On the durability of bindings between responses and response-irrelevant stimuli

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ABSTRACT

Previous research suggests that bindings between *irrelevant* stimuli and responses rapidly decay over time, which is a marked difference to bindings between relevant stimuli and responses. While the former bindings decay within two seconds after integration, the latter ones easily survive time periods of several minutes after only one encounter. Yet, assuming that bindings between irrelevant stimuli and responses are just 'weaker' as compared to bindings between relevant stimuli and responses, we analyzed bindings between response-irrelevant stimuli and responses under what we call optimal conditions. Response-irrelevant stimuli were repeated five times with the same response (albeit always with different targets), they were presented as fixation markers, and they preceded the targets for several milliseconds. Under these conditions, bindings between irrelevant stimuli and responses survived about one and a half minutes. The fast decay of single encounters between response-irrelevant stimuli and responses might in fact reflect a protective mechanism that prevents the establishment of incompatible behavioral routines.

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Humans easily form arbitrary associations between stimuli and the responses they make in the presence of those stimuli. Such stimulus–response (S–R) bindings, when retrieved, affect the way that people respond to the same, or related, stimuli (Henson, Eckstein, Waszak, Frings, & Horner, 2014). In many cases where stimuli are encountered repeatedly, it is adaptive to form a direct association between the stimulus and the (successful) response. The first appearance of S–R associations can be observed immediately after the first response to a new stimulus and it has been proposed that each encounter of a stimulus is encoded in an episodic memory trace, called an *instance* (Logan, 1988, 1990) or *event file* (Hommel, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001),that includes action and stimulus features. With the accumulation of instances of the same S–R association, fast memory based retrieval of earlier actions can replace the algorithmic processing of a response that is required when the stimulus is first encountered. A considerable amount of evidence exists that indicates short-term stimulus–response binding after a single encounter as well as the formation of long-term associations between stimuli and responses due to repeated encounters of similar events (e.g., Boronat & Logan, 1997; Hommel & Colzato, 2004, 2009; Horner & Henson, 2009; Lassaline & Logan, 1993; Logan, Taylor, & Etherton, 1996, 1999; Logan, 1992).

To understand the factors influencing the readiness with which long-term associations are formed, it is important to consider processes at work during event file formation. Indeed, several mechanisms have been identified that may modulate the encoding and retrieval of S–R associations. For example, event files that trigger erroneous responses are easily detected by our cognitive system (Wiswede, Rothermund, & Frings, 2013). In addition, event files that received negative feedback have been shown to be deleted from memory (e.g., Waszak & Pholulamdeth, 2009).

Importantly, it has been shown that even task irrelevant stimuli can become temporarily integrated with responses in a single encounter and trigger response retrieval on the next trial (Rothermund, Wentura, & De Houwer, 2005; see also, Frings, Rothermund, & Wentura, 2007). That is, stimuli that are not mapped to a response or even interfere with responding to the target can be integrated and later on retrieve the response. Although bindings of distractor- and response features are generally similar to bindings regarding target features (Hommel, 2004, 2005; Moeller, Frings, & Pfister, submitted for publication), one marked difference apparently lies at the duration of these immediate associations.

Particularly, former studies indicate that bindings between response irrelevant stimuli and responses are rather short lived and it is still unclear how such bindings evolve and eventually transfer into behavioral routines that can last longer than up to the next trial in a prime-probe sequence. In five experiments Horner (2010) found no evidence for longer lasting S–R bindings of irrelevant stimuli using a repetition priming

paradigm that otherwise yielded clear S–R bindings for relevant stimuli over longer lags (Horner & Henson, 2009, 2011). Frings (2011) analyzed S–R bindings for distractor stimuli in a prime-probe paradigm and varied the response–stimulus-interval between primes and probes (500 ms vs. 2000 ms). The results suggested that S–R bindings lasted from prime to probe for 500 ms intervals, but had already vanished at the time of probe responding if 2000 ms had elapsed since prime response execution. Note that Frings and Rothermund (2011) observed intact S–R bindings of irrelevant stimuli with an intervening trial (during a time shorter than 2000 ms) between the prime and the probe (Experiment 2b). Thus, it is reasonable to assume that the time elapsed after response execution and not possible intervening events during the 2000 ms were the deciding factor for the modulation.

