence for the integration of even task-irrelevant information (distractors) into S-R episodes has accumulated in recent years, demonstrating that distractor repetition alone suffices to trigger retrieval of central elements of the processing episodes (Rothermund, Wentura, & De Houwer, 2005; see also Frings &

Rothermund, 2011; Frings, Rothermund, & Wentura, 2007; Giesen & Rothermund, 2011, 2014a, 2014b, 2015; Horner, 2015). The study of distractor integration effects offers new and unique insights into the depth and range of S-R binding principles: For instance, distractor integration effects were demonstrated not only within diverse stimulus modalities (visual: Frings et al., 2007; Rothermund et al., 2005; tactile: Moeller & Frings, 2011; auditory: Mayr & Buchner, 2006; Mayr, Buchner, & Dentale, 2009; Moeller, Rothermund, & Frings, 2012), but also across different stimulus modalities (e.g., visual-auditory: Frings, Moeller, & Rothermund, 2013), indicating that stimuli are coded on multiple levels within a processing episode (i.e., in terms of perceptual, modality-specific as well as abstract/semantic representations; Denkinger & Koutstaal, 2009; Frings et al., 2013; Horner & Henson, 2011).

In comparison, far less is known about the way responses are coded within transient S-R episodes. A differentiation between abstract/semantic and more specific motor codes is important because these representational formats fulfill different functions for behavior regulation: Semantic response codes represent behavioral goals or the meaning of a response (e.g., “open the door”) but do not specify any concrete action, which allows for flexible goal implementation. Motoric response codes, on the other hand, represent specific motor programs (like pulling the door handle). Although somewhat more inflexible, such a representation is of advantage in situations that always require the same stereotypical responses and pave the way for an automatization of action routines.

Many studies on S-R binding and retrieval processes do not allow for a clear dissociation between these representational formats, because a (semantic) response category is always mapped to the same key press response. This implies that repeating or changing the response is perfectly confounded with repeating or changing a specific motor activation. Even those studies that addressed the question of

This article was published Online First February 25, 2016.

Carina Giesen and Klaus Rothermund, Department of Psychology, Friedrich-Schiller-Universität Jena.

This research was supported by a grant from the Deutsche Forschungsgemeinschaft to Klaus Rothermund (DFG RO1272/6-2). We thank Nils Meier for programming the experiments and Anne Grigutsch for her help in analyzing the data. This work is dedicated to Julia Döring, who conducted Experiment 1 as part of her bachelor thesis. Our thoughts are with you.

Correspondence concerning this article should be addressed to Carina Giesen, Department of Psychology, General Psychology II, Friedrich-Schiller University Jena, Am Steiger 3, Haus 1, 07743 Jena, Germany. E-mail: carina.giesen@uni-jena.de

response representation in S-R bindings more directly provide mixed evidence on this issue so far: For instance, Rothermund and colleagues (2005, Experiment 2) required a verbal prime response (e.g., saying “left” vs. “right”), but a manual (left vs. right) key press response in the probe. Retrieval of S-R episodes was unaffected by the different response modalities. Furthermore, S-R binding and retrieval effects were recently documented for response types that are characterized by an *absence* of a motoric response component (like stopped responses/“nonactions”: Giesen & Rothermund, 2014b; and responses of other actors that were merely observed: Giesen, Herrmann, & Rothermund, 2014). Together, these findings support the view that responses are represented at an abstract, semantic level rather than in terms of specific motor codes (see also Dennis, Carder, & Perfect, 2010; Dennis & Schmidt, 2003; Logan, 1990; Logan & Etherton, 1994; Moeller, Hommel, & Frings, 2015). In contrast, Mayr and Buchner (2010) found no evidence for the retrieval of S-R episodes when the task required a change in response modality from verbal (prime) to manual (probe) responses if preparation of manual responses was prevented during the prime. The authors concluded that responses in S-R episodes are represented in terms of modality-specific motor codes (for a similar conclusion, see Mayr et al., 2009).

Related evidence on the semantic versus motoric representation of responses was reported in the task switching literature.¹ An established finding in this research is that response repetition effects are moderated by task switching, that is, while repeating the same manual response produces a benefit in task repetition sequences, it leads to delayed responding if the task switches from prime to probe (Altmann, 2011). This finding is typically explained by assuming that responses are represented in terms of their meanings for the respective task: For example, pressing the right button is coded as indicating that a digit is “odd” in a parity task, but the same manual response is coded as signaling the category “vowel” in a letter categorization task. Because of this semantic response representation, a task switch implies that the same manual response is assigned to a different meaning, which leads to a partial mismatch when the same manual response has to be executed but signals different semantic response categories (Altmann, 2011; Meiran, 2000; Schuch & Koch, 2004). It should be noted, however, that different accounts have been suggested to explain this interaction effect of response repetition and task repetition (see Druey, 2014, for a detailed review), and not all of these accounts draw on the semantic representation of response codes (e.g., Druey, 2014; Hübner & Druey, 2006; Kleinsorge & Heuer, 1999). Another relevant finding from this literature is that (in-)congruency effects for bivalent stimuli (i.e., for stimuli that are assigned to different response categories under the two tasks) emerge even if the responses of the two tasks overlap only on a semantic level (e.g., pressing a left vs. right button with the left hand for Task A, but with the right hand for Task B; Gade & Koch, 2007; Hübner & Druey, 2006; Horner, 2015; Schuch & Koch, 2004). This finding indicates that responses are represented and selected at the semantic level.

Hence, evidence on the issue whether responses are represented at the level of motor codes or at the level of more abstract, semantic codes in S-R episodes is presently inconclusive (although the majority of studies favor the latter view). Note, however, that both views are not mutually exclusive, because recent findings suggest that S-R bindings involve *multiple* levels of response representations (motor codes, decisions, and semantic/categorical representations; Dennis & Perfect, 2013; Horner & Henson, 2009; Nett, Bröder, & Frings, 2015;

Moutsopoulou & Waszak, 2013; Moutsopoulou, Yang, Desantis, & Waszak, 2015).

Against this background, the present study aimed to experimentally dissociate at which level(s) responses are represented in S-R episodes. In particular, we aimed to clarify whether distractor-based retrieval processes trigger retrieval of a semantic response representation, a motor code, or both. In two experiments, we combined a sequential distractor-to-distractor repetition paradigm (Rothermund et al., 2005) with an adapted version of an approach/avoidance task (Eder & Rothermund, 2008; see also De Houwer, Crombez, Baeyens, & Hermans, 2001; Markman & Brendl, 2005). This paradigm has in the past successfully been used to disentangle semantic and motor representations of approach/avoidance behaviors (Eder & Rothermund, 2008). By introducing distractor repetitions versus changes (baseline) as an additional factor into the task, this paradigm allows us to estimate and compare response retrieval effects separately for semantic and motor levels of response representations within a single experiment and for identical materials. Specifically, in a sequence of prime and probe displays, neutral word stimuli were presented in different colors. Depending on each word’s color, participants were instructed to move the word either “towards” or “away from” a manikin (presented on the upper or lower screen borders) by pulling or pushing a joystick. The words’ meaning was irrelevant for this task, meaning that stimulus identity served as a distractor (Rothermund et al., 2005). Words could either repeat or change from prime to probe. Furthermore, semantic meaning of responses (i.e., “towards” vs. “away” movements of the word to vs. from the manikin) and motor responses (i.e., pulling or pushing the joystick) were manipulated orthogonally and could repeat or change independently of each other from prime to probe (see Figure 1). This allowed us to obtain separate estimates for the relative contribution of either type of response representation to distractor-based retrieval effects: If a prime distractor is bound to and later retrieves a semantic response representation, distractor repetition should produce facilitation effects for movement meaning repetitions in the probe (toward–toward; away–away), but should produce interference effects for movement meaning changes in probe (toward–away; away–toward). Statistically, such a retrieval of semantic response codes corresponds to an interaction of distractor relation and movement meaning relation. In turn, if a prime distractor is bound to and later retrieves a motor code, distractor repetition in the probe should produce facilitation effects for joystick response repetitions (pull–pull; push–push), but should produce interference effects for joystick response changes (pull–push; push–pull). Statistically, this retrieval of specific pull/push movements is indicated by an interaction of distractor relation and motor response relation.

Experiment 1

Method

Participants. Fifty-one native German-speaking psychology students of the University Jena were recruited for the experiment. Two participants had to be excluded: One was an outlier in terms of error rates (>17% errors), and one person did not meet the accuracy criteria for entering the main experiment after repeating

¹ We thank an anonymous reviewer for drawing our attention to this literature.

