

# Irrelevant Influences; when irrelevant stimuli influence our actions

Investigating the conditions under which distractors retrieve responses



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## Summary

At any given moment, our senses are assaulted with a flood of information from the environment around us. We need to pick our way through all this information in order to be able to effectively respond to that what is relevant to us. In most cases we are usually able to select information relevant to our intentions from what is not relevant. However, what happens to the information that is not relevant to us? Is this irrelevant information completely ignored so that it does not affect our actions? The literature suggests that even though we may ignore an irrelevant stimulus, it may still interfere with our actions. One of the ways in which irrelevant stimuli can affect actions is by retrieving a response with which it was associated. An irrelevant stimulus that is presented in close temporal contiguity with a relevant stimulus can be associated with the response made to the relevant stimulus – an observation termed *distractor-response binding* (Rothermund, Wentura, & De Houwer, 2005). The studies presented in this work take a closer look at such distractor-response bindings, and the circumstances in which they occur. Specifically, the study reported in chapter 6 examined whether only an exact repetition of the distractor can retrieve the response with which it was associated, or whether even similar distractors may cause retrieval. The results suggested that even repeating a similar distractor caused retrieval, albeit less than an exact repetition. In chapter 7, the existence of bindings between a distractor and a response were tested beyond a perceptual level, to see whether they exist at an (abstract) conceptual level. Similar to perceptual repetition, distractor-based retrieval of the response was observed for the repetition of concepts. The study reported in chapter 8 of this work examined the influence of attention on the feature-response binding of irrelevant features. The results pointed towards a stronger binding effects when attention was directed towards the irrelevant feature compared to when it was not. The study in chapter 9 presented here looked at the processes underlying distractor-based retrieval and distractor inhibition. The data suggest that motor processes underlie distractor-based retrieval and cognitive process underlie distractor inhibition. Finally, the findings of all four studies are also discussed in the context of learning.

## 1. Introduction

The world around us is full of objects that are combinations of different colours, shapes, and orientations. How do we manage to so efficiently combine all of these features in order to perceive objects as they are? How do we, for instance, correctly match colours to shapes and locations in a scene, so that we perceive a red car as being red, rather than as any other colour? This is not necessarily an easy question to solve, however, it is essential to our ability to correctly perceive and recognise objects in order to be able to respond to them. Unless we are able to correctly combine the features of a stimulus, we are unlikely to be able to correctly identify it. This issue of binding extends to responses as well. We require a similar sort of ‘binding’ when planning our actions – we need to be able to accurately ‘bind’ the features of a particular response (e.g. Hommel, 2004). Moreover, we generally tend to encounter the same stimuli more than once, and generally we need to respond in a similar manner to that stimuli at every encounter. Do we then compute the correct response every time by some kind of algorithmic process, or do we in time tend to associate a particular stimulus with a particular response? The general consensus is that we manage the binding of separate features in episodic traces, and in time we do in fact learn to associate particular responses with particular stimuli (e.g. Logan, 1988). For instance Logan (1988) postulated that stimuli and responses made to them are stored in what he referred to as *instances* in long-term memory. Other theories postulate similar episodic traces, in which stimuli and responses are stored, these episodic traces however are shorter lived than instances (e.g. event files, Hommel, 2004; S-R episodes, Waszak, Hommel, & Allport, 2003). It is these short-term associations between stimuli and responses that is the focus of the present work.

Specifically, questions pertaining to irrelevant stimuli are of interest in this dissertation. Along with stimuli that are relevant to our intentions, we are faced with any number of stimuli that are of no relevance to us. What happens to all those numerous irrelevant stimuli and how much of an influence do they have on our actions? And, what are the circumstances under which they influence our behaviour? Specifically the latter question has been examined in the presented work. Research has already proven that along with the relevant stimuli, even irrelevant stimuli are stored in episodic traces (instances, S-R episodes, event files) and they can influence our actions by, among other things, retrieving the response with which it was previously stored – *distractor-response binding* (Rothermund, Wentura, & De Houwer, 2005). There is a whole body of evidence detailing the nature of such distractor-response associations, their structure, and the conditions under which they occur. The studies

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presented and discussed in this dissertation have further examined some of the conditions under which irrelevant stimuli and/or features interfere with our actions. Retrieval by similar but not exactly the same stimuli was examined, as was retrieval due to concept repetition (in the absence of perceptual repetition). Furthermore, factors that may modulate the influence of irrelevant stimuli have also been examined, more precisely, the influence of attention on short-term associations between irrelevant features and responses was examined. And finally, the processes underlying distractor-response binding was identified. Since short-term bindings, or associations, between stimuli (both relevant and irrelevant) and responses have been suggested to be involved in the early stages of the learning process, the results of the studies presented here are also discussed with relation to long-term learning.

## 2. Feature Integration

Some of the early theories that attempted to answer the question of binding were essentially theories of attention, for instance, the *Feature Integration Theory of Attention* by Treisman and Gelade (1980), which postulated a series of cortical maps, *feature maps*, which coded features, and one *master map of locations*, which coded the locations in the visual field. Attention was assumed to function like a spotlight on the master map of locations, and all features present at the location at which attention was directed were, in an early stage, encoded in their own specialized feature maps, and, at a later stage combined together. The latter stage was assumed to require attention, a lack of which would lead to the building of incorrect combinations – ‘illusory conjunctions’ (Treisman & Schmidt, 1982). Once attention moved from one location on the master map of locations to the next, the feature combinations were lost.

Subsequent theories, such as the *object file* theory (e.g. Kahneman, Treisman, & Gibbs, 1992) were proposed to further the Feature Integration Theory of Attention, to be able to account for the integrated features once attention had shifted, and how we deal with changes that occur in objects. It postulated *object files*, temporary episodic traces of real world objects, as the outcome of perceptual processing (Kahneman et al., 1992). In essence an object file was assumed to contain stimulus features belonging to a single object, and they remained open as long as the object was in view, shortly after the object disappeared the file would be disintegrated. Object files could be updated if any changes were to occur in the object, for instance, if the object moved position, and they could also be matched to items seen in the environment immediately before.

Evidence for this theory was found in the *Reviewing Paradigm* (Kahneman, et al., 1992). In the basic paradigm, participants were briefly shown a preview display, with letters in particular positions before disappearing for a short duration. After this a letter was either repeated in the same position, in a different position, or a completely different letter was presented. The task of the participants was to classify the letter in the final display. The authors found, what they referred to as, *object specific preview benefits*, across experiments with both stationary and moving displays. If a letter was repeated in the same position, naming latencies were significantly shorter than if it was repeated at a different position. This was seen as evidence for a) object specific representation, and b) location being a key feature. It was argued that general accounts of priming, which propose an activation of nodes in semantic memory, could not account for their specific preview effects.

Priming theories could not account for the fact that only a specific letter-location combination would result in reaction time (RT) benefits, rather they would predict equal activation (for both letters in the preview display) and therefore similar benefits of repetition irrespective of whether location was repeated or not. Furthermore, the specific benefit observed when the location was repeated along with the letter, was seen as evidence for the fact that object files could only be accessed by their location code, in order for them to be either updated or matched with previous objects.

However, other research suggested that such episodic traces could be accessed not only by location, rather also by other feature codes. For example, Leslie, Xu, Tremoulet, and Scholl (1998) and Hommel (1998) suggested that such episodic representations could also be accessed by other stimulus features such as colour or form. Thus, these findings threw doubt upon the assertion that object files or episodic representation could only be accessed by the location feature. Furthermore, research combining perception and action planning suggested that such episodic representations were common to the domains of both perception and action planning (e.g. Prinz, 1997) and therefore any discussion on episodic representations must also consider actions and action planning.

### 3. Integration of perception and action planning

According to the common coding approach (Prinz, 1997) the feature codes used to represent objects and our actions come from the same pool of feature codes. This is entirely plausible, since the feature codes used to represent an object are similar to those needed to represent an action directed towards that object. Consider for instance the action of picking up a pen lying on a table. In order to do that, one would first need to see and locate the pen, and then plan the action of picking it up.

Once one has seen the pen, its properties or features will be represented, for instance, its colour, its location and position on the table, its size, and its shape. These are approximately the same feature codes needed in order to plan the action of picking it up. Its location will need to be known in order to know in which direction the hand movement has to be carried out, and its position, size and shape in order to plan how the pen is to be gripped.

That representations in the perceptual and action planning domains are based on the same set of feature codes is also evident in typical effects observed in experimental settings. For example in spatial stimulus-response compatibility tasks like, for instance, the Simon effect (Hommel, Müsseler, Aschersleben, & Prinz, 2001). The Simon effect is the observation that responses to targets that share their spatial location with the response are quicker than responses to targets that do not share spatial location (Simon, 1969). Such effects were attributed to a match or correspondence between stimulus and response sets (Fitts & Denninger, 1954; Fitts & Seeger, 1953) and later *dimensional overlap* (Kornblum, Hasbroucq, & Osman, 1990). Along similar lines, Hommel (1998) proposed that episodic traces did not just contain representational codes of the stimulus features, rather they also contained representational codes of response features, and faster responding to spatially compatible stimuli was attributed to some sort of coupling between the feature codes of the stimulus and response. The *Theory of Event Coding* (Hommel, et al., 2001) postulated that objects and responses to them are both coded in an *event file*. Essentially, an event file could be seen as an extension of the object file which, along with representations of stimulus features, also includes representations of response features. Event files, like object files, are temporary episodic structures that last for not more than a few seconds, or until a planned action has been carried out. Stimulus features that are task relevant or in some way salient are more likely to be integrated than features that are not (Hommel, 2004). Furthermore, each feature code can only be part of one event file. Should the same feature code be required for another event file, the previous one must first be dissolved (Hommel, et al., 2001).

Thus, encountering a stimulus and responding to it results in the creation of an event file (or a stimulus-response episode, see Waszak, Hommel, & Allport, 2003). A reencounter with the same stimulus will result in the event file being retrieved. If all stimulus and response features remain the same, or all of them change, then responding is easier than when only some of the stimulus and/or response features are changed. This is referred to as *partial-repetition cost* (Hommel, 2004). Partial-repetition costs are the result of conflicts that arise when the retrieved event file does not completely match or completely mismatch the current stimulus. This conflict usually manifests in longer reaction times and higher error rates.

For instance, Hommel (1998) had participants respond to stimuli that had three features; colour, form and location, of which only one was relevant. In each trial, participants responded to two stimuli sequentially. The response (R1) to the first stimulus (S1) was always pre-cued. The response (R2) to the second stimulus (S2) was a two-choice reaction task. The participants were instructed that there would be no systematic relationship either between S1 and R1, and that the two of the stimuli features were irrelevant and could be ignored.