These findings stand in clear contrast to S–R bindings of relevant stimuli and responses. It has repeatedly been reported that retrieval of S–R bindings can occur across longer lags of several seconds or minutes – even after a single encounter of relevant stimuli and responses (Denkinger & Koutstaal, 2009; Dennis & Schmidt, 2003; Dobbins, Schnyer, Verfaellie, & Schacter, 2004; Herwig & Waszak, 2012; Hommel & Colzato, 2004; Horner & Henson, 2009, 2011). One possibility is that bindings initially occur between all stimuli, relevant or irrelevant, in a short-lived 'event-file' (in the sense of Hommel, 1998, 2004), but only the bindings between responses and response-relevant stimuli have the potential to survive for longer periods of time (see Hommel, 1998, for an analog argument).

Yet, considering the ubiquity and flexibility of S–R bindings across so many different types of tasks and stimuli (Henson et al., 2014), we argue that even irrelevant S–R bindings can transfer into longer lasting behavior. However, in contrast to relevant stimuli the cognitive system might need 'more evidence' for this transfer than just a single pairing of a response-irrelevant stimulus and a response. In particular, in most previous studies looking into bindings between irrelevant stimuli and responses, the irrelevant stimuli were combined with different responses from trial to trial — often they were even orthogonally varied with all responses in that particular experiment. In addition, in many experiments they interfered with responding to the targets because the irrelevant stimuli were actually distractors that were mapped to incompatible responses. Naturally, one might not expect long-term associations between irrelevant stimuli and responses under these conditions.

Here we argue that it is principally possible to observe longer lasting bindings between non-target stimuli (i.e. stimuli that are not mapped to a response at all and can hence be labeled response-irrelevant) and responses. Therefore we tested for longer lasting S–R bindings between response-irrelevant stimuli and responses albeit in arguably optimal conditions (see Horner, 2010). In particular, we presented the response-irrelevant stimuli at fixation (that is, irrelevant stimuli were the fixation markers), we repeated irrelevant stimuli multiple times with the same response; thus, in contrast to previous experiments the responses and irrelevant stimuli were not orthogonally varied but instead they were completely dependent. Yet, each repetition of a response and fixation marker occurred with a different relevant stimulus to which the response was given, so that any bindings between the target and the fixation marker can be excluded (Giesen & Rothermund, 2014). Finally we presented the response-irrelevant stimulus before the onset of the relevant stimuli. If S–R bindings between irrelevant stimuli and responses transfer into longer lasting behavioral routines under these conditions, this would speak for a general binding mechanism that can exploit contingencies in the environment even between irrelevant stimuli and responses.

1. Experiment 1

In Experiment 1 participants judged on each trial whether the presented object (i.e. the relevant flanker stimulus) was larger or smaller than a shoebox. In the first five blocks each fixation marker appeared once with a different relevant flanker stimulus in each block, albeit

always requiring the same response. After five blocks participants went through a distracter task that lasted about two minutes before a test block started in which new and old fixation markers were again presented. Half of the old fixation markers were presented with compatible responses while the other half was presented with incompatible responses. All relevant flanker stimuli were novel at test. If S–R binding effects are present, we would expect to see faster RTs in compatible relative to incompatible trials.

1.1. Method

1.1.1. Participants

Forty-five students (27 females) from the University of Trier took part in the experiment. One participant failed to report her age. The median age of the remaining sample was 25 years with a range from 18 to 32 years. All participants took part in exchange for partial course credit. One participant was replaced because of a retention interval that was classified as a far-out (03:53 min; Tukey, 1977), a second participant was replaced because of an extreme learning index in the unexpected direction (longer response times in training blocks 4 and 5 than in blocks 1 and 2), and a third participant was replaced because none of the probe responses in the compatible condition qualified for analysis (due to a combination of prime errors, probe errors and very slow response times).

1.1.2. Design

The design for the variable of main interest comprised a single within-subjects factor, namely distractor-response compatibility (compatible vs. neutral vs. incompatible). In addition, the training phase followed a one-factorial design with the within-subjects factor training block (block 1 vs. block 2 vs. block 3 vs. block 4 vs. block 5). The power to detect medium-sized effects in binary comparisons of two levels of compatibility factor (i.e., $d = .5$; $\alpha = .05$, one-tailed) was $1 - \beta = .95$ (GPower 3; Faul, Erdfelder, Lang, & Buchner, 2007).