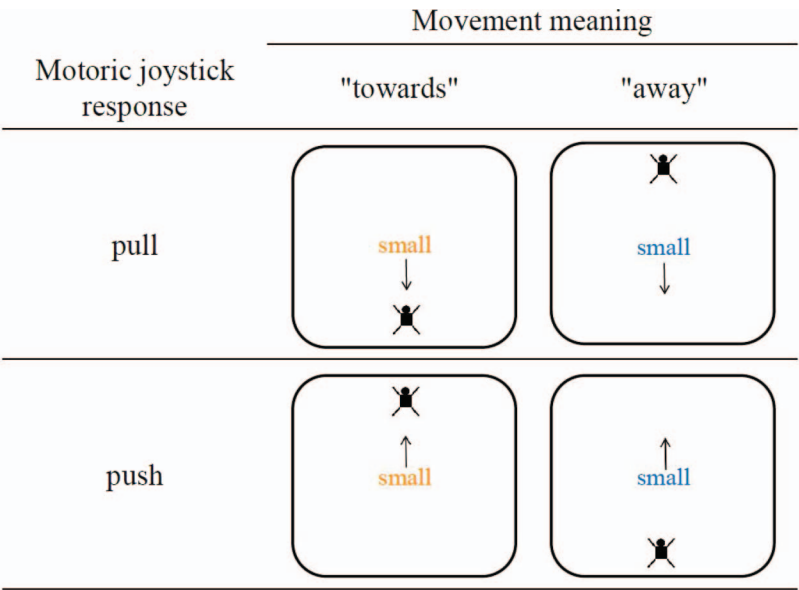


Figure 1. In Experiment 1, movement meaning and motor responses were independently manipulated by presenting the manikin either above or below the orange/blue word. Participants were instructed to move the word toward/away from the manikin on the screen, depending on the word's color. Examples correspond to the "orange = towards" (left column) and "blue = away" (right column) mapping rule. Arrows indicate the movement direction of word stimuli and are only added for illustrative purposes. Stimuli are not drawn to scale. See the online article for the color version of this figure.

the practice block three times. Data of 49 (31 women) participants ($M_{\text{age}} = 23.1$ years, $SD = 3.7$) were analyzed. Participants were tested individually and received partial course credits for their participation and sweets if their performance fulfilled both criteria of speed (i.e., 50% or more of all reaction time [RT] $\leq 1,000$ ms) and accuracy (error rates $\leq 20\%$) in the main experiment. Sessions lasted 30 min.

Apparatus and stimuli. The experiment was programmed with E-Prime 2.0. Stimuli were 25 neutral, frequent, mono- or disyllabic German adjectives, presented in Times New Roman font (18 pts.) on a white 17" CRT screen. Stimuli were presented in blue or orange font

color. A black manikin was constructed from geometrical shapes (i.e., a circle symbolizing the head, a square symbolizing the trunk, and four small lines representing arms and legs; overall size on screen approximated 4 cm height \times 1 cm width) and was presented centrally on the upper or lower screen borders. Participants gave their responses by pulling/pushing a joystick with their dominant hand, which resulted in moving the word stimulus away from/toward the manikin on screen (see Figure 1).

Design. The experiment comprised three orthogonal within-subject factors: Distractor relation, movement meaning relation, and motor response relation (see Table 1). Distractor relation was manip-

Table 1
Sample Stimuli for Prime-Probe Sequences in Experiment 1

Distractor relation	Movement meaning relation	Motor response relation	Prime stimulus	Prime correct response (meaning/motor response)	Prime manikin position (relative to word)	Probe stimulus	Probe correct response (meaning/motor response)	Probe manikin position (relative to word)
Distractor repetition	Repetition	Repetition	Small(b)	Away/push	Below	Small(b)	Away/push	Below
		Change	Small(b)	Away/pull	Above	Small(b)	Away/push	Below
	Change	Repetition	<i>Small(o)</i>	Towards/push	Above	Small(b)	Away/push	Below
		Change	<i>Small(o)</i>	Towards/pull	Below	Small(b)	Away/push	Below
Baseline	Repetition	Repetition	Quiet(b)	Away/push	Below	Small(b)	Away/push	Below
		Change	Quiet(b)	Away/pull	Above	Small(b)	Away/push	Below
	Change	Repetition	<i>Quiet(o)</i>	Towards/push	Above	Small(b)	Away/push	Below
		Change	<i>Quiet(o)</i>	Towards/pull	Below	Small(b)	Away/push	Below

Note. Prime/probe stimuli in boldface were presented in blue (b); stimuli in italics were presented in orange (o). Sample trials correspond to the "blue = away, orange = towards" mapping rule (counterbalanced between participants). For brevity, sample trials are only presented for blue probe words and "push" joystick movements; however, prime-probe sequences were counterbalanced within participants across probe color (blue/orange) and probe motor responses (push/pull).

ulated by repeating or changing the word meaning from prime to probe (50% distractor repetition, 50% baseline). Furthermore, movement meaning ("towards" vs. "away") could repeat or change from prime to probe (50% repetition, 50% change) and was manipulated via word color repetitions (i.e., meaning repetitions) or color changes (i.e., meaning changes) across prime and probe, respectively. Last, motor responses (pulling vs. pushing the joystick) could repeat or change from prime to probe (50% repetition, 50% change). Response latencies for movement onset served as the dependent variable of interest and were logged as soon as the joystick movement exceeded a perimeter of 20 pixels from the central position.

Procedure. Instructions were given on the screen. For both prime and probe displays, participants had to respond to the word's color and move the word stimulus either toward or away from the manikin by pulling or pushing the joystick. Word meaning was irrelevant for the task and served as a distractor (Rothermund et al., 2005). Half of the participants had to move the word toward the manikin if the word color was orange and to move it away from the manikin if the word color was blue; for the remaining participants, color-to-movement meaning mappings were reversed. Movement meaning and motoric responses were independently manipulated by presenting the manikin either above or below the blue/orange word (i.e., the position of the manikin in prime and probe depended on the combination of the movement meaning relation and motor response relation factors, see Table 1 and Figure 1). Prime stimulus color and prime motor response were counterbalanced; probe stimulus color depended on the factor "movement meaning relation," implying that 50% of all probe stimuli were blue or orange, respectively. Probe motor responses depended on the "motoric response relation" factor, implying that 50% of all probe trials required push or pull responses, respectively.

Participants performed 32 practice trials in which they received feedback for erroneous and/or too slow responses: When an error was committed, the message "Error: Wrong key!" appeared; if responses were slower than 1,000 ms, the message "Respond faster!" was presented; if participants failed to respond within 1,500 ms, the message "Error: No response!" was presented. All feedback messages were presented in white font on a red background for 1,000 ms. The practice block was repeated in case participants did not fulfill criteria of both speed ($\geq 50\%$ of all responses below 1,000 ms) and accuracy ($\leq 20\%$ errors).

After practice, participants performed 320 experimental prime-probe sequences that were constructed with respect to the factorial design. For each sequence, a prime word was randomly sampled from the stimulus list. In case of distractor repetition sequences, the same word was also used as probe word; for baseline trials, a different word was sampled from the stimulus list. Identical stimuli were never sampled for two successive prime-probe sequences.

Each prime-probe sequence started with the question "ready?" presented centrally in black. Once participants pressed the fire button of the joystick, a fixation cross (500 ms) appeared, followed by the prime stimulus. Words remained on screen until a joystick response was initiated (max. 1,500 ms) and finished (i.e., until the word reached the manikin or screen border). Once the joystick was put back to starting position (0° deflection), prime displays were followed by a fixation cross (500 ms) after which the probe stimulus was presented until a response was initiated (max. 1,500 ms) and finished. When the joystick was put back in starting position once again, an intertrial interval (1,250 ms) with a blank

white screen followed before the next prime-probe sequence started.

Halfway through the experiment, participants were given a short break. After the experiment, participants were debriefed and rewarded for their participation.

Results

Overall, 9.8% of all probe trials were discarded because of errors in the prime and/or probe and 3.3% of all probe trials because of RT-outlier values.² Mean probe onset RTs and error rates (see Table 2) were then entered into two separate 2 (distractor relation: repetition vs. baseline) \times 2 (movement meaning relation: repetition vs. change) \times 2 (motoric response relation: repetition vs. change) repeated measurement analyses of variance (ANOVA).

Probe RT. ANOVA results yielded significant main effects of movement meaning relation, $F(1, 48) = 276.29, p < .001, \eta_p^2 = .85$, and motor response relation, $F(1, 48) = 36.91, p < .001, \eta_p^2 = .44$, indicating that participants responded faster in sequences with movement meaning repetitions ($M = 485$ ms) versus changes ($M = 546$ ms), and were also faster in sequences with motor response repetitions ($M = 509$ ms) versus changes ($M = 522$ ms). These main effects were qualified by several interactions: First, distractor relation and movement meaning relation interacted significantly, $F(1, 48) = 5.67, p = .021, \eta_p^2 = .11$, indicating distractor-based retrieval of semantic response codes (Figure 2a, left side): Compared with baseline trials, distractor repetition in the probe produced a significant RT benefit when the movement meaning repeated from prime to probe, $\Delta = 3$ ms, $t(48) = 2.29, p = .013$ (one-tailed), $d_z = .33$, but produced a nonsignificant RT cost when movement meaning changed between prime and probe, $\Delta = -2$ ms, $t(48) = 1.15, p = .13$ (one-tailed), $d_z = .17$. Second, distractor relation and motor response relation interacted significantly, $F(1, 48) = 4.47, p = .040, \eta_p^2 = .09$, reflecting distractor-based retrieval of motor response codes (Figure 2a, right side): Compared with baseline, distractor repetition in the probe also produced a significant RT benefit when motor responses repeated from prime to probe, $\Delta = 4$ ms, $t(48) = 1.79, p = .04$ (one-tailed), $d_z = .26$, but produced a nonsignificant RT cost when motor responses changed from prime to probe, $\Delta = -3$ ms, $t(48) = 1.36, p = .09$ (one-tailed), $d_z = .19$. Third, movement meaning relation and motor response relation interacted, $F(1, 48) = 185.16, p < .001, \eta_p^2 = .80$, indicating that repeating or changing both the movement meaning and motoric response from prime to probe led to much faster responses ($M = 494$ ms) compared with conditions in which one response feature repeated while the other changed ($M = 536$ ms). Fourth, the three-way interaction of distractor relation, movement meaning relation, and motor response relation was not significant ($F < 1$), indicating that the distractor-based retrieval effects of movement meanings and motor codes were independent of each other.