The rationale behind pre-cueing R1 was that, in doing so all possible combinations of S1 and R1 features could be implemented. In a series of experiments, Hommel observed significant benefits of repeating the task relevant feature when the response was also repeated, and significant costs, when one of the features was alternated. Given that mainly the task relevant stimulus feature interacted with response relation, Hommel concluded that integration in an event file is not wholly non-selective. Rather, certain features are integrated with the response, while others might not be. Additionally, across all experiments, significant interactions of location and response relation was observed, even though it was never task relevant, leading to the conclusion that even some irrelevant features get integrated with the response.

## 4. Distractor-Response Binding

As suggested in the preceding example, event files or stimulus-response episodes do not only contain information that is specifically relevant for the task, rather irrelevant information, or distractors, are also integrated (e.g. Hommel, 1998; Rothermund, Wentura, & De Houwer, 2005; Frings, Rothermund, & Wentura, 2007). Superficially it might seem unnecessary, or even inefficient, to integrate irrelevant information, however, even such task-irrelevant information might be informative. For example, an irrelevant noise, or flashing light may be indicative of some kind of impending danger and thus act as a warning. These irrelevant features or stimuli, however, may interfere with our actions. For instance, the noise or the flashing light may cause one to suddenly startle, and possibly disrupt performance on a current task. One example of interference through irrelevant stimuli is the Eriksson Flanker task, in which irrelevant stimuli flanked the target (Eriksen & Eriksen, 1974). The irrelevant stimuli could either indicate the same response as the target (compatible), in which case response times are shorter, or a different response (incompatible), in which cases response times are longer.

Furthermore, not only do such irrelevant stimuli interfere with our current actions, they may also interfere with the planning and execution of future actions. Irrelevant stimuli can be integrated with target stimulus and response feature codes, and upon repetition could retrieve the previously integrated response, as observed in paradigms such as the Negative Priming (e.g., Mayr & Buchner, 2006). Negative priming is the observation that a distractor in trial n-1, when repeated as a target in trial n elicits longer reaction times and higher error rates. Negative priming can and has, along with inhibition theories (e.g. Houghton & Tipper, 1996), also been explained by episodic retrieval (e.g. Neill, 1997). For instance, Mayr and Buchner (2006) observed that repeating the distractor from trial n-1 as the target in trial n, resulted in retrieval of the prime response, i.e. the response with which the distractor (and target) was associated in the prime. The argument is, that along with the relevant stimulus and the response to it, even irrelevant stimuli (distractors) are integrated or stored in event files (e.g. Frings, et al., 2007). When a distractor is presented in close temporal contiguity with a target, it becomes associated with the response made to the target, and if the distractor is repeated it can retrieve the response – an effect called *distractor-response binding* (Rothermund, et al., 2005). Repeating the distractor will thus retrieve the response with which it was associated. Whether this leads to facilitation of performance or not, depends upon whether the response is repeated as well or not (Rothermund et al., 2005). In general,

distractor-response bindings can be described as short lived associations between an irrelevant stimulus or feature (the distractor) and a response. These associations are temporary and last only around 1000 ms (Frings, 2011).

## 4.1. General Paradigm and Predictions

Distractor-response binding is generally studied in a distractor-to-distractor priming paradigm. Each trial consists of a prime display and a probe display, with only the probe reaction times and errors being analysed. A target, to which participants must respond, is presented along with a distractor, this might be either an accompanying stimulus (e.g. stimuli in a flanker formation with the target in the centre – ‘DFD’) or an irrelevant feature of the stimulus (e.g. the colour of the object as the target and its shape as the distractor). Response relation (whether or not the response is repeated from the prime to the probe) and distractor relation (whether or not the distractor is repeated from the prime to the probe) are both orthogonally varied, resulting in four different conditions; Response Repetition-Distractor Repetition (RRDR), Response Repetition-Distractor Change (RRDC), Response Change-Distractor Repetition (RCDR), Response Change-Distractor Change (RCDC).

As early evidence for distractor-response binding came from literature in negative priming (see Mayr & Buchner, 2006), so did the theoretical approaches explaining this effect – one such theoretical approach being the Stimulus-Response Retrieval Model (Rothermund, et al., 2005). The Stimulus-Response Retrieval Model predicts differing outcomes of distractor repetition depending upon whether the response is repeated or not. If both the distractor and the response are to be repeated, faster responding, or fewer errors are predicted, since both the response and the distractor indicate/retrieve the same response. If the distractor is repeated and the response is changed slower responding, or more errors are predicted, since now the response and distractor both indicate/retrieve different responses.

According to the Stimulus-Response Retrieval Model, we would thus expect the RTs in the condition in which the response and distractor are repeated (RRDR) to be shorter than in the condition in which the response is repeated but the distractor is changed (RRDC). Reaction times in the condition in which both the response and the distractor are changed (RCDC) are predicted to be shorter than those in the condition with a changed response and a repeated distractor (RCDR). Thus repeating the distractor leads to an advantage in responding if the response is repeated as well, but to a disadvantage if the response is changed. The theoretically predicted data pattern is depicted in **Fig. 1**.

The distractor-response binding (DRB) effect, indicated by an interaction response relation and distractor relation, is calculated as the difference of the differences between distractor change and distractor repetition in response repetition and response change trials, i.e.  $DRB = (RRDC - RRDR) - (RCDC - RCDR)$ .

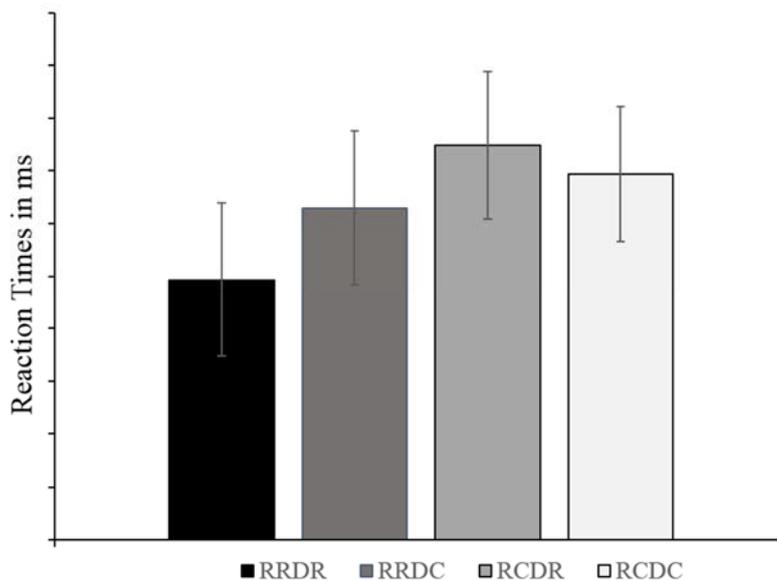


Figure 1. Pattern of results as predicted by the Stimulus-Response Retrieval model.

## 4.2. S-R Binding and D-R Binding

Stimulus-response bindings have been able to explain a number of findings, for instance, repetition priming (e.g. Denkinger & Koutstaal, 2009), negative priming (e.g. Rothermund, Wentura, & De Houwer, 2005), and task switching (e.g. Koch & Allport, 2006). Due to the similarities between them, stimulus-response bindings are often - as also in the presented work - discussed in relation with distractor-response bindings. In order to paint a clearer picture of each of these separate, yet similar types of bindings, they are briefly discussed along side each other in the following.

Like stimulus-response bindings, distractor-response bindings are also associations between a stimulus and a response. While distractor-response bindings refer to associations between an irrelevant stimulus (distractor) and a response, stimulus-response bindings refer to associations between a relevant stimulus (target) and a response.

Stimulus-response bindings generally last longer than distractor-response bindings. Whereas distractor response-bindings are generally observed to last only for around 1000 to 1200ms (Frings, 2011; Frings & Rothermund, 2011), stimulus-response bindings have been known to last longer, around 4 seconds (Zmigrod & Hommel, 2010) or even upto several minutes (Horner & Henson, 2009).

Aside from their differences, there are apparent similarities between stimulus-response and distractor-response bindings; they have both been shown to be more complex than simply an association between a stimulus and a response. Repetition of both targets and distractors leads to the retrieval of the response that was previously integrated with them (e.g. Hommel, 1998, Waszk, Hommel, & Allport, 2003; Rothermund, Wentura, & De Houwer, 2005; Frings, Rothermund, & Wentura, 2007). Both types of bindings have been shown to exist at motor (retrieval of a motor response e.g. right key press or left key press), conceptual (retrieval of concepts or conceptual information, e. g. ‘living’, ‘non-living’), and decisional levels (retrieval of specific decisions, e.g. ‘yes’, ‘no’) (Frings, Moeller, Rothermund, 2012; Giesen & Rothermund, 2014; Henson, Eckstein, Waszak, Frings, & Horner, 2014; Nett, Bröder, Frings, 2015).

Both stimulus-response bindings and distractor-response bindings have been discussed as possibly being early stages in the learning process. (Logan, 1988), the role that they may or may not play in the learning process is unclear, although certain findings would suggest at least some similarity between them (e.g. Giesen & Rothermund, 2014; Singh, Moeller, & Frings, 2016).

Both of these types of bindings, stimulus-response and distractor-response bindings, are thus essential for, and contribute to action planing and control.

## 5. Selected Questions on Distractor-Response Binding

Distractor-response bindings have been observed in the visual, auditory, and tactile modalities (e.g. Frings, et al., 2007; Mayr & Buchner, 2006; Moeller & Frings, 2011; Rothermund, et al., 2005) and has also been observed across modalities (Frings, Moeller, & Rothermund, 2013) and under certain conditions, distractor-response bindings have even been shown to survive an effector change (Moeller, Frings, Hommel, 2015).

The studies presented in this work all deal with distractor-response bindings in the visual modality. More specifically, in the presented studies the influence of irrelevant features of one single stimulus were examined, i.e. one feature of the stimulus was always the target and therefore response relevant, and another feature was always irrelevant to the response (except chapter 9). The questions probed in these studies aimed at delving a little further into the nature of distractor-response bindings and the circumstances under which they can be observed.

As mentioned above, distractor-response bindings are temporary associations between an irrelevant stimulus or feature and a response (e.g. Frings, 2011). The theory of event coding (Hommel, et. al., 2001) postulated individual, or binary, bindings between each of the features codes within a particular event file i.e. the structure of such bindings is binary, each feature code is bound to every other feature code. Although these predictions were made with respect to feature-response binding, and not specifically for distractor-response binding, a very similar structure has been observed in the case of distractors as well (Giesen & Rothermund, 2014; Moeller, Frings, & Pfister, 2016). For instance, Moeller, Frings, and Pfister found that when more than one distractor is present (in their experiment they used 2 distractor features), each distractor is independently bound with the response, and the sum of the individual retrieval effects is not different from the retrieval effect when both distractors are repeated simultaneously. Thus, each distractor feature was bound to, and retrieved the response independently of the other distractor.