1.1.3. Materials

The experiment was conducted using the E-prime software (E-prime 2.0). Instructions and stimuli were shown on a white background on a standard CRT screen. A total of 140 target stimuli were colored pictures of various objects that had a horizontal visual angle of 0.5° to 5.3° and a vertical visual angle of 0.2° to 3.6°(as used in Horner & Henson, 2009). Response-irrelevant stimuli were 20 different letters, one digit numbers and punctuation characters, presented in black. All response-irrelevant stimuli subtended a horizontal visual angle of 0.2° to 1.1° and a vertical visual angle of 0.9° to 1.0°. Targets and distractors were presented within the black outline of a rectangle that subtended a horizontal visual angle of 12.4° and a vertical visual angle of 4.3°. Viewing distance was approximately 60 cm.

1.1.4. Procedure

Participants were tested individually in soundproof chambers. Instructions were given on the screen and summarized by the experimenter. Participants were instructed to place their left index finger on the C key and their right index finger on the M key of a standard computer keyboard. Their task throughout was to categorize the target pictures. On each display an identical picture was presented on the left and right side of the fixation marker (i.e. the response-irrelevant stimulus). During the training blocks, participants always imagined the depicted item in its natural size and decided whether it is larger (right response) or smaller (left response) than a shoebox. During the test block they decided whether it is larger or smaller than a waste bin (i.e., a larger comparator object as to avoid transfer effects). Stimuli were surrounded by a rectangular outline and this entire setup appeared vertically central on the screen and shifted randomly on the horizontal axis for up to 2.3° to each side off the center. The fixation marker always preceded the targets and rectangle by 100 ms and participants were instructed to always

fixate on this letter or digit as soon as it appeared. In addition, participants were instructed to react as quickly and as accurately as possible.

Each trial included the following events (see Fig. 1). The intertrial interval had a duration of 1500 ms. Then the distractor appeared at a horizontally random position, 100 ms before the target pictures appeared flanking the fixation marker. All stimuli remained on the screen until participants responded. The same 20 response-irrelevant stimuli appeared in each training phase in a random order, while target items were never repeated. During the training phases, half of the response-irrelevant stimuli always appeared together with targets that required a right/larger response, and the other half appeared together with targets requiring a left/smaller response. During the test block, half of these response-irrelevant stimuli were presented together with targets requiring the same response as associated with the response-irrelevant stimulus during training (compatible trials, the same number of right and left responses) and the other half appeared together with response-irrelevant stimuli requiring the opposite response (incompatible trials, the same number of right and left responses). In addition, 20 new response-irrelevant stimuli were presented during the test block − 10 together with a left and the other 10 together with a right response (neutral trials). These new response-irrelevant stimuli provide a baseline measure with which to measure possible facilitation affects for compatible trials and interference effects for incompatible trials.

Each participant worked through five training blocks of 20 trials each and through one test block including 40 trials. For each participant, four sets of distractor stimuli were assigned to compatible, incompatible, neutral right, and neutral left trials. This assignment was rotated between participants according to a Latin square. Five target lists were rotated in an incomplete Latin square to be used as targets in the five training phases. During the test phase, targets in compatible, incompatible, neutral left, and neutral right trials were (with the restriction of fitting the current trial type) randomly drawn from two target pools that consisted of 20 targets each that required left and right responses, respectively. Before the first training block started, participants were familiarized with the task and practiced it for eight trials. Neither targets nor response-irrelevant stimuli of these practice trials were used in the training or test blocks of the experiment.

In the retention phase participants had thrice to count black dots presented on a white display. The average retention time between the last practice block and the start of the test block was $M = 1{:}33$ min ($SD = 0{:}29$ min).

1.2. Results

For the analysis of response times (RTs), we considered only those trials with correct responses to the targets in the test phase (error rate during test was 3.9%). RTs that were more than 1.5 interquartile ranges above the third quartile of the RT distribution of the sample (Tukey, 1977), and those that were shorter than 200 ms, as well as all test trials presenting response-irrelevant stimuli that had at least once appeared in an incorrectly answered training trial were excluded from the main analysis. Due to these constraints, 23.4% of all trials were discarded (note that the same pattern was found for a less strict prime correct criterion). Mean RTs and error rates are shown in Table 1.