Probe errors. The same ANOVA on error rates revealed significant main effects of distractor relation, $F(1, 48) = 17.95, p < .001, \eta_p^2 = .27$, movement meaning relation, $F(1, 48) = 52.03, p < .001, \eta_p^2 = .52$, and response relation, $F(1, 48) = 40.49, p < .001, \eta_p^2 = .46$, suggesting that participants made more errors in sequences with distractor repetitions ($M = 6.4\%$) versus changes ($M = 5.0\%$), move-

² Probe reaction times (RTs) below 150 ms or more than 1.5 interquartile ranges above the third quartile of the sample distribution of probe RTs were regarded as outliers (Tukey, 1977).

Table 2

Means (SD) of Probe Onset Reaction Times and Error Rates in Experiment 1 and 2

Study	Movement meaning relation	Motor response relation	RT (ms)			Errors (%)		
			Distractor relation		DR-effect	Distractor relation		DR-effect
			DR	B		DR	B	
Experiment 1	Repetition	Repetition	454 (48)	460 (51)	6** [2]	1.4 (2.0)	1.4 (2.6)	.0 [.3]
		Change	512 (57)	513 (56)	1 [3]	6.9 (6.6)	5.0 (4.2)	-1.9* [.8]
	Change	Repetition	560 (70)	561 (73)	1 [3]	14.7 (10.2)	12.0 (8.9)	-2.7** [1.0]
		Change	535 (64)	529 (64)	-6* [3]	2.6 (3.3)	1.4 (2.1)	-1.1* [.4]
Experiment 2	Repetition (ID)	Repetition	444 (46)	454 (53)	10** [3]	.2 (.8)	.3 (1.4)	.1 [.2]
		Change	532 (71)	528 (67)	-4 [3]	4.9 (6.5)	3.9 (6.9)	-1.0 [.9]
	Repetition (SCP)	Repetition	511 (58)	530 (66)	19*** [5]	2.4 (3.1)	2.3 (3.4)	-.1 [.6]
		Change	551 (66)	557 (65)	5 [4]	4.6 (6.1)	4.1 (5.8)	-.5 [.8]
	Change	Repetition	579 (62)	578 (64)	-1 [3]	4.9 (4.6)	4.5 (5.2)	-.4 [.6]
		Change	561 (60)	555 (57)	-6* [3]	2.2 (5.3)	1.8 (4.1)	-.4 [.3]

Note. DR = distractor repetition; B = baseline; DR-effect = distractor repetition effect, computed as the difference between baseline minus identical repetition (B-DR). In Experiment 2, trials with identical color (ID) repetitions were excluded from the main analyses, meaning that in movement meaning repetition sequences, the other color of the same color pair (SCP) was used in the probe. *SEMs* in square brackets.

* $p < .05$. ** $p < .01$. *** $p < .001$.

ment meaning changes ($M = 7.7\%$) versus repetitions ($M = 3.7\%$), and motor response repetitions ($M = 7.4\%$) versus changes ($M = 4.0\%$). Furthermore, these main effects were qualified by an interaction of movement meaning relation and motor response relation, $F(1, 48) = 96.12$, $p < .001$, $\eta_p^2 = .67$: Similar to probe RTs, repeating or changing both response features (movement meaning and motor response) produced much less errors ($M = 1.7\%$) than repeating one feature while changing the other feature ($M = 9.7\%$). Finally, the three-way interaction of distractor relation, movement meaning relation, and motor response relation was also significant, $F(1, 48) = 7.54$, $p = .008$, $\eta_p^2 = .14$, indicating that effects of a distractor-based retrieval of movement meaning and motoric response codes were underadditive: Compared with the condition in which both features repeated ($\Delta = 0.0\%$, $|t| < 1$), distractor repetitions produced more errors for conditions in which one of the two response features changed (movement meaning change: $\Delta = -2.7\%$, $t(49) = 2.71$, $p = .009$, $d_z = .38$; motor response change: $\Delta = -1.9\%$, $t(49) = 2.42$, $p = .019$, $d_z = .34$), indicating a retrieval of the inappropriate response feature that led to an increase in the number of errors. Compared with these conditions, however, distractor repetitions effects were smaller, however, when *both* response features changed ($\Delta = -1.1\%$, $t(49) = 2.49$, $p = .016$, $d_z = .35$).

Discussion

Results of Experiment 1 indicate that once a former prime distractor is repeated in the probe, it triggers retrieval of *both*, semantic response representations as well as motor codes of the previously executed prime response. Distractor repetitions in the probe produced facilitation effects (faster RTs and less errors in the probe) when the meaning of the prime response (moving toward or away from the manikin) was repeated in the probe, but produced interference effects when the meaning of the response changed in the probe. Distractor repetitions in the probe also produced facilitation effects when the specific motor response of the prime (pulling or pushing the joystick) had to be repeated, but produced interference effects when joystick responses in prime and probe differed.

More important, the absence of a higher order interaction for probe RTs suggests that retrieval effects of both representational

formats were independent of each other, yielding additive retrieval effects. For probe errors, however, a significant three-way interaction obtained, apparently suggesting that the distractor-based retrieval effects for response meanings and motor codes are underadditive, and thus not independent. Taking a closer look at the pattern of findings, however, revealed that this three-way interaction for the error data is likely because of differences in absolute error percentages between conditions. The very high percentage of accurate responses in conditions in which either both response features are repeated or changed severely limits error-based distractor-response retrieval effects in these conditions, yielding numerically much lower estimates for those effects compared to the conditions in which one of the response features repeats while the other feature changes. Because of a much higher frequency of erroneous responses, these conditions provided much more leeway for the emergence of these effects. Rather than inferring a truly interactive effect of the two types of distractor-based response retrieval effects, we would argue that the three-way interaction for the error data is an artifact. In line with this interpretation, a post hoc power analysis revealed that the power of Experiment 1 to detect such a three-way interaction in the RT data was indeed substantial (i.e., the probability to detect a medium-sized effect of $f = .25$ was $1 - \beta = .96$; power analyses were conducted with G*Power 3.1 software; Faul, Erdfelder, Lang, & Buchner, 2007). The fact that there was no indication of such a three-way interaction in the RT analysis thus suggests that distractor-based binding and retrieval effects for semantic and motoric response codes are independent. This assumption is furthered by a Bayes-Factor analysis on the three-way interaction for the RT data, which yielded a Bayes-Factor Score of $BF_{01} = 6.08$, indicating that the null hypothesis (i.e., nonexistence of the three-way interaction) was six times more likely than the alternative hypothesis in Experiment 1, which can be considered as positive evidence for the validity of the null hypothesis (cf. Kass & Raftery, 1995).

To bolster this interpretation, we conducted another experiment in which we tried to reduce or eliminate the difference in error percentages between these conditions, yielding comparable conditions for distractor repetition effects across trial types. The difference that