Similarly, apart from target-response bindings, Giesen and Rothermund (2014) found that a distractor is not only bound with the response (distractor-response binding), rather it is also bound with the target (distractor-target binding), and accordingly can retrieve both the response and the target. Both of these types of bindings (distractor-response, and distractor-target) were found to be independent of each other. Based on these findings, the authors suggested a similarity in the structure of distractor-response bindings and Pavlovian conditioning. In chapter 6 a further similarity between distractor-response binding and

Pavlovian conditioning was examined. If both processes have a similar underlying structure, then one might expect certain functional similarities as well. This question was addressed in the sixth chapter. A well-known phenomenon in Pavlovian conditioning is that of *generalisation*; chapter six of this work examined whether generalisation can be observed in distractor-response binding as well.

Distractor-response bindings have not only been found at a perceptual level, rather even at a conceptual level (Frings, Moeller, & Rothermund, 2013). The seventh chapter examined whether even abstract concepts could be bound to responses. Stimulus-response and distractor-response bindings have been found for concrete concepts (Denkinger & Koutstaal, 2009; Frings, Moeller, & Rothermund, 2013). However concrete concepts have the advantages of having multiple sensory representations, and possessing specific labels. In the seventh chapter therefore, we examined whether even abstract concepts, that did not have sensory representations and specific labels, could be bound to and retrieve responses.

Distractor-response binding has been considered to be an automatic effect that requires little, if any attention. However, there does not seem to be too much consensus on this issue in the literature. Some studies have found no effect of attentional manipulations on binding (e.g. Hommel, 2005; Hommel & Colzato, 2004), whereas other have suggested an influence of attention (Memmelink, & Hommel, 2013). In the eighth chapter, the issue of attention and distractor-response binding was raised. Specifically, the influence of attention on distractor-response binding, when more than one distractor was present was examined. Under the assumption that distractor-response binding requires no attention, one would expect both irrelevant features to be bound with the response. If, however, binding does require attention, only the attended feature should be bound with the response.

In the ninth chapter, two processes, distractor-based retrieval, and distractor inhibition were measured and the level at which the processes operated, whether at a motor level or a cognitive level, was specified. It has been established that both distractor based inhibition and distractor based retrieval are independent effects (Giesen, Frings, & Rothermund 2012), however, what is yet unknown, is whether both effects are caused by the same process or by different processes. The study presented in chapter 9 attempts a disassociation of the two effects and the processes that underlie them.

## **5.1. Generalisation in retrieval: Can similar distractors retrieve a response?**

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It has been well established in the literature that repeating the same distractor leads to the retrieval of the response with which it was previously integrated, and nearly all distractor-response binding studies up to now have used exact repetitions of the distractor (e.g. Frings, Rothermund, & Wentura, 2007; Moeller, Frings, Pfister, 2016). However, what does the repetition of a similar (but not exactly the same) distractor result in? Furthermore, what does manipulating the extent of the similarity of the distractor lead to, does it influence retrieval at all? This is a question well worth asking for a couple of reasons.

Firstly, there is the evidence found in priming literature and in stimulus-response binding literature. Priming effects can be explained in terms of stimulus-response retrieval (e.g. Henson, Eckstein, Waszak, Frings, & Horner, 2014) and are thus of relevance to the present purpose. As early as 1982 Warren and Morton showed that prior presentation of an object could lead to facilitation in a recognition task up to 45 minutes later. Furthermore, they observed this facilitation both for exact repetitions of a stimulus, and even for different exemplars of the stimulus, the priming effect was however larger for the exact repetition condition. Subsequent studies using paradigms that tested priming effects at shorter intervals with shorter presentation times also found similar result patterns (e.g. Biederman & Cooper, 1991; Biedermann & Gerhardstein, 1993). For instance Biederman and Cooper (1991) also found that visual priming effects extend to different exemplars of an object, but these effects were however smaller than for exact repetitions of the object. In their experiment, participants had to name picture stimuli that were either exactly the same as in the previous presentation, or that were different exemplars of the object. Participants were significantly faster in naming both exact repetitions and different exemplars in a recognition block compared to the first presentation, however, participants were also faster at naming exact repetitions compared to different exemplars. Biederman and Cooper took this as evidence that at least some part of the priming effect was visual. Similar results have been obtained in studies using a related task, in which, instead of naming objects, participants had to categorise objects as either larger or smaller than a particular reference size, for example, a shoe box (e.g. Denkinger & Koutstaal,

2009; Koutstaal, Wagner, Rotte, Maril, Buckner, & Schacter, 2001; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; Vuilleumier, Henson, Driver, & Dolan, 2002). In all of these studies reliable but smaller priming or retrieval effects were found in the condition in which a different exemplar was presented compared to the condition in which the exact same stimulus was repeated. Given that distractor-response bindings resemble stimulus-response bindings in many ways, one might also expect to see a similar pattern for distractor-based retrieval.

The second reason that the question of response retrieval by similar distractors is interesting is the similarity between distractor-response bindings and learning, specifically in this case, Pavlovian conditioning. Despite the apparent differences between distractor-response bindings and learning (e.g. their vastly different time-frames), distractor-response bindings (and stimulus-response binding in general) have been discussed as an early stage in the learning process (Henson et al., 2014; Moeller & Frings, 2014). Giesen and Rothermund (2014) observed that the structure of distractor-response bindings resembled that of stimulus-response associations in Pavlovian conditioning. In view of this similarity, it might be valid to raise the question of functional similarities between distractor-response binding and Pavlovian conditioning. One well established concept within Pavlovian conditioning is that of *generalization*. Generalization is the observation of responding that occurs even in circumstances that are not exactly the same as in the learning stage, i.e. when responding occurs to stimuli that are slightly different from the learnt stimulus. The term *generalization decrement* is used to refer to the transfer of learning (to a different stimulus than the learnt one) that is less than complete, i.e. when the learning effect is weaker. The effects of generalization and generalization decrement have both been well established in the literature on Pavlovian conditioning (Pearce, 1987), and it might be argued that given the structural similarity between distractor-response binding and Pavlovian conditioning, one might expect to find a similar pattern of generalization and generalization decrement in distractor-based retrieval as well.

In the Article presented in chapter 6, we tested whether generalization and generalization decrement would be observed in distractor-based retrieval of responses. To this end we used a slightly different manipulation of the distractor than is generally found in distractor-response binding studies. Instead of presenting either the exact same or a completely different distractor, we manipulated the similarity between the distractors in five levels of similarity. The distractor-response binding effects were calculated for each of the

different levels of distractor similarity, and then compared. Considering the evidence of similarity between Pavlovian conditioning and distractor-response bindings, we would expect to see evidence of generalization, i.e. decrease in the strength of the binding effects along with a decrease in the distractor similarity.

## **5.2. Retrieval in the absence of perceptual repetition**

*Singh, T., Frings, C., & Moeller, B. (2017). Binding Abstract Concepts.*

*Psychological Research, doi: <https://doi.org/10.1007/s00426-017-0897-z>*

Repetition of a stimulus, whether relevant or irrelevant, retrieves the response with which it was stored in the event file. As the article presented in chapter 6 shows, it is not necessary to repeat the exact same stimulus, a perceptually similar stimulus can retrieve the response as well. Along with retrieval at a perceptual level however, stimulus response bindings can also occur at a conceptual level (Henson, et al., 2014). According to the TEC (Hommel, et al., 2001) one would expect the all the features of the stimulus, including its category, to be stored in the event file, thus repeating this category would lead to a retrieval of the response. This has been observed in, among others, the repetition priming and the negative priming paradigms. Repetition priming is the finding that performance is facilitated upon a repeated presentation of a stimulus; such facilitation is observed even when the stimulus is presented in a different format or as a different exemplar (Horner & Henson, 2011; Denkinger & Koutstaal, 2009). Horner and Henson (2011) found that even repeating a stimulus in a different format (word-picture, picture-word) resulted in response facilitation. Similarly, Denkinger and Koutstaal (2009) used repetitions of either the exact same object (e.g. classical guitar-classical guitar) or different exemplars of the same object (classical guitar-electric guitar). They found evidence for response facilitation even for repetitions of different exemplars of the stimulus, thus suggesting that stimulus-response bindings exist at a conceptual level.

Further evidence for conceptual binding comes from studies on distractor effects, e.g. negative priming (e.g. Tipper & Driver, 1988). Negative Priming is the finding that when a distractor from trial  $n-1$  is presented as the target in trial  $n$  responding is hindered. For instance, Tipper and Driver (1988) presented stimuli either as pictures or as words, i.e. on an ignored repetition trial, the distractor from trial  $n-1$  could be repeated as the target in trial  $n$  either in the same format (e.g. word-word, picture-picture) or the format could change (e.g.

word-picture, picture-word). They observed cost effects to responding in the ignored repetition condition even when the distractor format (word or picture) was changed from trial  $n-1$  to trial  $n$ , suggesting that even the repetition of the concept hindered responding.

Similarly, Frings, Moeller, and Rothermund (2013) used a distractor-to-distractor priming paradigm, i.e. distractors were only repeated as distractors, and presented either as pictures or sounds as targets and distractors. They found distractor-response binding effects even when changing the modality of the distractor from the prime to the probe, e.g. a picture of a bird as the distractor in the prime and the chirping of a bird as the distractor in the probe. These results suggest that like relevant stimuli, even bindings between irrelevant stimuli and responses go beyond simplistic object specific bindings, rather they extend to a more abstract or conceptual level.

However, there are a couple of methodological points that could be raised with respect to previous studies. Firstly, past studies have generally used concrete concepts in order to study retrieval. The differences between concrete and abstract concepts are well established in the literature (e.g. Holmes & Langford, 1976; Paivio, Walsch, & Bons, 1994; Plaut & Schallice, 1991). Concrete concepts have been observed to have an advantage over abstract concepts in a number of tasks. For instance, concrete concepts are classified faster and recalled better than abstract concepts (Holmes & Langford, 1976; Paivio, Walsch, & Bons, 1994), and reading times are shorter for concrete concepts (Schwanenflugel & Shoben, 1983). In general, this advantage has been explained by the amount of information that concrete concepts can activate (Paivio, 1991; Schwanenflugel & Shoben, 1983). Concrete concepts have a larger number of sensory representations than abstract concepts. For instance we generally have visual, auditory, and tactile representations of concrete concepts. Abstract concepts on the other hand do not have as many sensory representations. Furthermore, concrete concepts have a larger number of specific features, whereas as features of abstract concepts are generally more unspecified (Wiemer-Hasting & Xu, 2005). Thus, if concrete concepts generally have an advantage over abstract concepts in a number of cognitive tasks, it would be valid to question whether observations made with concrete concepts can be extended to abstract concepts.