1.2.1. Training phase

Mean response times in the five training blocks were entered into a one dimensional ANOVA. The response times differed significantly over the five training blocks, $F(4,41) = 3.57$, $p = .014$, $\eta_p^2 = .26$, indicating that RTs decreased over time. In fact, the linear trend just missed significance, $F(1,44) = 4.00$, $p = .052$, $\eta_p^2 = .21$. In the same analysis on training error rates none of the effects was significant, $Fs < 2.1$, $ps > .15$.

1.2.2. Test phase

In a repeated measures ANOVA with the single factor response-irrelevant stimulus–response compatibility (compatible vs. neutral vs. incompatible), the main effect of compatibility was not significant, $F(2,43) = 1.72$, $p = .192$, $\eta_p^2 = .07$. However, in support of our primary hypothesis, we saw significantly faster RTs for compatible relative to incompatible trials, $t(44) = 1.83$, $p = .037$, $d = .27$ (one tailed). Response times to trials with new (i.e., neutral) response-irrelevant stimuli were significantly faster than incompatible, $t(44) = 1.72$, $p = .047$, $d = .26$ (one tailed), and numerically (but not significantly) slower than compatible trials $t(44) = 0.72$, $p = .476$, $d = .12$. The same analyses for error rates did not reveal any significant results, all $Fs < 1$, $ps > .3$.
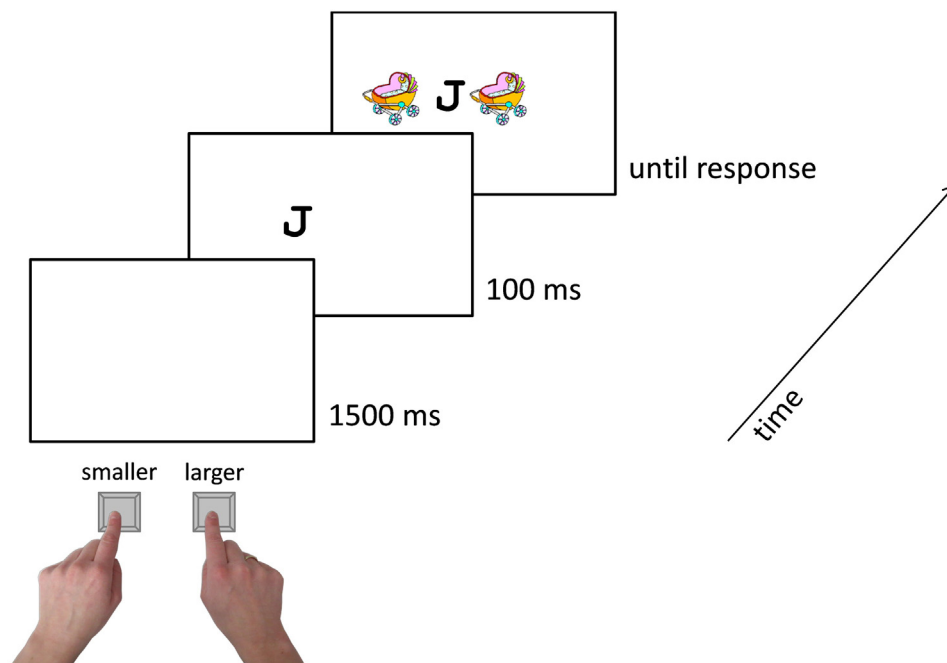

Fig. 1. Sequence of one trial in either training or test block in the experiments. Participants always categorized the size of the depicted item. Stimuli are not drawn to scale.

Table 1
Mean response times and error rates in Experiment 1.

	Training					Test		
	Block 1	Block 2	Block 3	Block 4	Block 5	Compatible	Neutral	Incompatible
Response times (ms)	810	765	755	749	778	748	756	783
Error rates (%)	6.4	5.7	5.8	6.8	7.7	5.5	4.2	5.1

1.3. Discussion

Experiment 1 revealed tentative evidence for longer lasting S–R bindings. In fact, participants were significantly slower (albeit only at the one-tailed level) when in the test block the response-irrelevant stimuli retrieved a response incompatible to the currently demanded response as compared to when the responses were compatible or when the response-irrelevant stimuli were novel (i.e., no S–R association was available for retrieval).