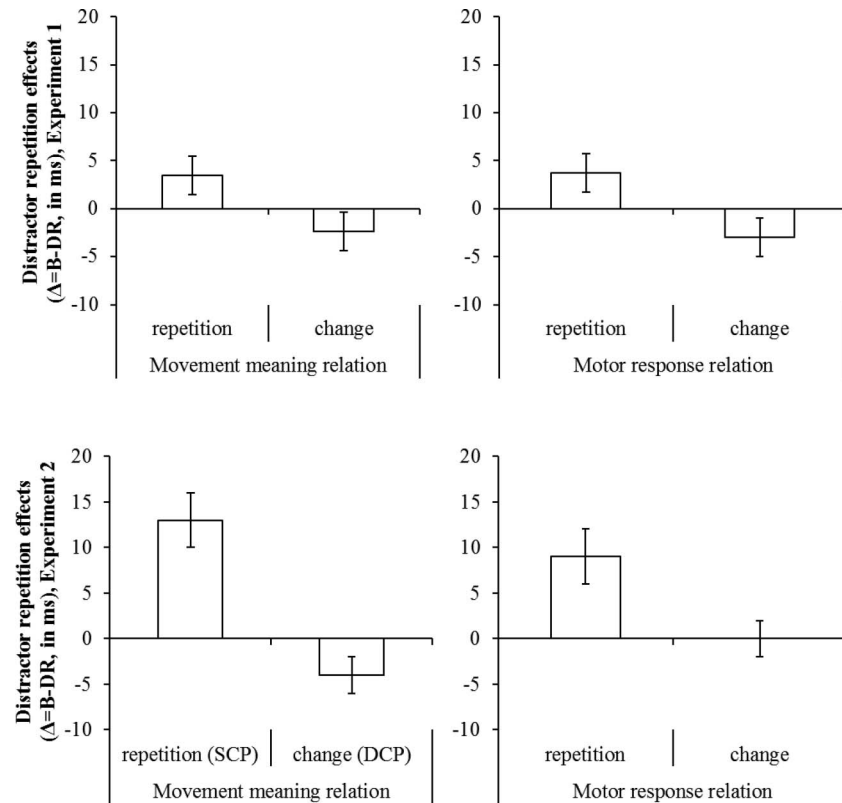


Figure 2. Effects of movement meaning relation (left side) and motor response relation (right side) on distractor repetition effects (baseline [B] – distractor repetition [DR]) computed from probe onset reaction time (RT) in (a) Experiment 1 and (b) Experiment 2 (for movement meaning repetition sequences, only probe trials in which the other color of the same color pair [= SCP] were considered; movement meaning changes by definition used colors of the different color pair [= DCP] in the probe). Error bars depict *SEM*. Positive (negative) values indicate facilitation (interference) because of distractor repetition compared with baseline.

obtained in Experiment 1 is probably because of a simple response strategy known as the “bypass rule” (Fletcher & Rabbitt, 1978). According to this heuristic, participants tend to respond with the same response if the current trial is similar to the previous trial, whereas they tend to switch their responses when the current trial deviates from the previous trial. That is, whenever the color is repeated (changed) from prime to probe, there will be a tendency to execute the same (the opposite) motoric movement as in the previous trial, which perfectly explains the strong interaction effect that obtained between color (movement) repetitions and motor response repetitions. More important, such effects will be much stronger for bipolar stimulus dimensions, like in Experiment 1 (stimulus color was either orange or blue). Using four instead of two colors should reduce this tendency to respond on the basis of the bypass rule and should thus also reduce the difference in error rates between conditions in which both response features are repeated/changed and those in which one features repeats while the other one changes.

A second advantage of using four colors instead of two is that this allows us to address another caveat of the first experiment. Using only one color for each movement meaning implies that movement meaning and word color were perfectly confounded. Therefore, we cannot exclude the possibility that facilitation (interference) effects in sequences with movement meaning repetition (changes) are in fact

(partly) because of color repetitions (changes). Rather than reflecting the retrieval of genuine stimulus–response associations for movement meanings, the respective interaction of distractor and color repetitions might instead indicate associations between different stimulus features (word content and color; this form of stimulus–stimulus [S-S] associations reflect distractor–target [D-T] bindings; Giesen & Rothermund, 2014a). Using four colors that are mapped on two movement meanings allows us to assess pure effects of binding and retrieval between distractors and movement meanings. More important, sequences with identical color repetition were excluded from all analyses. Focusing only on those sequences in which two different colors are presented that are assigned to the same movement meaning, therefore, yields effects of binding and retrieval between stimuli and movement meanings that are free from binding effects between different stimulus features.

Experiment 2

In Experiment 2, we used four colors that determined the response that had to be given in each trial, mapping two different colors onto each movement meaning. Consequently, movement meaning could be repeated while at the same time, the stimulus color changed from prime to probe trials. Furthermore, only probe

trials with color changes were analyzed in the main analyses. This was advantageous for two reasons: First, it eliminates explanations in terms of S-S bindings (distractor-based retrieval of the previous word color) as an alternative explanation for retrieval effects regarding movement meaning (semantic response representations). Second, using four colors instead of two should reduce the likelihood that responding is driven by a simple strategy (bypass rule) that increases error rates for sequences in which one response feature (meaning or motor movement) repeats while the other one changes. This should undermine application of this strategy, thus preventing strong asymmetries in error rates between these conditions.

Method

Participants. Fifty native German-speaking students of the University Jena were recruited for the experiment. Applying the same criteria as in Experiment 1, no participant had to be excluded. Data of 50 (29 women) participants ($M_{\text{age}} = 21.5$ years, $SD = 2.3$) were analyzed. Participants were tested individually and received €3.50 for their participation and a bar of chocolate if their performance fulfilled both criteria of speed and accuracy. Sessions lasted 40 min.

Apparatus, stimuli, design, and procedure. Apparatus, stimuli, design and procedure paralleled Experiment 1 except for the following changes: In Experiment 2, four instead of two word colors were used (orange, green, red, and blue), with two colors mapped onto each movement meaning. For instance, participants were told to move the word toward the manikin when the word color was orange or green and to move the word away from the manikin when the word color was red or blue (mapping of the color pairs orange/green and red/blue to movement meanings was again counterbalanced between

participants). This allowed us to repeat movement meaning from prime to probe independently of color repetitions (see Table 3): In half of all movement meaning repetition trials, the prime color was repeated as probe word color (i.e., blue-blue); in the remaining half of movement repetition trials, the other color of the same color pair was used as prime word color (i.e., red-blue). More important, prime-probe sequences with identical color repetitions were excluded from the main analyses (but see Footnote 3). Thus, movement meaning repetition was no longer confounded with identical color repetition. For sequences with a change of movement meaning from prime to probe, the two colors of the “other” color pair were used in the prime, with half of all prime trials using the first color (i.e., orange-blue), and the other half using the second color of the pair (i.e., green-blue).

Like in Experiment 1, participants started with 32 practice trials, followed by 384 experimental prime-probe sequences that were constructed with respect to the factorial design (see Table 3) and with the same constraints as Experiment 1. Because the task in Experiment 2 was slightly more difficult, participants were given more time to respond: Prime and probe stimuli remained on screen until a joystick response was initiated (max. 2,000 ms) and finished. The speed criterion during practice and to win the extra reward was altered accordingly (slow responses: 1,500 ms < RT ≤ 2,000 ms). Further procedural details (trial procedure, debriefing) corresponded to Experiment 1.

Results

According to the same criteria as in Experiment 1, 9.0% of all probe trials were discarded (5.1% because of errors in the prime and/or probe). Mean probe onset RTs and error rates (see Table 2) were entered into separate 2 (distractor relation: repetition vs.

Table 3
Sample Stimuli of Prime-Probe Sequences in Experiment 2

Distractor relation	Movement meaning relation	Color relation	Motor response relation	Prime stimulus (color)	Prime correct response (meaning/motor response)	Prime manikin position (relative to word)	Probe stimulus (color)	Probe correct response (meaning/motor response)	Probe manikin position (relative to word)
Distractor repetition	Repetition	ID	Repetition	Small(b)	Away/push	Below	Small(b)	Away/push	Below
			Change	Small(b)	Away/pull	Above	Small(b)	Away/push	Below
		SCP	Repetition	Small(r)	Away/push	Below	Small(b)	Away/push	Below
			Change	Small(r)	Away/pull	Above	Small(b)	Away/push	Below
	Change	DCP	Repetition	Small(o)	Towards/push	Above	Small(b)	Away/push	Below
			Change	Small(o)	Towards/pull	Below	Small(b)	Away/push	Below
			Repetition	Small(g)	Towards/push	Above	Small(b)	Away/push	Below
			Change	Small(g)	Towards/pull	Below	Small(b)	Away/push	Below
		ID	Repetition	Quiet(b)	Away/push	Below	Small(b)	Away/push	Below
			Change	Quiet(b)	Away/pull	Above	Small(b)	Away/push	Below
		SCP	Repetition	Quiet(r)	Away/push	Below	Small(b)	Away/push	Below
			Change	Quiet(r)	Away/pull	Above	Small(b)	Away/push	Below
Baseline	Repetition	DCP	Repetition	Quiet(o)	Towards/push	Above	Small(b)	Away/push	Below
			Change	Quiet(o)	Towards/pull	Below	Small(b)	Away/push	Below
		ID	Repetition	Quiet(g)	Towards/push	Above	Small(b)	Away/push	Below
			Change	Quiet(g)	Towards/pull	Below	Small(b)	Away/push	Below
	Change	DCP	Repetition	Quiet(o)	Towards/push	Above	Small(b)	Away/push	Below
			Change	Quiet(o)	Towards/pull	Below	Small(b)	Away/push	Below
		SCP	Repetition	Quiet(r)	Away/push	Below	Small(b)	Away/push	Below
			Change	Quiet(r)	Away/pull	Above	Small(b)	Away/push	Below

Note. Orange/green and red/blue served as color pairs in Experiment 2. ID = identical color; SCP = same color pair; DCP = different color pair. Letters (in parentheses) indicate word color for prime/probe stimuli: o = orange; g = green; r = red; b = blue. Sample trials correspond to the “red/blue = away, orange/green = towards” mapping rule (counterbalanced between participants). Again, prime-probe sequences were counterbalanced within participants across probe color (orange, green, red, or blue) and probe motor responses (push/pull).

baseline) \times 2 (movement meaning relation: repetition³ vs. change) \times 2 (motoric response relation: repetition vs. change) repeated measurement ANOVA.