A second issue is that of perceptual repetition. For instance, in the Denkinger and Koutstaal study (2009), even while repeating a different exemplar of the object, there was a certain degree of perceptual repetition involved. For example, all guitars have the same main components, a body, a neck, and strings. Thus irrespective of whether one presents a different exemplar or not, these components, or features, will be repeated, which may in turn initiate

the retrieval process. Thus for a more true test for conceptual bindings concepts must be repeated without any perceptual repetition. Frings, Moeller, and Rothermund (2013) achieved conceptual repetition without perceptual repetition in their experiment by using modality changes. However, in that study as well concrete concepts were used. Thus apart from each concept having a well-defined set of features, representations in different modalities, they also had well learned labels. It is therefore possible, that the repetition of such a clear and well learned label caused the retrieval of the response.

Thus in order to test whether it is really a concept that retrieves the response it might be prudent to use abstract concepts. In the article presented in chapter 7 of this work, this is precisely the question that was examined using an abstract concept as the distractor. This way it would be possible to exclude perceptual repetition, since, among other things, as their features are more unspecified than concrete concepts they might allow for a more diverse forms of representation. In addition, since the concept used did not have a clear label, retrieval due to a well-learned label can also be excluded. If retrieval effects due to distractor repetition are still observed, it would confirm, and further previous findings that distractor-response bindings can exist at a conceptual level.

### **5.3. Attention and Retrieval**

*Singh, T., Moeller, B., Koch, I., & Frings, C. (2017). May I Have Your Attention Please: Binding of Attended but Response Irrelevant Features. Manuscript submitted for publication.*

What dictates how many features are encoded in an event file? Is binding unconditional, such that all features end up with a place in the event file or are only certain features encoded into the event file, for instance only features that are attended? There are valid arguments for both propositions. Some theories argue that attention is a necessary pre-requisite for integration. For instance, Treisman and Gelade (1998) found inadequate attention hindered the correct binding of stimulus features. This, they found, resulted in what they termed ‘illusory conjunctions’, i.e. incorrect bindings of features, when attention to the stimuli was hindered, whereas this was not the case when the stimuli received adequate attention. According to their Feature Integration Theory of Attention, all features within the locus of attention are integrated. In their model consisting of cortical feature maps, attention works like a spotlight on a master map of locations, and all features present within the attentional spotlight were integrated. Another theory that postulated a role for attention in integration is

the Instance Theory of Automatization (Logan, 1988). According to this theory, a stimulus and a response made to it are stored together in an instance. An accumulation of a number of such instances would, in time, lead to behaviour being driven by the automatic retrieval of such an instance, rather than by algorithmic processing. Logan suggested, in his theory, that integration was an unavoidable consequence of attention, suggesting that anything that receives attention will be stored in an instance. Other theories take the stance that only features or stimuli that are in some way relevant or salient are integrated into event files (e.g. TEC, Hommel et., al., 2001; Hommel, 2004). Memelink and Hommel (2013) proposed a system of ‘intentional weighting’, which adjusts the weights of the features or stimuli based upon their relevance to the intentions of the actor, and those features or stimuli that are relevant have a higher likelihood of being integrated.

The evidence on this subject doesn’t necessarily paint a consistent picture. While there are studies that have examined the influence of attention on binding, different studies examined different types of attention (e.g. spatial, feature-based, central attention) and thus delivered differing results. For instance, studies focussing on spatial attention reveal relatively consistent results. These studies found stronger integration for stimuli that share the same spatial location (Van Dam & Hommel, 2010). Additionally only those features or stimuli that are in a location that is attended are encoded in event files (e.g. Moeller & Frings, 2014, Moeller & Frings, 2015). For instance, Moeller and Frings (2014) found that when spatially separated, only those distractors that were relevant to a second task were integrated in the event file. With respect to central attention, as well, there would seem to be some consensus in the evidence. Studies examining feature binding and stimulus (distractor)-response bindings have found no influence of central attention. For instance, Hommel (2005) progressively increased the task difficulty in a series of experiments to absolutely no effect on feature-respond binding. Moeller and Frings (2015) manipulated attention using a dual-task set-up, and found no disruptions in distractor-response binding. These findings can be taken as evidence that such integration does not require too much of the cognitive resources.

Finally, with respect to feature based attention, the picture is not very clear. While some studies found that generally only task relevant features were encoded (e.g. Hommel, 1998) others found that all distractor features were integrated (e.g. Moeller, Frings, & Pfister, 2016). For instance, Hommel (1998, Exp. 1) only found integration for the response relevant feature and the position feature, but not for a third, response irrelevant, feature. On the other hand, in their study, Moeller, Frings and Pfister (2016) found evidence for feature-response binding for both response irrelevant features. In a related paradigm, Spruyt, De Houwer, &

Hermans (2009) found that only when attention was directed to one of the stimulus features via a second task, were any priming effects observed. For the other, unattended feature, no priming effects were found. On the other hand in an S-R binding paradigm, Hommel and Colzato (2004) found that although increasing attention to stimulus features via a second task increased the overall attention to the stimulus, it had no effect upon the strength of the feature integration.

The Article presented in chapter 8 here provides evidence for the influence of feature based attention on the feature-response integration of irrelevant features of a single stimulus. Using a second task attention was encouraged towards one of two irrelevant features. It must be noted here, that even though attention was directed towards one of the two irrelevant features, they were never relevant to the speeded RT task. Binding effects for irrelevant features were calculated for the condition in which attention was directed towards them and for the condition in which attention was directed towards the other irrelevant feature. In doing so, it was possible to compare irrelevant feature-response binding effects for conditions with attention towards that feature and in conditions with attention towards the other feature. If attention modulates feature-response binding for the response irrelevant feature, we would expect to observe stronger binding effects for the feature that is currently relevant to the second task. If attention does not modulate feature response binding for the response irrelevant task, we would expect comparable effects when a feature is relevant in the second task, as well as when it is not.

#### **5.4. Dealing with distractors; a tale of two processes: Inhibition and Retrieval.**

*Singh, T.<sup>1</sup>, Laub, R., Burgard, J. P., & Frings, C. (in press). Disentangling Inhibition-based And Retrieval-based After-Effects of Distractors: Cognitive Versus Motor Processes. Journal of Experimental psychology: Human Perception and Performance.*

Until now the work presented in this dissertation has dealt only with distractor-based retrieval. However, this is not the only way in which we deal with irrelevant stimuli, and neither is it the only manner in which irrelevant stimuli influence our actions. Another

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<sup>1</sup> Shared Co-Authorship Tarini Singh & Ruth Laub. This paper came about in the process of my doctoral studies, but does not count towards the fulfilment of the official requirements for this dissertation.

outcome of encountering an irrelevant stimulus is distractor inhibition. Distractor inhibition is indispensable to our daily functioning in our environment. Distractor inhibition allows us to inhibit irrelevant stimuli so that it is easier to select those stimuli which are relevant to our intentions. Both mechanisms, distractor-based retrieval and distractor inhibition, are aids to dealing efficiently with the large amount of sensory input from the environment. Distractor inhibition is typically discussed in the negative priming literature (e.g. Fox, 1995; Tipper, 2001). However, inhibition is also observed outside of the negative priming paradigm – like in the distractor-response binding paradigm.

Since distractor-response binding is studied in a distractor-to-distractor repetition paradigm, it is possible to observe both distractor-based retrieval and distractor inhibition. Distractor-based retrieval is the observation of response retrieval due to a repeated distractor, evident in the interaction of response relation and distractor relation, i.e. distractor repetition facilitates responding if the response is also repeated, but hinders responding if the response is changed. Distractor inhibition on the other hand, is the observation of carry-over inhibition for a repeated distractor, evident in the main effect of distractor relation, i.e. faster responding when a distractor is repeated compared to when it is changed. Such a paradigm allows a measurement and comparison of both these effects. Both of these effects have been found to operate independently of each other. For instance Giesen, Frings, and Rothermund (2012) found that while compatibility of the distractors (compatible, incompatible, or neutral distractors) affected the strength of the inhibition, it had no effect on the strength of the distractor-response binding effect. They observed that incompatible distractors produced stronger inhibition effects compared to compatible and neutral distractors, however, there was no difference in the binding effects for the different distractor compatibility types. Although we thus know that both effects are independent of each, we do not know what processes underlie these effects.

Looking at the literature on distractor-based retrieval, one might postulate that such retrieval is mainly a motor process. Indeed evidence has been found for direct bindings between stimuli and responses (e.g. Dobbins, Schyner, Verfaellie, & Schacter, 2004; Giesen & Rothermund, 2014). More specifically to distractor-based response retrieval, Giesen and Rothermund (2014) found evidence for separate bindings between a distractor and a target, a target and a response, and importantly, a distractor and a response. They observed that a distractor could retrieve a response even when the target was changed. Further evidence for direct bindings between a distractor and a response, comes from studies showing a specific type of error – prime retrieval errors; the finding that when a distractor is repeated in the

probe, participants erroneously respond with the response that was associated with it in the prime (Mayr & Buchner, 2006; Wiswede, Rothermund, & Frings, 2013). For instance Wiswede, Rothermund, and Frings (2013) differentiated between prime retrieval errors (errors caused by retrieval of the prime episode), flanker errors (errors caused by flanking distractors), and random errors (errors that were caused neither by prime retrieval or the flanking distractors). Within the distractor repetition condition, they found that prime retrieval errors occurred more often than either flanker errors or random errors. These findings might suggest that the process underlying the distractor-based retrieval effect is a motor process.

The literature on distractor inhibition, on the other hand, might suggest that the process underlying this effect is a stimulus based process and at a cognitive level. Distractor inhibition is typically assumed to effect stimulus representations (Houghton & Tipper, 1996). Evidence for this comes from findings in the negative priming studies in which distractors presentations switched between words and pictures (Tipper, Driver, 1988). Even though the distractor was presented once as a word and then a picture (or vice-versa) significant negative priming effects were observed, suggesting that it was the central stimulus representation that was inhibited and not just a specific picture or word. Inhibition has sometimes also been described as functioning in a manner similar to that of spreading activation (Neumann & De Schepper, 1991). Furthermore, Neill, Lissner, and Beck (1990) discussed cognitive representations of stimuli as the 'locus of inhibition' rather than a specific response.