However, one procedural caveat must be considered. The relevant stimuli between the compatible and incompatible conditions were not balanced across participants. For each participant, stimuli were randomly selected for these conditions from a single pool of stimuli (though split by left/right responses). While this may not be a problem in a typical priming experiment with 100 and more trials, here we used only 10 trials per condition and as a result the base RTs needed to classify the relevant objects as smaller or larger than a waste bin might have added too much noise for the comparison to be significant (as an example, imagine that for a particular participant 7 or 8 pictures with a high base RT were selected for the compatible condition). Thus, we replicated Experiment 1 without this procedural caveat and made sure that the task relevant stimuli were shown equally often in the compatible and incompatible conditions across participants.

2. Experiment 2

Essentially, Experiment 2 was a replication of Experiment 1. Yet, we balanced the stimulus material across participants following a Latin square so that the relevant objects in the test block were identical in compatible and incompatible conditions (across participants). We also increased the number of participants in Experiment 2 relative to Experiment 1 to increase the statistical power. Finally, we dropped the neutral condition to increase the number of compatible and incompatible trials relative to Experiment 1. Note that the compatibility effect is defined as the difference between compatible and incompatible trials. Neutral trials are only relevant when assessing facilitation (in the compatible condition) vs. interference (in the incompatible condition) effects relative to a neutral baseline — a question that is not central to the current studies.

2.1. Method

2.1.1. Participants

Seventy-five students (59 female) from the University of Trier took part in the experiment. Their median age was 21 years with a range from 19 to 33 years. Participants took part in exchange for partial course credit or a small monetary compensation. Five participants were replaced because they were outliers according to Tukey (1977; i.e. they had extremely long retention intervals).

2.1.2. Design

The design for the variable of main interest comprised a single within-subjects factor, namely response-irrelevant stimulus–response compatibility in the test blocks (compatible vs. incompatible). We removed the neutral condition in Experiment 2, to increase power in our main comparison of interest. In addition, the training phase followed a one-factorial design with the within-subjects factor training

block (block 1 vs. block 2 vs. block 3 vs. block 4). The power to detect medium-sized effects in binary comparisons of two levels of compatibility factor (i.e., $d = .5$; $\alpha = .05$, one-tailed) was $1 - \beta = .995$ (GPower 3; Faul et al., 2007).

2.1.3. Materials and procedure

Materials and procedure were the same as in Experiment 1 with the following exceptions. Participants worked through four practices and through two test blocks and always decided whether the depicted target object is larger or smaller than a shoebox in real life. Only compatible and incompatible trials were presented during the test. One response-irrelevant stimulus list was assigned to the compatible and another to the incompatible condition. Both for left and for right responses, four target lists were assigned to the four training blocks of the participants according to a Latin square. In each test block, two left-response target lists and two right-response target lists were assigned to compatible and incompatible test trials, respectively. Each list was used in compatible trials for half of the participants and in incompatible trials for the other half. The average retention time between the last practice block and the start of the test block was $M = 1{:}26$ min ($SD = 0{:}20$ min).

2.2. Results

For the analysis of response times (RTs), we considered only those trials with correct responses during test (error rate during test was 7.1%). RTs that were more than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant (Tukey, 1977), and those that were shorter than 200 ms, as well as all test trials presenting response-irrelevant stimuli that had at least once appeared in a training trial with an incorrect response were excluded from the main analysis. Due to these constraints, 32.9% of all trials were discarded. Mean RTs and error rates are shown in Table 2.

2.2.1. Training phase

Mean response times in the four training blocks were entered into a one-way ANOVA. The response times differed significantly, $F(4,72) = 5.48$, $p = .002$, $\eta_p^2 = .19$, RTs decreased over the four training blocks in a linear fashion, in fact, the linear trend was significant as well, $F(1,74) = 12.96$, $p = .001$, $\eta_p^2 = .15$. In the same analysis on error rates no effect was significant, $Fs < 1$, $ps > .9$.