Probe RT. ANOVA results revealed significant main effects of distractor relation, $F(1, 49) = 6.00, p = .018, \eta_p^2 = .11$, movement meaning relation, $F(1, 49) = 129.23, p < .001, \eta_p^2 = .73$, and motor response relation, $F(1, 49) = 5.46, p = .024, \eta_p^2 = .10$. That is, participants responded faster in sequences with distractor repetition ($M = 551$ ms) versus baseline ($M = 555$ ms), movement meaning repetitions ($M = 537$ ms) versus changes ($M = 568$ ms), and motor response repetitions ($M = 550$ ms) versus changes ($M = 556$ ms). These main effects were again qualified by several interactions: First, distractor relation and movement meaning relation interacted significantly, $F(1, 49) = 19.07, p < .001, \eta_p^2 = .28$, indicating distractor-based retrieval of semantic response codes (see Figure 2b, left side): Compared with baseline trials, distractor repetition in the probe produced a significant RT benefit when the movement meaning repeated from prime to probe, $\Delta = 13$ ms, $t(49) = 3.81, p < .001, d_z = .54$, but produced a significant RT cost when movement meaning changed between prime and probe, $\Delta = -4$ ms, $t(49) = 2.15, p = .036, d_z = .30$. Second, distractor relation and motor response relation interacted as well, $F(1, 49) = 6.14, p = .017, \eta_p^2 = .11$, which reflects distractor-based retrieval of motor response codes (see Figure 2b, right side): Compared with baseline, distractor repetition in the probe also produced a significant RT benefit when motoric responses repeated from prime to probe, $\Delta = 9$ ms, $t(49) = 3.26, p = .002, d_z = .46$, but produced a nonsignificant RT cost when motoric responses changed from prime to probe, $\Delta = 0$ ms, $|t| < 1, p = .90, d_z = .02$. Third, movement meaning relation and motor response relation interacted significantly, $F(1, 49) = 77.42, p < .001, \eta_p^2 = .61$, indicating faster responses for conditions in which prime-probe relations were identical for both movement meaning and motor responses (i.e., both repeated or changed; $M = 539$ ms) compared with conditions in which one response feature was repeated while the other one changed ($M = 566$ ms). Fourth, the three-way interaction was not significant, $F(1, 49) = 1.55, p = .22, \eta_p^2 = .03$, indicating that the two types of distractor-based response retrieval effects were independent of each other.

Probe errors. The same ANOVA on error rates revealed only a significant interaction of movement meaning relation and motor response relation, $F(1, 49) = 46.91, p < .001, \eta_p^2 = .49$, indicating that less errors were made for conditions with identical relations for movement meaning and motor responses (i.e., both repeated or changed; $M = 2.1\%$) compared with the conditions in which these relations were opposite for semantic and motoric response features ($M = 4.5\%$). More important, however, this effect was much smaller than in the previous experiment ($\Delta = 2.4\%$ in Experiment 2 compared with $\Delta = 8.0\%$ in Experiment 1). No other effect reached conventional levels of significance (all F s < 1.4 , all p s $> .24$). Of particular importance, there was no indication of a three-way interaction, $F < 1, p = .74$.

Discussion

The findings of Experiment 2 closely replicate the pattern of results that obtained in Experiment 1: Distractor repetitions in the probe produced facilitation effects when the movement meaning repeated in the probe, but led to interference effects when move-

ment meaning changed between prime and probe. In addition, distractor repetition in the probe also produced facilitation effects when motor (i.e., joystick) responses repeated, but led to interference effects when motor responses changed from prime to probe. Furthermore and like in Experiment 1, the higher order interaction was not significant. More important, we obtained these results although sequences with identical color repetitions were excluded from all analyses. Facilitation (interference) in case of movement meaning repetitions (changes) therefore cannot be explained by distractor-based retrieval of the former prime target feature color. The present results support the conclusion that distractors independently retrieve semantic response representations as well as motor codes of the previously executed prime response.⁴

With respect to the error data, we now no longer observed a three-way interaction between distractor repetition, movement meaning repetition, and motoric response repetitions. This finding corroborates our interpretation that the effect obtained in Experiment 1 was in fact an artifact that was because of excessive usage of the bypass rule because of binary color and response codes. Using four colors with a 4-to-2 mapping strongly reduced the influence of this strategy and produced levels of accuracy that were more comparable across conditions, eliminating artificial differences with regard to distractor retrieval effects that were caused by the possible value range of these effects. Another post hoc power analysis showed that the power was again substantial (with a probability of $1 - \beta > .96$ to detect a medium-sized effect), which bolsters the interpretation of the null hypothesis with regard to the three-way interaction and supports the assumption that distractor-based binding and retrieval effects for movement meanings and motor responses were independent of each other. Another Bayes-Factor analysis on the three-way interaction term for the RT

³ Only sequences in which two different colors from the "same color pair" that were assigned to the same movement meaning were presented in the prime and probe trials entered into the repeated condition. This was done to eliminate effects of color retrieval (because of identical color repetition) from all analyses in Experiment 2. We provide results of the full analysis (including identical color repetitions) in the Appendix, which effectively revealed the same pattern of effects.

⁴ When comparing the Distractor Relation \times Movement Meaning Relation interaction between Experiments 1 and 2 (see Figure 2), it appears that this interaction was even more pronounced in Experiment 2. A post hoc joint analysis with experiment as additional factor confirmed this, $F(1, 97) = 5.23, p = .024, \eta_p^2 = .05$ (net $D \times M$ interaction effects per experiment: $D \times M_{Exp1} = 6$ ms and $D \times M_{Exp2} = 16$ ms, respectively; net interaction effects were computed as the difference of distractor repetition effects for movement meaning repetitions minus distractor repetition effects for movement meaning changes [$\Delta = (B-DR)_{\text{meaning repetition}} - (B-DR)_{\text{meaning changes}}$] separately for each experiment. Positive values indicate interaction effects that conform with expected effects because of distractor-based retrieval of semantic response codes (i.e., positive DR-Effects for probe trials with movement meaning repetition and negative DR-Effects for probe trials with movement meaning changes). Neither the effect of a distractor based retrieval of motor response codes ($D \times R$) nor the three-way interaction ($D \times M \times R$) revealed differences between the two experiments, both F s $< 1.5, p > .23$. Although this is clearly post hoc and speculative, a possible reason for why the $D \times M$ interaction might be more pronounced in Experiment 2 may be the fact that the experiment put more emphasis on a correct identification of the respective semantic movement direction because of the more difficult 4-to-2 mapping. It is, therefore, likely that participants paid more attention to the semantic dimension of each response and held semantic response codes more actively represented in memory, which would account for the stronger interaction effects in Experiment 2.

data in Experiment 2 yielded a Bayes-Factor of $BF_{01} = 3.13$. Although somewhat smaller than in Experiment 1, this indicates that the null hypothesis (nonexistence of a three-way interaction) was about three times more likely than the alternative hypothesis in Experiment 2, again providing positive evidence for the validity of the null hypothesis (Kass & Raftery, 1995).

General Discussion

Although episodic binding and retrieval of stimuli and responses reflects an established and robust finding in the literature (e.g., Denkinger & Koutstaal, 2009; Frings et al., 2007; Giesen & Rothermund, 2014a; Henson et al., 2014; Hommel, 1998; Logan, 1988; Rothermund et al., 2005), the particular representational format of the retrieved response in these event files remained a somewhat enigmatic and underresearched topic: The evidence that has been accumulated on this issue so far does not indicate an unambiguous answer to this question, with some studies supporting the view that semantic codes or response meanings are what is encoded in and retrieved from S-R episodes (Giesen et al., 2014; Giesen & Rothermund, 2014b; Logan, 1990; Rothermund et al., 2005), whereas others seem to indicate that responses are represented at the level of motor codes (Mayr & Buchner, 2010; Mayr et al., 2009). The present study sought to fill this gap by investigating both forms of response binding and retrieval independently and simultaneously within a single experiment, that is, under highly matched conditions. In two experiments, a sequential distractor repetition paradigm (Rothermund et al., 2005) was combined with an adapted approach/avoidance task (Eder & Rothermund, 2008; see also De Houwer et al., 2001; Markman & Brendl, 2005) that allowed us to manipulate distractor relation, motor response relation, and semantic response relation independently of each other. Results of both experiments support the view that distractor repetitions are bound to and retrieve both, semantic representations and motor codes of the previously executed prime response. More important, our findings suggest that both representational formats are encoded and retrieved independently of each other and in parallel.