Although the distractor-to-distractor repetition paradigm allows for a separate measurement of distractor-based retrieval and distractor inhibition, it is not possible to identify the processes underlying these two effects with a traditional RT analysis. For this purpose, in the article presented in chapter 9, along with the traditional RT analysis, another method of data analysis was employed. The parameters of the exponential Gaussian distribution were estimated and analysed separately. The Ex-Gaussian distribution is a convolution of three parameters, the exponential parameters ( $\tau$ ) reflecting the thickness and skewness of the tail, the Gaussian parameters  $s$  of ( $\mu$ ) reflecting the leading edge of the distribution and ( $\sigma$ ) reflecting the variance of the Gaussian distribution (Moutsopolou & Waszak, 2012). In a number of studies including the Stroop task, across-task priming and working memory tasks, the ( $\mu$ ) parameter has been shown to reflect motor processing and the ( $\tau$ ) parameter cognitive processing. Using such an analysis method it was possible to examine at which level of processing distractor-based retrieval and distractor inhibition occur. In the study presented in chapter 9, in the first step a more traditional analysis on the Gaussian distribution was carried out, in order to confirm that both effects were indeed present in the

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data. In a next step the parameters of the ex-Gaussian distribution were estimated and analysed separately. The distractor-based retrieval effect was expected to be observed in the ( $\mu$ ) parameter, while the distractor-inhibition effect was expected to be observed in the ( $\tau$ ) parameter.

## **6. Five Shades of Grey: Generalization in distractor-based retrieval of S-R episodes.**

*Singh, T., Moeller, B., & Frings, C. (2016). Attention, Perception & Psychophysics, 78, 2307-2312.*

# *Five shades of grey: Generalization in distractor-based retrieval of S-R episodes*

**Tarini Singh, Birte Moeller & Christian Frings**

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## SHORT REPORT

# Five shades of grey: Generalization in distractor-based retrieval of S-R episodes

Tarini Singh<sup>1</sup> · Birte Moeller<sup>1</sup> · Christian Frings<sup>1</sup>Published online: 8 September 2016  
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**Abstract** Binding theories assume that a stimulus and a response made to it are bound together, as in the case of the theory of event coding, in an *event file* (Hommel, Müsseler, Aschersleben, & Prinz, *Behavioral and Brain Sciences*, 24(05), 849–937, 2001). This binding occurs after even a single encounter with the stimulus and the response. Repeating any part of the event file will cause the entire file to be retrieved. However not only are relevant stimuli bound with responses but even irrelevant stimuli that co-occur with the target can be bound with the response, and repeating such a distractor will result in the event file being retrieved. Yet previous studies focused on retrieval effects due to repetition of the same distractor. In this experiment we analysed whether perceptually similar distractors still influence actions due to distractor-based retrieval of responses. Thirty-one participants responded to the shape of the stimulus while ignoring the luminance (5 different shades of grey). The similarity of the stimulus luminance between two consecutive trials influenced response times on response repetition trials. Response repetition effects were particularly facilitated with exact repetitions of the irrelevant feature luminance, and the strength of this effect diminished with increasing dissimilarity of luminance in a linear fashion. We conclude that response-retrieval effects due to distractor bindings follow the rules of generalization, as discussed in the conditioning literature.

**Keywords** Perception and Action · Attention and executive control

Often, our actions in situations that require quick responses are fast and perceived as requiring relatively little effort. A number of processes allow the cognitive system to function in this manner. One these is the fast integration of stimulus (S) and response (R) features into S-R bindings, and the retrieval of such bindings (Henson, Eckstein, Waszack, Frings, & Horner, 2014). S-R bindings are temporary associations between a stimulus and a response. If the stimulus is reencountered while the binding is still intact or can be retrieved, making the same response is faster because the required response information is available. Stimulus and response codes pertaining to an episode are integrated in an *event file* (Hommel, 1998, 2004; Hommel, Müsseler, Aschersleben, & Prinz, 2001). An event file is thus a temporary structure containing bindings between stimulus and response feature codes of an episode.

Even irrelevant stimuli or features can be integrated into event files and are consequently integrated with the response—this has been called *distractor-response binding* (Frings, Rothermund, & Wentura, 2007). Thus, repeating the distractor can retrieve the response with which it was integrated. After distractor-response integration, repeating the distractor or irrelevant feature is advantageous if the response is repeated because the retrieved response information matches the response to be made. By contrast, repetition of a distractor or irrelevant feature leads to a disadvantage if the response is changed because the retrieved response information is inappropriate. That is, distractor-response binding and retrieval is indicated by a significantly larger distractor repetition benefit in response repetition than in response change trials. Distractor-response binding effects are calculated as the

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difference of differences between distractor change and repetition in response repetition and change trials—that is, (RRDC–RRDR)–(RCDC–RCDR).

Considerable research using a prime-probe design with repeating or changing distractors (or irrelevant features) has reported evidence for distractor-based retrieval effects (e.g., Frings, 2011; Giesen & Rothermund, 2014; Mayr & Buchner, 2006; Rothermund, Wentura, & De Houwer, 2005). Distractor-based retrieval of S-R episodes has been shown with different stimuli (e.g., words, colours, pictures; Frings et al., 2007; Frings, Moeller, & Rothermund, 2013; Hommel, 1998; Hommel & Colzato, 2009; Mayr & Buchner, 2006; Moeller & Frings, 2011; Moeller, Rothermund, & Frings, 2012; Rothermund et al., 2005). However, in nearly all studies investigating distractor-response binding effects, distractor repetition always implied a perceptually *exact* repetition of the distractor (see Frings et al., 2013, for an exception).

In a related paradigm, Denkinger and Koutstaal (2009) analysed S-R bindings between targets and responses if a perceptually and conceptually similar stimulus was repeated. They presented either the exact same item or a different exemplar of it (e.g., different pictures of a guitar). Still, Denkinger and Koutstaal observed evidence for retrieval of S-R episodes and concluded that such repetition effects can be generalized to new stimuli. In their study for perceptually similar stimuli, the concepts (e.g., guitar) of the presented objects were repeated and may have started response retrieval. However, because the extent of similarity between the original item and its different exemplars was not explicitly varied, it is difficult to decide what part of retrieval was due to concept repetition and what part due to repetition of perceptually similar stimulus features.

In this study we expand the idea of generalization of retrieval effects to distractor-based retrieval while keeping the contribution of distractor concept repetition constant. In addition, we systematically varied the degree of perceptual similarity between repeated irrelevant features. The theoretical motivation for systematically varying the degree of similarity between repeated irrelevant features stems from comparison of binding effects with learning (e.g., Colzato, Raffone, & Hommel, 2006; Giesen & Rothermund, 2014; Henson et al., 2014).

Although associations formed in learning paradigms are typically longer lasting than those in binding paradigms, there are similarities between binding and learning. For instance, Giesen and Rothermund (2014) discussed structural similarities between Pavlovian conditioning and distractor-response bindings. They compared the target in the distractor-response binding paradigm to the unconditioned stimulus in Pavlovian conditioning, the response to the target to the unconditioned response, and the distractor to the conditioned stimulus. Pairing the target (unconditioned stimulus) and the distractor

(conditioned stimulus) leads to an association between target and distractor and distractor and response (see Giesen & Rothermund, 2014, for a detailed discussion). If these structural similarities are more than a coincidence, and binding and conditioning indeed share similar mechanisms, then other phenomena observed for learning should be observable for binding effects. One example might be context-dependent retrieval (Godden & Baddeley, 1975). Godden and Baddeley (1975) observed better performance when environmental context remained constant for learning and retrieval. Studies in S-R bindings have observed a comparable effect. Repeating an item initially presented in a particular task context in a different context retrieved the initial task set (Waszak, Hommel, & Allport, 2003). Thus, task set seems to be integrated in the event file and retrieved if the stimulus is repeated.

Here we focused on another possible example. Generalization is a central concept in Pavlovian conditioning: Conditioned responding can occur in circumstances that are similar to those in the learning stage but not exactly the same (Pearce, 1987). Closely related to generalization is the concept of generalization decrement: in circumstances similar but not exactly the same as in the learning stage, this transfer of learning is not complete. Thus, generalization is observed when at least some of the features from the training phase are repeated in the test phase and the strength of generalization is dependent upon how much is repeated or how similar the stimuli are (Pearce, 1987). Assuming binding and conditioning rely on comparable mechanisms, we hypothesized that generalization might also be observed in binding paradigms. In line with the principle of generalization decrement, the effect would be expected to decrease with increasing dissimilarity between the stimuli.

We used a prime-probe paradigm that orthogonally varied response and irrelevant feature repetition between prime and probe events (see Frings et al., 2007) and systematically varied perceptual deviations of the distractor feature between integration event and retrieval event. If binding mechanisms resemble mechanisms in Pavlovian conditioning, then we expected decreasing strength of the distractor-response binding effect with increasing perceptual differences.

## Experiment

### Method

**Participants** Thirty-one (5 male) students from the University of Trier participated for either partial course credit or monetary reimbursement. The median age of the participants was 21 years (range 18–26 years). All participants reported normal or corrected-to-normal vision. The sample size was calculated according to previous distractor-based binding effects, which typically lead to middle to large sized effects (Cohen's *d*

between .4 and 1). Thus, we planned to run  $N = 30$  participants, leading to a power of  $1 - \beta = .96$  (assuming an  $\alpha = .05$ ) (GPower 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007).

**Design** The experimental design consisted of two within-subjects factors; response relation (repetition vs. change) and distractor relation (exact repetition vs. repetition with 1 step deviation vs. repetition with 2 steps deviation vs. repetition with 3 steps deviation vs. change).

**Materials** The experiment was run using E-Prime Software, Version 2.0. Four shapes (square, diamond, cross and triangle) and five lightness values (10, 30, 50, 70 and 90 of the  $L$  value in the LAB colour space; the  $a$  and  $b$  values were kept at zero) were varied orthogonally, resulting in 20 different stimuli. Stimuli were  $1.43^\circ \times 1.43^\circ$ . They were presented on a  $3.34^\circ \times 3.34^\circ$  black-and-white striped background. Stimuli were displayed on a standard LCD monitor with a white background.

**Procedure** Participants were tested individually in soundproofed chambers.

Experimental instructions were presented on-screen and summarized by the experimenter. Participants were asked to place their right hand index finger on the  $J$  key and their left hand index finger of the  $F$  key at the beginning of the experiment and were asked to respond to the shape of the stimulus with the appropriate key press. Two shapes were mapped to one key. Half the participants responded to the square and cross shapes with the  $F$  key and the diamond and triangle shapes with the  $J$  key. The other half received the opposite mapping.