2.2.2. Test phase

Response times in trials in which responses were compatible to retrieved responses due to response-irrelevant stimuli were faster than in incompatible trials, $t(74) = 2.03$, $p = .046$, $d = 0.23$. Error rates did not differ significantly, $t(74) = 1.53$, $p = .130$, $d = 0.18$.

2.3. Discussion

Experiment 2 confirmed and replicated the tentative evidence from Experiment 1. S–R bindings between irrelevant stimuli and responses can last much longer than from the prime to the next probe display. In fact, here they lasted for over a minute. The more sensitive design together with the higher sample size made the binding effects observable.

Table 2
Mean response times and error rates in Experiment 2.

	Training				Test	
	Block 1	Block 2	Block 3	Block 4	Compatible	Incompatible
Response times (ms)	760	741	730	721	729	745
Error rates (%)	6.8	6.3	6.7	6.8	7.5	9.3

3. General discussion

In two experiments we observed evidence for S–R retrieval due to response-irrelevant stimuli even when more than a minute elapsed between encoding and retrieval. This finding stands in contrast to previous attempts to observe distractor-based retrieval of event-files that failed when more than a few hundred milliseconds elapsed between encoding and retrieval. Yet, this finding fits to previous results concerning the binding of relevant stimuli and responses which seem to survive longer intervals (e.g., Horner & Henson, 2009, 2011). Thus, our results support the idea that longer lasting bindings between irrelevant information and responses are possible, but perhaps only in 'optimal conditions'. Presumably, under conditions used in previous studies, bindings between irrelevant stimuli and responses were short-lived and rapidly decayed over time (Hommel, 1998; Henson et al., 2014).

A possible caveat of our experiments was that if participants noticed the contingency between a particular fixation marker and the responses in the prime blocks, they could have possibly used this contingency for responding and the resulting binding effects would thus have been the aftereffects of a contingency-based strategy (which would completely foil the idea that the fixation markers should have been processed as irrelevant with respect to responding). Yet, if participants indeed used such a strategy their prime RTs should have speeded up at the end of the prime blocks; thus if the probe block effects were due to such a strategy one expects a negative correlation between prime block RTs and the size of the probe compatibility effect. Yet, for example, in Experiment 2, correlations between the last prime block (or the last two prime blocks) and the probe compatibility effect were not significant, r between .14 and .18 with p-values ranging from .12 to .22. Note, that all observed (non-significant) correlations were positive. With respect to these results one can exclude the possibility that our data reflect just intentional strategies based on the contingency between fixation markers and prime responses.[1]

Of course one might ask whether the response-irrelevant stimuli in our experiments were truly irrelevant to the task as they were presented at fixation and furthermore cued the target stimuli; that is, they will definitely have allocated attention at least at the start of a trial. Yet, participants were explicitly instructed to respond according to their decision about the size of the depicted targets and apparently complied with these instructions (as indicated by the correlation analyses reported above). In addition, fixation marks did not have any predictive value in relation to the response required in the test phase — in this sense these stimuli were irrelevant for responding. In addition, the role attention plays for binding is still an issue under research (e.g., Hommel, 2005; Moeller & Frings, 2014; Henson et al., 2014). Attention appears to increase the probability of retrieval when it is directed towards the stimulus which retrieves the response whereas its impact for encoding of S–R episodes is questionable. In turn, in our experiments we ensured that the irrelevant stimulus received attention and this might be a further aspect of what we call 'optimal conditions' under which even irrelevant stimuli can become part of long term S–R associations.

The fast decay of bindings between irrelevant stimuli and responses may reflect an efficient adaptive mechanism. The potential number of incompatible bindings that would occur if the cognitive system bound responses to all (even irrelevant) stimuli present at response would

be high. Presumably, the cognitive system needs to limit the number of possible incompatible bindings and thereby prevent their transfer to incompatible behavioral routines. Gestalt principles (Frings & Rothermund, 2011; Moeller, Rothermund, & Frings, 2012) and semantic matching (Giesen & Rothermund, 2011) have been proposed so far as to hedge against the establishment of incompatible S–R episodes. The fast decay of bindings between (response-)irrelevant stimuli and responses might be another mechanism that limits the influence of incompatible S–R episodes on regular responses. Only if the evidence for irrelevant S–R episodes is strong (e.g., multiple repetitions of the same irrelevant stimulus and response) do long-term bindings become established, leading to retrieval of S–R episodes due to repetition of response-irrelevant stimuli after longer retention periods. Ultimately, under such conditions, S–R episodes including stimuli not related to responding at all might be transferred into a behavioral routine. Hence, the cognitive system is protected against the formation of random S–R bindings while still exploiting contingencies between actions and response irrelevant stimuli in the surroundings.