Although numerically, distractor repetition effects produced (positive) facilitation as well as (negative) interference effects (see Figure 2), follow-up tests showed that only the former, but not the latter, were consistently different from zero. This asymmetry is not an uncommon finding in studies on distractor-based binding and retrieval effects and has been reported before (e.g., Frings & Rothermund, 2011; Frings et al., 2007; Horner, 2015; Rothermund et al., 2005). Two points however are noteworthy in this regard: First, the most central test for distractor-based binding and retrieval effects is the interaction term (i.e., the net effect of both facilitation and interference effects). More important, these were always significant for the effects of interest. Second, interpretation of simple distractor repetition effects within conditions is difficult because other processes might be at work in parallel that produce general facilitatory priming effects that might supersede interference effects in the response change conditions. For instance, it is possible that the irrelevant stimulus dimension (word meaning) was actively inhibited during the prime and that this inhibitory effect persisted until the probe. Such distractor inhibition is indicated by faster responses in distractor repetition versus baseline probes (Frings & Wühr, 2007; Neumann & DeSchepper, 1991)

and occurs independently of distractor-response binding processes (Giesen, Frings, & Rothermund, 2012). More important, however, facilitation because of distractor inhibition will add to (i.e., artificially enhance) facilitation effects in distractor repetition probes with meaning or motor response repetition, but will counteract (i.e., neutralize) interference effects in distractor repetition probes with meaning or motor response changes. Ultimately, this will lead to ordinal (rather than disordinal) interaction effects and can therefore account for the fact that only facilitation, but not interference effects were significant in the present experiments.

In the present study, evidence for an independent distractor-based retrieval of semantic and motor response codes of the former prime response was limited to probe RT data and did not produce a corresponding pattern of effects in the error data. Such dissociation between RT-based and error-based analyses is not unusual in studies of S-R binding and retrieval effects and may simply indicate that error rates are less reliable and thus less sensitive to detect distractor-based retrieval effects. Alternatively, it is conceivable that RTs and accuracy of responses are affected by different underlying processes (for a more detailed discussion of this topic, see Giesen & Rothermund, 2011). Although no significant distractor-based retrieval effects were found for either movement meanings or motor responses, the direction of distractor-based retrieval effects still was in line with the pattern that was found for the RT data: Distractor repetition effects were negative for conditions in which one or two response features changed, indicating retrieval of a mismatching response feature, whereas no such distractor-based interference effects were observed for the condition in which both response features were repeated. At least, this pattern of findings allows us to rule out that RT effects are because of speed-accuracy trade-offs.

Theoretical Implications

Purely motoric response codes. The present findings shed some light on the heterogeneous evidence reported in the literature concerning the level(s) of response representations in S-R episodes. That is, our findings suggest that semantic response codes as well as motor codes contribute to stimulus-based response retrieval effects whenever prime and probe trials share the same response modalities. In turn, when prime responses are characterized by an absence of a motoric response component (Giesen & Rothermund, 2014b; Giesen et al., 2014), S-R retrieval effects can only be because of retrieval of semantic response representations. In principle, the same holds true for designs in which the response modality switches between prime and probe trials (Rothermund et al., 2005; Experiment 2). What is presently lacking, however, is positive and unambiguous evidence for an independent effect of a retrieval of motor response codes in a situation in which the influence of abstract, semantic response codes is ruled out. Such an effect is notoriously difficult to investigate and find (see also Dennis & Perfect, 2013).

On the one hand, response meanings and specific motor responses are typically confounded in an experimental set-up. In such a situation, response retrieval effects cannot be unambiguously attributed to motoric representations and tests of an involvement of motor codes in retrieval have to rely on indirect evidence. For example, Mayr and Buchner (2010) showed that blocking the execution of motor responses (during the prime trials) eliminated

response retrieval effects. This finding suggests that motoric response execution is (at least sometimes) a necessary component of stimulus-response retrieval effects, but this evidence is (a) negative (i.e., it eliminates an effect and thus rests on a null finding, rather than producing a significant effect that positively indicates a specific retrieval of motor codes) and (b) indirect (i.e., blocking response execution might have eliminated not just the emergence of motor codes but might also have weakened or eliminated semantic response representations [despite the fact that conceptual processing of the prime stimuli was shown to remain intact in that experiment]).

On the other hand, typical experimental tasks use simple key presses as responses that are characterized by a high degree of similarity and overlap with regard to their motoric codes and signatures, whereas semantic response codings are what is typically emphasized in the task instructions. This often creates an asymmetric situation with regard to the distinctness and salience of semantic versus motor codes of responses that might disfavor motoric response representations, which is why semantic response representations typically dominate over or replace motor codes of responses.

In this respect, the joystick task that was used in the present experiments has the advantage of providing fairly distinct motor responses that involve an activation of various larger muscle areas, leading to motor responses that are characterized by distinct activation patterns and motoric signatures. Establishing clearly distinguishable motor responses can be seen as being an important prerequisite for a fair and meaningful test of potential S-R bindings at the level of motor codes. Another advantage of the present study is that it allows us to provide positive and independent tests of the two types of response retrieval effects within one and the same study with exactly identical procedural parameters.

Still, a note of caution is appropriate with regard to the interpretation of the interaction between distractor repetitions and the relation between motor response codes.⁵ Although we can rule out that semantic codes were confounded with motor codes in our study, we cannot fully eliminate the possibility that participants spontaneously invented semantic labels for the motor responses (e.g., “upwards” and “downwards”) that might have mediated the interaction effects that we observed. This problem is notoriously hard to control, because one cannot fully control what strategies and labels are used during a task. Although we think it unlikely that semantic codes were invented and used to label the motor responses in addition to the semantic labels that were instructed for the task (i.e., “towards” and “away”), leading to dual semantic coding, we cannot rule out this possibility. Further investigations into this question are necessary to more analyze the role of spontaneous semantic coding in S-R binding and retrieval. A promising way to more systematically address this question could consist in a comparison of situations in which spontaneous semantic codings are more or less likely (e.g., using motor responses for which semantic labels are either highly salient or awkward and unfamiliar).

Multiple response coding. An important theoretical implication of our findings is that response coding in S-R episodes takes place on multiple representational levels (Dennis & Perfect, 2013; Horner & Henson, 2009; Moutsopoulou & Waszak, 2013; Moutsopoulou et al., 2015). Note, however, that whereas previous studies were concerned with (long-lag) repetition priming using a

delayed study-test design, our study is the first to show that (a) multilevel response coding takes place in transient (i.e., trial-to-trial) designs as well and that (b) these multiple response codes can be accessed and retrieved in parallel based on the repetition of irrelevant stimulus features alone.

The insight that not only (distractor) stimuli, but also responses are coded on multiple levels within an S-R episode or event file bears some important implications for the more general framework of the “Theory of Event Coding” (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001) as well. According to the TEC, stimuli and responses are mentally represented as compounds of feature codes; event files, in turn, consist of a grid of multiple binary and independent bindings between these feature codes. The fact that we observed not only the Distractor Relation \times Movement Meaning Relation and Distractor Relation \times Motor Response Relation interactions, but also an interaction of semantic and motor response codes in combination with the absence of a higher-order interaction is, therefore, in agreement with the very principles of event file integration (see also Giesen & Rothermund, 2014a; Hommel, 1998). These interaction effects provide evidence for binary bindings between distractors and semantic response codes, distractors and motor response codes, and also bindings between semantic and motor response codes. Consistent with the reasoning of the TEC, these local bindings emerged independently of each other and were retrieved in parallel, whereas more complex bindings involving more than two features did not obtain; in particular, stimuli were independently associated with semantic and motoric response codes, but not with combinations of these codes. Initially, stimulus and response feature codes were considered to be abstract in nature (exemplifying the *common-coding* principle). However, the present findings as well as existing evidence (Frings et al., 2013; Horner & Henson, 2011) suggest that in addition to abstract feature codes (that reflect the concept or identity of a stimulus or the meaning or goal of a response), more specific (i.e., perceptual or motor) codes constitute integral parts of the processing episode as well.

Implications for theories of task switching. Our current research is closely related to the task switching literature. In fact, our study can be described as a task switching paradigm.⁶ From this perspective, the word colors (blue vs. orange) denote different task rules that translate the two positions of the manikin into two response categories (e.g., blue: top \rightarrow upward, bottom \rightarrow downward; orange: top \rightarrow downward, bottom \rightarrow upward). Under this description, the semantic response relation factor becomes the task switching factor. Although such a paradigm is atypical for most of the task switching literature (e.g., the same stimulus features are translated into the same response categories in both tasks, but according to opposite assignment rules), it nevertheless fulfills the basic features of a task switching experiment. Further corroborating this description, the two way interaction between semantic and motoric response relations that we observed in our study then represents a replication of the standard finding of the task switching

⁵ We owe thanks to an anonymous reviewer who pointed out this problem.