The stimuli were presented in the middle of the screen. Each trial began with a fixation cross at the centre of the screen for 1,000 ms; participants were instructed to fixate this cross. The fixation cross was followed by the prime display, which remained on-screen until a response was detected, then a blank screen followed for 500 ms, and then the probe display, which remained on screen until a response was detected. Once a response was detected, the next trial began. The experiment was divided into a practice and a test block. The practice block consisted of 32 trials, where participants learned the appropriate responses. Feedback was provided after every response, indicating whether it was correct or not. The test block consisted of 600 trials. After half of the trials, participants were instructed to take a self-paced break. In the test block, feedback was only provided after incorrect responses.

Responses were indicated by the form of the target. In response repetition (RR) trials, the form of the target in the prime and probe always indicated the same response. In response change (RC) trials, the form of the target in the prime and probe always indicated different responses. Lightness

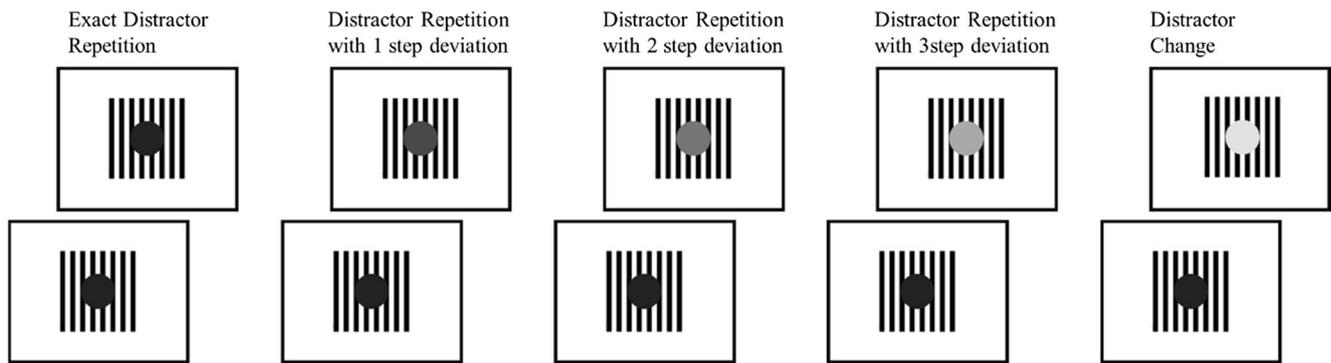
values were used as distractor features. In distractor repetition (DR) trials, lightness value of the stimulus could either be exactly repeated or could be repeated in lightness values of varying degrees of similarity (with similarity decreasing with increasing difference in lightness value). There were three different degrees of similarity, the most similar (one step deviation) varying by 20 units of the  $L$  value, the middle by 40 (two steps deviation), and the least similar by 60 (three steps deviation). Trials including the largest possible lightness value change between prime and probe (80 units) were defined as distractor change (DC) trials (see Fig. 1).

## Results

**Reactions times** Only trials with correct responses to both prime and probe were included in the analysis. Trials shorter than 200 ms or longer than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant (Tukey, 1977) were not included in analysis. This resulted in a total of 11.73 % of the data being excluded from the RT analysis (0.01 % fast responses, 4.78 % slow responses, 3.2 % prime error rate, and 3.74 % probe error rate). See Table 1 for mean RTs and probe error rates.

In a  $2$  (target relation)  $\times 2$  (response relation)  $\times 5$  (distractor relation) MANOVA on probe response times, the factor target relation (repetition vs. change) did not further modulate any of the relevant effects. The same was true for probe error rates. Similar results have been reported in other studies (e.g. Giesen & Rothermund, 2014). For the sake of clarity, we therefore collapsed the target-relation factor. Probe response times were analysed in a  $2$  (response relation)  $\times 5$  (distractor relation) MANOVA with Pillai's trace as the criterion.

Significant main effects for response relation,  $F(1, 30) = 67.64$ ,  $p < .001$ ,  $\eta^2 = .69$ , and distractor relation,  $F(4, 27) = 2.96$ ,  $p = .038$ ,  $\eta^2 = .31$  were observed indicating faster responses in trials with repeated responses and faster responses with increasing similarity of the distractors. The interaction of response relation and distractor relation was also significant,  $F(4, 27) = 6.00$ ,  $p = .001$ ,  $\eta^2 = .47$ , indicating that repeating the exact lightness value when the same response was required facilitated responding, and this facilitation weakened with increasing dissimilarity between lightness values. In the same sense, repeating the exact lightness value when the response changed from prime to probe interfered with responding, and this interference decreased with increasing dissimilarity between prime and probe lightness values. To pinpoint this interaction, distractor-response binding effects (i.e. the interaction of Response Repetition  $\times$  Distractor Repetition) were computed and compared across different levels of lightness deviation. We used the largest possible deviation as the distractor change condition. Thus, four distractor-response binding effects could be computed—one with exact repetition of the distractor in the distractor repetition condition and three



**Fig. 1** Distractor repetition and distractor deviations. In exact repetition trials, the exact same lightness value was repeated. In distractor repetition trials with one step deviation, the next higher or lower lightness value was presented. In distractor repetition trials with two steps deviation, a lightness value that was two values higher or lower was presented. In

distractor repetition trials with three steps deviation, a lightness value that was three values higher or lower was presented. In distractor change trials, the lightness value that was four values higher or lower was presented

distractor-response binding effects with increasing lightness deviations in the distractor repetition condition. The distractor-response binding effects were submitted to a single-factor ANOVA, with the strength of deviation as the only factor. The strength of deviation was significant  $F(3, 28) = 5.81, p = .003, \eta^2 = .38$ , indicating the largest distractor-response binding effect for an exact replication and progressively weaker effects with increasing deviation. The linearly decreasing effects were reflected in the significant linear trend,  $F(1, 30) = 11.29, p = .002, \eta^2 = .27$  (see Fig. 2a).

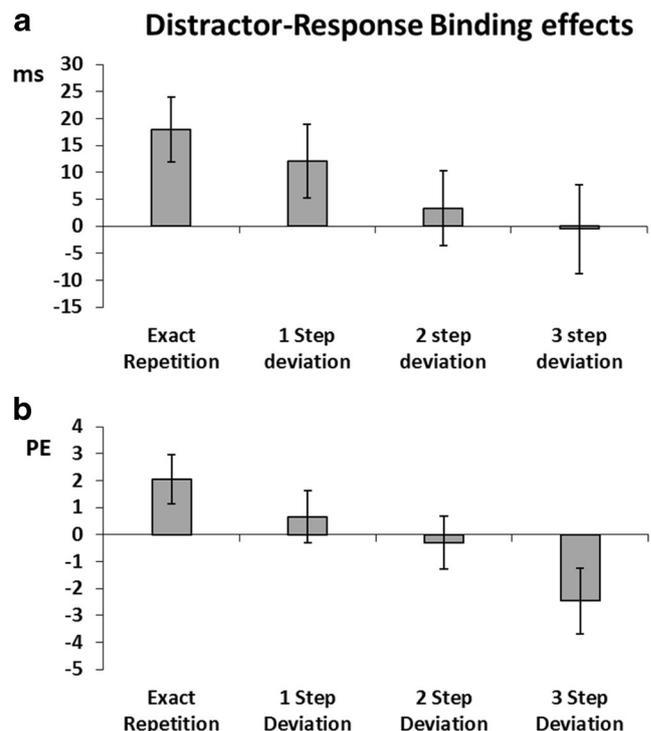
**Error rates** The same MANOVA was conducted on probe error rates yielding a significant interaction of response relation and distractor relation,  $F(4, 27) = 3.7, p = .016, \eta^2 = .35$ , indicating binding. None of the other effects were significant,  $F_s < 3.7, p_s > .229$ . As with the RTs, the same four distractor-response binding effects were computed and were submitted to a single-factor ANOVA, with the strength of deviation as the only factor. The strength of deviation was significant,  $F(3, 28) = 4.85, p = .008, \eta^2 = .34$ , and the linearly decreasing effects were reflected in the significant linear trend,  $F(1, 30) = 15.48, p < .001, \eta^2 = .34$  (see Fig. 2b).

**Table 1** Mean reaction times (in ms) and error rates in percentages (in parentheses)

	Response Repetition	Response Change
Distractor Repetition		
Exact Repetition	479 (2.95)	525 (5.60)
1 step deviation	484 (3.54)	524 (4.79)
2 steps deviation	490 (3.63)	522 (3.95)
3 steps deviation	492 (4.77)	520 (2.92)
Distractor Change	495 (3.91)	524 (4.51)

**Discussion**

The aim of the study was to test whether presentation of a similar but not exact same distractor could retrieve the response with which the distractor was bound, and whether the strength of this retrieval diminished with increasingly dissimilar distractors. Our results showed that this was indeed the case. Presentation of exactly the same distractor produced the strongest D-R binding effect. If the repeated distractor feature was similar but not exactly the same as the previously



**Fig. 2** Distractor-response binding effects in milliseconds for reaction times (a) and error percentages (b) for the four distractor repetition conditions. Distractor-response binding effects are calculated as the difference between distractor repetition effects in response repetition and response change trials

integrated one, we still observed binding effects. Yet the size of the binding effect decreased in a linear fashion as the dissimilarity between the distractor features in prime and probe increased.

This pattern of results is in line with the assumption that binding mechanisms are similar to mechanisms in Pavlovian conditioning. Applying the findings in conditioning to binding effects, the retrieval effect would indeed be expected to be strongest for exact repetitions but to generalize to perceptually similar stimuli. However, because the strength of generalization is dependent upon the similarity of the stimuli, the retrieval effect should also be stronger for stimuli that are similar than for stimuli with decreasing similarity. Apparently, after integrating a specific event file or instance (e.g. Logan, 1988), a stimulus showing large feature overlap with elements of the stored event file can trigger retrieval (Hommel, 1998; Moeller, Frings, & Pfister, 2016). Moreover, these results indicate that the likelihood of retrieval also increases with increasing similarity of an individual retrieving feature. In a nutshell, these data suggest the generalization and generalization decrement processes observed in Pavlovian conditioning are also observed in the binding paradigm. This might be a further indication of similarity between Pavlovian conditioning and distractor-response binding—or learning and binding processes in general (see e.g. Giesen & Rothermund, 2014; Henson et al., 2014; Moeller & Frings, 2014).