Yet, if task-irrelevant S–R bindings decay rapidly, one would need to assume that there is a 'contingency-detector' that identifies repeated S–R episodes across longer temporal gaps. In the present studies, there were relatively long lags (~60 s) between the different repetitions of a particular S–R episode in the prime blocks. Therefore, one must assume that this 'contingency-detector-mechanism' can accumulate evidence for a particular combination of an irrelevant stimulus and the response across time. Once enough evidence accumulates, this S–R episode will ultimately be encoded within a longer-lasting S–R binding. This assumption fits nicely with arguments put forward by Herwig and Waszak (2012) suggesting that long-term associations are not only accumulated short-term associations but need further processes (in their specific case intention-based actions) that make this transfer possible.

Of course, a large number of previous studies provide evidence that contingencies between (response-irrelevant) stimuli and responses can be learned quickly and incidentally (e.g., Garner & Felfoldy, 1970; Logan, 1988, 1990; Miller, 1987; Nissen & Bullemer, 1987; Schmidt, Crump, Cheesman, & Besner, 2007; Frings & Wentura, 2006). For example, Miller (1987) correlated flankers in an Eriksen flanker task (Eriksen & Eriksen, 1974) with responses and observed RT facilitations for compatible stimulus–response pairings regarding these flanker stimuli. Yet, these previous studies were concerned with long term effects of learning processes as they repeated S–R combinations up to 192 times before testing compatibility effects. In contrast, the present results suggest that longer lasting associations indeed start to form after few stimulus encounters. In fact, one might assume that the smallest learning unit (i.e., a single encounter of a particular contingency) is reinforced by recurrence. In this regard, it seems that short-term associations between distractors and responses can ultimately transfer into long-term associations.

Our results are also in line with findings of Logan and colleagues (Boronat & Logan, 1997; Logan & Etherton, 1994). The authors found stimulus–stimulus as well as distractor-response associations after repeating consistent word pairings 16 or more times during a training phase. The participants' learning curves suggested that a large part of facilitation within training was already formed during the first four or five repetitions of the stimulus pairs. Yet, neither these curves nor the results in the transfer blocks can say much about the very first formation of longer lasting bindings between distractors and responses. On the one

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[1] We want to thank two anonymous reviewers for pointing out this alternative and suggesting the control analysis.

hand, facilitation effects during training (that might have been due to increasingly longer lasting associations between distractors and responses) cannot be differentiated from a number of other effects like the formation of target-response associations, or increasing stimulus familiarity. On the other hand, it remains unclear whether consistent distractor–target pairing is a necessary prerequisite for the rapid learning process reported by the authors (i.e., distractor-response compatibility effects after only 16 trials). Our findings provide a first insight into these issues. We found that bindings between irrelevant stimuli and responses can have a relatively long lifespan after only a few consistent pairings (4–5 in our experiments). Moreover, neither target repetition, nor distractor–target consistency seems to be necessary for the rapid formation of longer lasting S–R bindings with response-irrelevant stimuli.

Taken together, our results suggest that retrieval of S–R episodes due to response-irrelevant stimuli needs more evidence and/or optimal conditions to survive periods longer than 1000 ms. Indeed, when a S–R episode is repeated five times (even if the target to which one responds differs) a binding between the response-irrelevant stimulus and the response remains intact and influences responding after more than a minute has elapsed. This result shows how fine-tuned and adaptive our cognitive system is: on the one hand it can exploit contingencies between irrelevant stimuli and responses after very few repetitions, which may transfer into S–R learning and behavioral routines. On the other hand, it is immune to random co-occurrence of irrelevant stimuli and responses as these bindings rapidly decay and thus do not automatically transfer into S–R learning and behavioral routines.

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