



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



Christian Frings^{a,*}, Birte Moeller^a, Aidan J. Horner^{b,c}

^a University of Trier, Germany

^b UCL Institute of Cognitive Neuroscience, United Kingdom

^c UCL Institute of Neurology, United Kingdom

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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, Müssele, 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

* Corresponding author at: Cognitive Psychology, University of Trier, D-54286 Trier, Germany.

E-mail address: chfrings@uni-trier.de (C. Frings).

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

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