This study was not the first to find response retrieval due to repetition of perceptually different distractors. Frings et al. (2013) used pictures and sounds of animals as distractors. Distractor repetition trials were realized via repetition of animal identity, while distractor modality could change (e.g., from a picture to a sound). They observed a retrieval effect, even if distractor modality switched between prime and probe. Notably, retrieval effects in the mentioned and the present studies are interpreted to rely on different mechanisms. Frings and colleagues (2013) presented evidence for response retrieval due to *concept* repetition, excluding retrieval due to repetition of perceptual features. Our results indicate larger retrieval effects with increasing *perceptual* similarity of integrated and retrieving distractor features.

Together these studies confirm the idea that S-R bindings are not just simple associations between a specific stimulus and specific response; rather, they appear to be structured bindings involving multiple levels of representation of responses, stimuli and tasks.

Our results are also in line with previous research in repetition priming. Priming effects are observed even with presentation of different exemplars of the same object. These effects, however, are not as strong as when the same exemplar is repeated (e.g. Biederman & Cooper, 1991; more recently, Denkinger & Koutstaal, 2009). The authors found priming effects for both exact repetition as well as repetition of a different exemplar of the object. However the priming effect for

exact repetition was stronger than for repetition of different exemplars. Furthermore, they found that disruptions in priming due to decision changes occurred for both exact repetitions and repetitions of different exemplars. The authors argue that the bindings are “to some extent, abstract, in that they generalize to categorically and perceptually similar instances” (Denkinger & Koutstaal, 2009, p. 750). In addition, the present results indicate retrieval generalization on a perceptual level is also possible without additional retrieval due to repetition of an object category.

Another theoretical approach that is often considered in connection with S-R binding is the instance theory of automatization (Logan, 1988). According to this theory, each encounter with a stimulus-response episode is encoded and stored as an *instance* in long-term memory. A repeated encounter with any stored stimulus retrieves all stored instances that include the stimulus, and this retrieval-based processing competes with the newly generated response. With an accumulation of instances, the probability increases that one of the retrieval processes wins this race. Hence, responding becomes memory based rather than algorithmic-processing based with increasing experience with a certain situation. It is difficult to distinguish instances and event files (e.g. Horner & Henson, 2009; Moeller & Frings, 2014). In fact, it has been speculated that bindings are individual steps in the learning process described by Logan (e.g. Logan, 1988; Moeller & Frings, 2014). These finding seems to point to a crucial characteristic enabling bindings to contribute to learning. Because repetitions in a learning process are hardly ever exact, it appears to be adaptive that stimuli, sharing a large similarity with a stored stimulus, can also retrieve the response bound to this stimulus and further learning.

In conclusion, we found the principle of generalization, as suggested in conditioning research, also works in tasks that measure distractor-based retrieval of S-R episodes—retrieval of responses due to repetition of distractors or irrelevant features gradually declines with increasing dissimilarity of repeated distractors.

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## **7. Binding Abstract Concepts.**

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# Binding abstract concepts

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# Binding abstract concepts

Tarini Singh<sup>1</sup> · Christian Frings<sup>1</sup> · Birte Moeller<sup>1</sup>

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**Abstract** Binding theories assume that a stimulus and the response made to it are bound together in an *event file* (Hommel et al., Behav Brain Sci 24(05):849–937, 2001). Such bindings can occur even after single encounters. If the stimulus or parts of its features are repeated within the time frame in which the event file is still intact, the previously integrated response is retrieved. Stimulus–response binding can exist at a perceptual, conceptual or a response selection level (Henson et al., Trends Cogn Sci 18(7):376–384, 2014). The current experiments test whether the observed binding of concepts with responses can be extended from concrete to abstract concepts (detailedness) and whether abstract concepts can retrieve the previous response, in the absence of perceptual repetition. In the present experiment participants responded to a target feature (colour) while the detailedness of the stimulus was irrelevant to the task. The results showed a significant interaction of response relation and detailedness relation, even in the absence of perceptual repetition. This interaction is interpreted as evidence for response-retrieval due to abstract concept repetition. Thus, our data suggest a broader impact of binding mechanism on performance as even abstract concepts can be integrated into event-files and later modulate behaviour.

## Introduction

During the last 20 years, cognitive psychologists discovered that perception and action are closely intertwined rather than being separate functional modules that operate

in isolation. In this regard, the idea of ‘binding’ stimulus and response features into action plans can be seen as a key mechanism for action control. Binding theories assume that repeatedly encountering a stimulus can facilitate responding if the response is also repeated (e.g., Hommel, 1998; Horner & Henson, 2009; Rothermund, Wentura, & De Houwer, 2005). According to the *Theory of Event Coding*, stimuli that are encountered, are integrated along with the responses made to them into event files, and upon repetition, can retrieve the previous response (Hommel, Müssele, Aschersleben, & Prinz, 2001; Hommel, 1998, 2004). An event file thus contains feature codes of a stimulus and a response within a particular stimulus–response episode. It is a temporary structure that lasts for only a few seconds or until a planned action has been carried out, after which the event file disintegrates (Hommel, 1998; Hommel & Colzato, 2004; Stoet & Hommel, 1999). Should the same stimulus or part of the stimulus be re-encountered while the event file is still intact, then the response that was integrated in the same event file with the stimulus can be retrieved (an effect of stimulus–response binding). If the retrieved and the required response are identical then responding is facilitated. If however a different than the retrieved response is required a conflict arises which results in slower responding or more errors (Hommel, 2004). In addition, the integration of information into an event file is not restricted to the relevant stimulus and the response. Even accompanying stimuli that might be irrelevant to the task or irrelevant features of the target are integrated along with the response (Frings, Rothermund, & Wentura, 2007).

Stimulus–response bindings are flexible and are encoded at various levels of representation. For example, target stimuli are encoded at a perceptual level, which might facilitate identification of the stimulus, at a conceptual level, which may include retrieval of semantic information

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and at a response selection level, which may retrieve previous responses made to the stimulus (Horner & Henson, 2011; Henson, Eckstein, Waszak, Frings, & Horner, 2014). For instance, Denkinger & Koutstaal (2009) found evidence for the generalisation of S–R bindings to stimuli that were similar (different exemplars of the same category) to previously presented stimuli. This result was taken as evidence for conceptual bindings between the stimulus and the response. In the same vein, Frings, Moeller and Rothermund (2013) found that after seeing a picture of a particular animal as a distractor, presenting the sound, typical of that animal as the distractor in the next trial retrieved the response bound with the picture of it. Hence, it was not necessary to repeat a perceptually identical distractor in order for it to retrieve the response. Instead a conceptually related stimulus retrieved the response as well. This finding can be explained by the assumption that like the target stimuli (Denkinger & Koutstaal, 2009; Henson et al., 2014), even the distractors are processed up to a conceptual level before integration and that repetition of the concept can then trigger response retrieval. Yet, at a closer look it is not clear whether the findings in the mentioned studies of Frings and colleagues (2013) or Denkinger and Koutstaal (2009) can be seen as strong evidence in favour of concept binding in general as we will outline below. The aim of the present article is therefore to yield clear-cut evidence for the retrieval of S–R episodes due to the repetition of a concept without repeating any perceptual feature.

With regards to concepts and conceptual learning there is a well-known distinction in the literature between concrete concepts and abstract concepts. Concrete concepts are those that refer to specific things (e.g. a table) and abstract concepts refer to concepts that are usually exist only as ideas (e.g. freedom). Concrete concepts are observed to have an advantage over abstract concepts in recall and sentence judgement tasks (e.g. Holmes & Langford, 1976; Nelson & Schreiber, 1992; Paivio, Walsh, & Bons, 1994). This advantage has been described by the dual-coding theory (Paivio, 1991) and the context availability model (Kieras, 1978; Schwanenflugel & Shoben, 1983). Both theories explain the benefits of concrete over abstract concepts by larger amounts of diverse information that are assumed to be activated by concrete as compared to abstract concepts. Moreover, Plaut & Shallice (1991) suggested that concrete and abstract concepts differ in the number of semantic representations they have, with concrete concepts having a larger number of representations on average.

Although it can be assumed that conceptual bindings are possible (Henson et al., 2014; Denkinger & Koutstaal, 2009; Frings et al., 2013), in the Frings et al. (2013) study the concepts that were used were concrete concepts (all

referring to animals) that had semantic representations in more than one modality, had a well-defined set of features that belonged to each category and were well learned. Moreover, each feature set included a clear label (bird, frog, lamb, chicken). Hence, it is possible that not the presented stimuli (or features) themselves directly caused retrieval, rather they simply reactivated a well learned label, and this reactivation of a well-known label contributed to the reported retrieval effect. Similarly in the Denkinger and Koutstaal study (2009) the stimuli presented were also concrete concepts with well-defined features and well known labels. The authors found retrieval even if they did not repeat the exact same stimulus, rather only a different exemplar of it. However it is possible that the perceptually repeated features in the different exemplar caused the retrieval at a perceptual level (e.g. even a different exemplar of a guitar still had its main components of body, neck and strings), or that perceptually similar stimuli caused retrieval (see Singh, Moeller, & Frings, 2016), or as in the Frings et al. (2013) study that the repetition of the well-known label caused the retrieval. Taken together, by using concrete concepts and possibly due to the concept-label response association introduced in the mentioned studies, it is difficult to ascribe the reported retrieval effects purely to the repetition of concepts free of perceptual feature repetition.

To get an understanding of whether concepts can generally be integrated with and later on retrieve a response, it seems therefore more promising to analyse binding effects regarding abstract concepts as they offer the possibility to avoid the procedural caveats of previous attempts to demonstrate conceptual binding, by allowing a repetition of the concept without any perceptual repetition, and by excluding retrieval due to the repetition of any well learned label.

In the present study we used the detailedness (whether highly detailed or not highly detailed) of the stimuli as an abstract concept that was completely irrelevant to the task and analysed S–R binding effects when the detailedness repeated or changed. We used the detailedness of the stimulus as an operationalization of an abstract concept. Concrete concepts refer to physical entities, that have spatial boundaries and perceivable attributes (Wiemer-Hastings & Xu, 2005). The currently used concept of detailedness has none of these attributes; Firstly, it is not a physical entity, and it does not exist in a concrete form—in as much as there is no prototypical exemplar of a detailed banana, as there are for concrete concepts. Also, there is no particular selection of features that must be present in order for the stimulus to be classified as highly detailed or not. Secondly, it is not spatially bound by definite boundaries, except that of the object to which it refers. And finally there is no clear label for this concept, rather the participants

must make up a label during the course of the experiment (e.g., ‘has a lot of detail’ vs. ‘has not much detail’). In other words, unlike concrete concepts the presently used concept did not have a definite label prior to the beginning of the experiment. Thus, unlike in previous studies, if evidence of binding is found in the present study, it cannot be attributed to repetition of specific perceptual features or clear/well learned labels. In the experiment reported below, evidence of S–R binding due to abstract concept binding would be reflected in the interaction of abstract concept relation and response relation.