⁶ We are indebted to an anonymous reviewer for pointing this out. See also Footnote 1.

literature, that is, the interaction between task switching and response repetition (e.g., Altmann, 2011).

to account for certain phenomena in the task switching and S-R binding literature (e.g., episodic retrieval and association theories; Altmann, 2011; Brown, Reynolds, & Braver, 2007; Meiran, 2000), so it should come as no surprise that some of these accounts that figure prominently in the task switching literature can also be used to explain the current findings. To be able to explain the present findings, however, these accounts have to be expanded by incorporating the role of specific stimuli and identical stimulus repetitions, a dimension that is typically ignored or excluded in the task switching literature. Episodic retrieval accounts will then explain the basic finding of an interaction between stimulus repetitions and response repetitions/changes in terms of more binary matches (and less mismatches) in case of conditions in which stimuli and responses both repeat or change compared with conditions in which either the stimulus repeats while the response changes or vice versa (cf. Altmann, 2011). To assimilate our findings, associative learning accounts have to assume associative links between specific stimuli and response categories. Having responded to a specific stimulus with a certain response can then be assumed to establish or strengthen the association between this stimulus and the respective response category so that re-encountering the same stimulus later leads to benefits if the same response is to be executed again, but produces costs if a different response has to be executed. Going beyond previous findings in the task switching and S-R binding literatures, the results of our present study also indicate that semantic as well as motoric representations of responses should be taken into account when calculating matches and mismatches for task switch and task repetition sequences (episodic retrieval account), but also when reflecting on what constitutes the same or a different response on a later occasion (associative learning account). Although effects of S-R binding and retrieval indicated by an interaction of stimulus and response features do not contradict other accounts of task switch effects (e.g., reconfiguration account, Kleinsorge & Heuer, 1999; priming and inhibition account, Druey, 2014; Hübner & Druey, 2006), they at least cannot easily be accommodated by these accounts since they do not refer to possible influences of stimulus repetitions.

Implications for motivational theories of approach/avoidance responses. On a different note, our findings also have important implications for motivational theories of approach and avoidance (Eder, Elliot, & Harmon-Jones, 2013). The finding of a simultaneous (dual) coding of movement meanings (toward vs. away) and motor responses (push vs. pull) within a paradigm that is commonly denoted as an “approach/avoidance task” should not be read to imply that both levels of response coding have these motivational implications. To the contrary, the fact that motor codes are processed independently and can easily be detached from semantically meaningful motivational representations in a completely orthogonal design is hard to reconcile with “embodiment” accounts of approach/avoidance behavior that argue for strong connections between these motivational tendencies and specific motor responses (e.g., Chen & Bargh, 1999; Kozlik, Neumann, & Lozo, 2015; Neumann, Lozo, & Kunde, 2014; Solarz, 1960). Instead, the finding that distractor-based retrieval effects for the two kinds

of codes did not interact in our study rather provides further support for the view that motivational implications are exclusively tied to abstract, semantic levels of response representations that refer to the goals and motivational implications of certain actions and behaviors (Eder & Rothermund, 2008, 2013; Markman & Brendl, 2005).

Conclusion

The present results show that repeating one element of an S-R episode (even if that element is irrelevant for the task at hand) will trigger retrieval of semantic as well as motor response codes. In our view, the integration of multiple response representations into transient processing episodes is adaptive, because it provides the basis for flexible and appropriate behavior in the future: In particular, an integration of semantic response codes (that do not specify any particular action) provides our cognitive system with the flexibility to select the most appropriate action whenever the semantic response code is retrieved in the future. The integration of motor codes, in turn, is of merit in those contexts in which stimuli repeatedly co-occur with the same motor action. Stimulus-based retrieval of motor codes then paves the way for processes of behavior automatization.

References

- Altmann, E. M. (2011). Testing probability matching and episodic retrieval accounts of response repetition effects in task switching. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 37, 935–951. <http://dx.doi.org/10.1037/a0022931>
- Brown, J. W., Reynolds, J. R., & Braver, T. S. (2007). A computational model of fractionated conflict-control mechanisms in task-switching. *Cognitive Psychology*, 55, 37–85. <http://dx.doi.org/10.1016/j.cogpsych.2006.09.005>
- Chen, M., & Bargh, J. A. (1999). Consequences of automatic evaluation: Immediate behavioral predispositions to approach or avoid the stimulus. *Personality and Social Psychology Bulletin*, 25, 215–224. <http://dx.doi.org/10.1177/0146167299025002007>
- De Houwer, J., Crombez, G., Baeyens, F., & Hermans, D. (2001). On the generality of the affective Simon effect. *Cognition and Emotion*, 15, 189–206. <http://dx.doi.org/10.1080/0269993004200051>
- Denkinger, B., & Koutstaal, W. (2009). Perceive-decide-act, perceive-decide-act: How abstract is repetition-related decision learning? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 742–756. <http://dx.doi.org/10.1037/a0015263>
- Dennis, I., Carder, H., & Perfect, T. J. (2010). Sizing up the associative account of repetition priming. *Psychological Research*, 74, 35–49. <http://dx.doi.org/10.1007/s00426-008-0224-9>
- Dennis, I., & Perfect, T. J. (2013). Do stimulus—Action associations contribute to repetition priming? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 39, 85–95. <http://dx.doi.org/10.1037/a0028479>
- Dennis, I., & Schmidt, K. (2003). Associative processes in repetition priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 532–538. <http://dx.doi.org/10.1037/0278-7393.29.4.532>
- Druey, M. D. (2014). Stimulus-category and response-repetition effects in task switching: An evaluation of four explanations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40, 125–146. <http://dx.doi.org/10.1037/a0033868>
- Eder, A. B., Elliot, A. J., & Harmon-Jones, E. (2013). Approach and avoidance motivation: Issues and advances. *Emotion Review*, 5, 227–229. <http://dx.doi.org/10.1177/1754073913477990>

- Eder, A. B., & Rothermund, K. (2008). When do motor behaviors (mis)-match affective stimuli? An evaluative coding view of approach and avoidance reactions. *Journal of Experimental Psychology: General*, 137, 262–281. <http://dx.doi.org/10.1037/0096-3445.137.2.262>
- Eder, A. B., & Rothermund, K. (2013). Emotional action: An ideomotor model. In C. Mohiyeddini, M. Eysenck, & S. Bauer (Eds.), *Psychology of emotions, motivations and actions. Handbook of psychology of emotions* (Vol. 1): Recent theoretical perspectives and novel empirical findings (pp. 11–38). Hauppauge, NY: Nova Science Publishers.
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191. <http://dx.doi.org/10.3758/BF03193146>
- Fletcher, B., & Rabbitt, P. M. (1978). The changing pattern of perceptual analytic strategies and response selection with practice in a two-choice reaction time task. *The Quarterly Journal of Experimental Psychology*, 30, 417–427. <http://dx.doi.org/10.1080/00335557843000025>
- Frings, C., Moeller, B., & Rothermund, K. (2013). Retrieval of event files can be conceptually mediated. *Attention, Perception, & Psychophysics*, 75, 700–709. <http://dx.doi.org/10.3758/s13414-013-0431-3>
- Frings, C., & Rothermund, K. (2011). To be or not to be included in an event file: Integration and retrieval of distractors in stimulus-response episodes is influenced by perceptual grouping. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 37, 1209–1227. <http://dx.doi.org/10.1037/a0023915>
- Frings, C., Rothermund, K., & Wentura, D. (2007). Distractor repetitions retrieve previous responses to targets. *The Quarterly Journal of Experimental Psychology*, 60, 1367–1377. <http://dx.doi.org/10.1080/17470210600955645>
- Frings, C., & Wühr, P. (2007). On distractor-repetition benefits in the negative-priming paradigm. *Visual Cognition*, 15, 166–178. <http://dx.doi.org/10.1080/13506280500475264>
- Gade, M., & Koch, I. (2007). The influence of overlapping response sets on task inhibition. *Memory & Cognition*, 35, 603–609. <http://dx.doi.org/10.3758/BF03193298>
- Giesen, C., Frings, C., & Rothermund, K. (2012). Differences in the strength of distractor inhibition do not affect distractor-response bindings. *Memory & Cognition*, 40, 373–387. <http://dx.doi.org/10.3758/s13421-011-0157-1>
- Giesen, C., Herrmann, J., & Rothermund, K. (2014). Copying competitors? Interdependency modulates stimulus-based retrieval of observed responses. *Journal of Experimental Psychology: Human Perception and Performance*, 40, 1978–1991. <http://dx.doi.org/10.1037/a0037614>
- Giesen, C., & Rothermund, K. (2011). Affective matching moderates S-R binding. *Cognition and Emotion*, 25, 342–350. <http://dx.doi.org/10.1080/02699931.2010.482765>
- Giesen, C., & Rothermund, K. (2014a). Distractor repetitions retrieve previous responses and previous targets: Experimental dissociations of distractor-response and distractor-target bindings. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40, 645–659. <http://dx.doi.org/10.1037/a0035278>
- Giesen, C., & Rothermund, K. (2014b). You better stop! Binding “stop” tags to irrelevant stimulus features. *The Quarterly Journal of Experimental Psychology*, 67, 809–832. <http://dx.doi.org/10.1080/17470218.2013.834372>
- Giesen, C., & Rothermund, K. (2015). Adapting to stimulus-response contingencies without noticing them. *Journal of Experimental Psychology: Human Perception and Performance*, 41, 1475–1481. <http://dx.doi.org/10.1037/xhp0000122>
- Henson, R. N., Eckstein, D., Waszak, F., Frings, C., & Horner, A. J. (2014). Stimulus-response bindings in priming. *Trends in Cognitive Sciences*, 18, 376–384. <http://dx.doi.org/10.1016/j.tics.2014.03.004>
- Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition*, 5, 183–216. <http://dx.doi.org/10.1080/713756773>
- Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24, 849–878. <http://dx.doi.org/10.1017/S0140525X01000103>
- Horner, A. J. (2015). Retrieval of bindings between task-irrelevant stimuli and responses can facilitate behaviour under conditions of high response certainty. [Advance online publication]. *The Quarterly Journal of Experimental Psychology*, 1–13. <http://dx.doi.org/10.1080/17470218.2015.1061567>
- Horner, A. J., & Henson, R. N. (2009). Bindings between stimuli and multiple response codes dominate long-lag repetition priming in speeded classification tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 757–779. <http://dx.doi.org/10.1037/a0015262>
- Horner, A. J., & Henson, R. N. (2011). Stimulus-response bindings code both abstract and specific representations of stimuli: Evidence from a classification priming design that reverses multiple levels of response representation. *Memory & Cognition*, 39, 1457–1471. <http://dx.doi.org/10.3758/s13421-011-0118-8>
- Hübner, R., & Druey, M. D. (2006). Response execution, selection, or activation: What is sufficient for response-related repetition effects under task shifting? *Psychological Research*, 70, 245–261. <http://dx.doi.org/10.1007/s00426-005-0219-8>
- Kass, R. E., & Raftery, A. E. (1995). Bayes Factors. *Journal of the American Statistical Association*, 90, 773–795. <http://dx.doi.org/10.1080/01621459.1995.10476572>
- Kleinsorge, T., & Heuer, H. (1999). Hierarchical switching in a multi-dimensional task space. *Psychological Research*, 62, 300–312. <http://dx.doi.org/10.1007/s004260050060>
- Kozlik, J., Neumann, R., & Lozo, L. (2015). Contrasting motivational orientation and evaluative coding accounts: On the need to differentiate the effectors of approach/avoidance responses. *Frontiers in Psychology*, 6, 563. <http://dx.doi.org/10.3389/fpsyg.2015.00563>
- Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, 95, 492–527. <http://dx.doi.org/10.1037/0033-295X.95.4.492>
- Logan, G. D. (1990). Repetition priming and automaticity: Common underlying mechanisms? *Cognitive Psychology*, 22, 1–35. [http://dx.doi.org/10.1016/0010-0285\(90\)90002-L](http://dx.doi.org/10.1016/0010-0285(90)90002-L)
- Logan, G. D., & Etherton, J. L. (1994). What is learned during automatization? The role of attention in constructing an instance. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 1022–1050. <http://dx.doi.org/10.1037/0278-7393.20.5.1022>
- Markman, A. B., & Brendl, C. M. (2005). Constraining theories of embodied cognition. *Psychological Science*, 16, 6–10. <http://dx.doi.org/10.1111/j.0956-7976.2005.00772.x>
- Mayr, S., & Buchner, A. (2006). Evidence for episodic retrieval of inadequate prime responses in auditory negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, 32, 932–943. <http://dx.doi.org/10.1037/0096-1523.32.4.932>
- Mayr, S., & Buchner, A. (2010). Auditory negative priming endures response modality change; prime response retrieval does not. *The Quarterly Journal of Experimental Psychology*, 63, 653–665. <http://dx.doi.org/10.1080/17470210903067643>
- Mayr, S., Buchner, A., & Dentale, S. (2009). Prime retrieval of motor responses in negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, 35, 408–423. <http://dx.doi.org/10.1037/0096-1523.35.2.408>
- Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research*, 63, 234–249. <http://dx.doi.org/10.1007/s004269900004>

- Moeller, B., & Frings, C. (2011). Remember the touch: Tactile distractors retrieve previous responses to targets. *Experimental Brain Research*, 214, 121–130. <http://dx.doi.org/10.1007/s00221-011-2814-9>
- Moeller, B., Hommel, B., & Frings, C. (2015). From hands to feet: Abstract response representations in distractor-response bindings. *Acta Psychologica*, 159, 69–75. <http://dx.doi.org/10.1016/j.actpsy.2015.05.012>
- Moeller, B., Rothermund, K., & Frings, C. (2012). Integrating the irrelevant sound. *Experimental Psychology*, 59, 258–264. <http://dx.doi.org/10.1027/1618-3169/a000151>
- Moutsopoulou, K., & Waszak, F. (2013). Durability of classification and action learning: Differences revealed using ex-Gaussian distribution analysis. *Experimental Brain Research*, 226, 373–382. <http://dx.doi.org/10.1007/s00221-013-3445-0>
- Moutsopoulou, K., Yang, Q., Desantis, A., & Waszak, F. (2015). Stimulus-classification and stimulus-action associations: Effects of repetition learning and durability. *The Quarterly Journal of Experimental Psychology*, 68, 1744–1757.
- Nett, N., Bröder, A., & Frings, C. (2015). When irrelevance matters: Stimulus-response binding in decision making under uncertainty. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41, 1831–1848. <http://dx.doi.org/10.1037/xlm0000109>
- Neumann, E., & DeSchepper, B. G. (1991). Costs and benefits of target activation and distractor inhibition in selective attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 17, 1136–1145. <http://dx.doi.org/10.1037/0278-7393.17.6.1136>
- Neumann, R., Lozo, L., & Kunde, W. (2014). Not all behaviors are controlled in the same way: Different mechanisms underlie manual and facial approach and avoidance responses. *Journal of Experimental Psychology: General*, 143, 1–8. <http://dx.doi.org/10.1037/a0032259>
- Rothermund, K., Wentura, D., & De Houwer, J. (2005). Retrieval of incidental stimulus-response associations as a source of negative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31, 482–495. <http://dx.doi.org/10.1037/0278-7393.31.3.482>
- Schuch, S., & Koch, I. (2004). The costs of changing the representation of action: Response repetition and response-response compatibility in dual tasks. *Journal of Experimental Psychology: Human Perception and Performance*, 30, 566–582. <http://dx.doi.org/10.1037/0096-1523.30.3.566>
- Solarz, A. K. (1960). Latency of instrumental responses as a function of compatibility with the meaning of eliciting verbal signs. *Journal of Experimental Psychology*, 59, 239–245. <http://dx.doi.org/10.1037/h0047274>
- Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison Wesley.

(Appendix follows)

Appendix

Results of 2 (Distractor Relation: Repetition vs. Baseline) \times 3 (Movement Meaning Relation: Meaning Repetition/ID vs. Meaning Repetition/SCP vs. Meaning Change/DCP) \times 2 (Motoric Response Relation: Repetition vs. Change) Repeated Measures ANOVA for the Full Factorial Design of Experiment 2 for Mean Probe RT and Errors, Respectively

Variables	RT				% Errors			
	<i>df</i>	<i>MSE</i>	<i>F</i>	η_p^2	<i>df</i>	<i>MSE</i>	<i>F</i>	η_p^2
Distractor relation (D)	1,49	263.35	8.53**	.15	1,49	.001	2.21	.04
Movement meaning relation (M)	2,48	868.24	286.27***	.92	2,48	.001	5.74**	.19
Contrast 1: ID vs. DCP	1,49	2176.38	571.46***	.92	1,49	.002	9.01**	.16
Contrast 2: SCP vs. DCP	1,49	1509.73	129.23***	.73	1,49	.003	.01	.00
Motor response relation (R)	1,49	1483.42	99.34***	.67	1,49	.006	2.93	.06
D \times M	2,48	303.14	10.55***	.31	2,48	.001	.02	.00
Contrast 1: ID vs. DCP	1,49	323.15	5.845*	.11	1,49	.002	.01	.00
Contrast 2: SCP vs. DCP	1,49	680.69	19.07***	.28	1,49	.002	.05	.00
D \times R	1,49	319.97	13.81**	.22	1,49	.001	.94	.02
M \times R	2,48	887.22	119.76***	.83	2,48	.001	31.97***	.57
Contrast 1: ID vs. DCP	1,49	2190.55	236.15***	.83	1,49	.004	60.60***	.55
Contrast 2: SCP vs. DCP	1,49	1918.03	77.42***	.61	1,49	.002	46.91***	.49
D \times M \times R	2,48	345.60	1.21	.05	2,48	.001	.33	.01
Contrast 1: ID vs. DCP	1,49	542.32	1.51	.03	1,49	.002	.66	.01
Contrast 2: SCP vs. DCP	1,49	634.44	1.56	.03	1,49	.001	.11	.00

Note. To disentangle effects of identical color repetitions and movement meaning repetitions, the movement meaning relation factor was decomposed into two a priori orthogonal contrasts (contrast 1: meaning repetition/ID vs. meaning change/DCP; contrast 2: meaning repetition/SCP vs. meaning change/DCP). The first contrast corresponds to the factorial design of Experiment 1 and, therefore, allows for a direct test of replicating its results (which was the case for RT, because the D \times M and M \times R two-way interactions were significant for this contrast whereas the three-way D \times M \times R interaction was not). The second contrast corresponds to the results of Experiment 2 presented in the main text. ID = identical color repetition; SCP = same color pair; DCP = different color pair; ANOVA = analysis of variance.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Received September 21, 2015
Revision received January 15, 2016
Accepted January 24, 2016 ■