## Experiment

Typically in studies that test stimulus–response binding effects with irrelevant features in prime–probe designs two stimulus features are orthogonally varied, one is response relevant and the other is not. It is assumed that after each response both features and the response are integrated into a short-lived event-file. Repetition effects of the irrelevant feature in the probe depend on response repetitions. If the irrelevant features repeats from prime to probe while the response changes, repetition benefits are smaller than if the response repeats, too (often costs instead of benefits are observed). The reason is that the irrelevant features retrieve the response from the prime which can be compatible or incompatible to the demanded probe response.

In the present experiment, two stimulus features were orthogonally varied, one was response relevant (colour) and the other was response irrelevant (detailedness). Participants classified the colour of the stimuli (banana) by pressing one of two possible keys, while ignoring the detailedness (whether the stimulus was highly detailed, i.e. with a lot of individual features, or whether it was not highly detailed, i.e. with only one individual feature) of the stimuli. In response repetition conditions, the colour was repeated from the prime to the probe, and in response change conditions, the colour was changed. In distractor repetition conditions the same detailedness level was repeated from the prime to the probe, and in distractor change conditions, the detailedness level was changed. Importantly, we made sure that when the detailedness repeated from prime to probe, the individual features (that made up the detail) were never repeated. Since in the present study none of the individual features were perceptually repeated, retrieval could not occur due to the perceptual repetition of these features. Further, because the concept of detailedness is not a concrete one consisting of a prototypical exemplar, or of a well-defined set of features and/or a well-defined label, retrieval could not be due to the repetition of these factors either. Any retrieval then, must be due to the repetition of the category, experienced by the

participants only during the experiment, which we call ‘detailedness’ of the stimulus.

## Method

### *Participants*

Thirty-three students (4 male) from the University of Trier participated for either partial course credit or for monetary reimbursement. The median age of the participants was 20 years (18–29). The age data of one participant was not logged. All participants reported normal or corrected-to-normal vision. The sample size was calculated according to previous distractor-based binding effects, which typically lead to middle to large sized effects (Cohen’s  $d$  between 0.4 and 1). Thus, we planned to run a minimum of  $N = 30$  participants, leading to a power of  $1 - \beta = 0.96$  (assuming an  $\alpha = 0.05$ ) (GPower 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007).

### *Design*

The experimental design consisted of two within subject factors, namely, response relation (repetition vs. change), and detailedness relation (repetition vs. change).

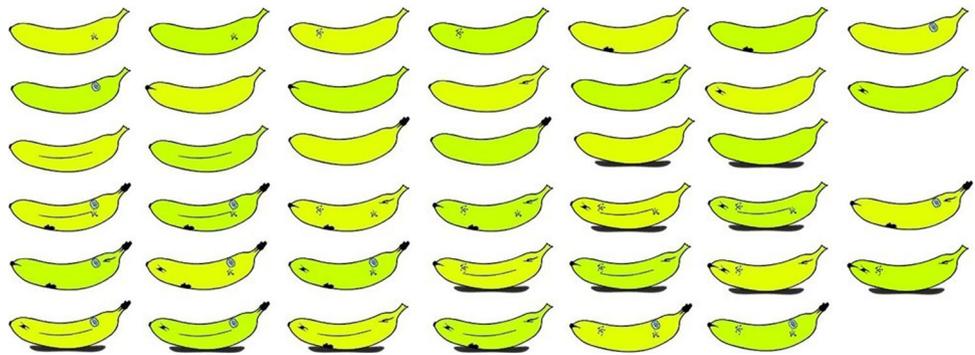
### *Materials*

The experiment was run using the E-Prime Software, Version 2.0. The stimuli were 40 pictures of bananas 20 of which were yellow and 20 green, and 20 of which had low detailedness and 20 high detailedness (Fig. 1). The images were  $1.7^\circ$  high and  $4.2^\circ$  wide and the viewing distance was approximately 60 cm. The stimuli were displayed on a standard LCD monitor with a white background.

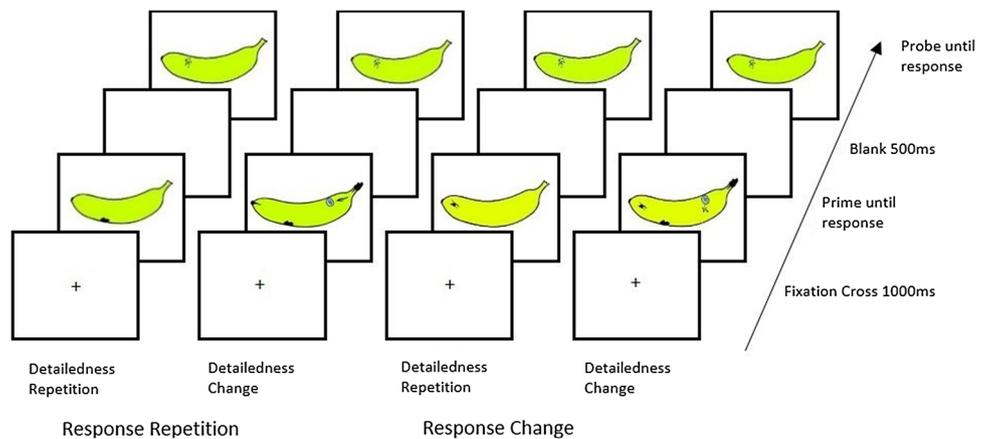
### *Procedure*

The participants were tested individually in soundproof chambers. The experimental instructions were presented on screen and summarized by the experimenter. The participants were asked to place their left hand index finger on the F key and their right hand index finger on the J key. The participants were instructed to respond to the colour of the displayed stimulus with the appropriate key press. Half the participants responded to the colour yellow with the ‘F’ key and green with the ‘J’ key and the other half of the participants received the opposite mapping instructions. The colours were made similar to each other, so as to make the classification task more difficult. The stimuli were always presented in the middle of the screen. The trials were ordered in a prime–probe sequence, with the following sequence of events. Each trial began with a fixation

**Fig. 1** Stimuli used in the experiment



**Fig. 2** The trial sequence for each of the four conditions in which response relation and level of detail relation were orthogonally varied, without repetition of individual features within a single trial



cross presented at the center of the screen for 1000 ms, the participants were asked to fixate the cross as that was the position the stimuli would appear at. The fixation cross was followed by the prime display, which remained on screen until a response had been made. A blank screen followed the prime for 500 ms, and was followed by the probe display which remained on screen until a response was made. Once a response to the probe was made the next trial started immediately (Fig. 2). The experiment was divided into a practice block and a test block. The practice block consisted of 32 trials where the participants learned the appropriate responses. The test block consisted of 320 trials.

## Results

### Reaction times

Only RTs with correct responses to both the prime and the probe were included in the analysis. RTs that were either shorter than 200 ms or longer than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant (Tukey, 1977) were not included in the analysis. As a result 10.96% of the data was excluded from the RT analysis. Note that the result pattern does not hinge on these particular outlier criteria.

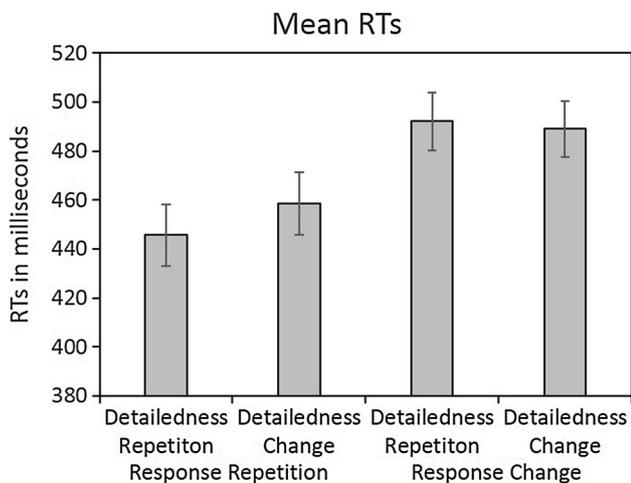
The data was analysed in a 2 (response relation: repetition vs. change)  $\times$  2 (detailedness relation: repetition vs. change) MANOVA with Pillai's trace as the criterion. The mean RTs and error rates are shown on Table 1, mean RTs are also depicted in Fig. 3. A significant main effect for response relation,  $F(1, 32) = 81.36$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.718$ , and a significant main effect detailedness relation,  $F(1, 32) = 14.01$ ,  $p = 0.001$ ,  $\eta_p^2 = 0.305$ , was observed indicating faster responses if the response was repeated and faster responses if the detailedness was repeated, respectively. A significant interaction of response relation and detailedness relation was observed,  $F(1, 32) = 20.48$ ,  $p < 0.001$ ,  $\eta_p^2 = 0.390$ , indicating more facilitation due to the repetition of detailedness in response repetition than in response change trials.

### Errors

The same analysis was run for error rates. The only significant effect was a main effect of response relation,  $F(1, 32) = 12.25$ ,  $p = 0.001$ ,  $\eta_p^2 = 0.277$ , suggesting lower error rates if the response was repeated. No other effect reached significance, numerically however the data pattern matched that of the reaction time analysis.

**Table 1** Mean reaction times and error rates (in parenthesis) for response relation  $\times$  detailedness relation

	Distractor relation	
	Repetition	Change
Response relation		
Repetition	446 (2.47)	459 (2.69)
Change	492 (5.63)	489 (5.12)

**Fig. 3** The mean RTs depicting the interaction of response relation and detailedness relation

## Discussion

The aim of the current experiments was to test whether abstract concepts are integrated with responses and can retrieve the response upon repetition. We used abstract concepts that did not refer to specific objects, had less contextual information than concrete concepts and less semantic features associated with them (see Paivio, 1991; Schwanenflugel & Shoben, 1983; Plaut & Shallice, 1991). That is, abstract concepts in the present study, did not have clear labels or a well-defined set of features. Our data suggests that even such concepts are integrated with responses and retrieve the response even in the absence of perceptual repetition.

In the present study the features were controlled such that the concept was repeated without any repetition of any individual features of which it was comprised. The response relation and detailedness relation interaction was significant, indicating response integration with and response retrieval due to the repetition of the detailedness. Since no individual feature was repeated, it can be safely concluded that the retrieval in this case was due to the repetition of the concept, rather than any individual feature. The present findings might be seen as an extension of the generality of the S–R bindings. According to the theory of

event coding, feature codes of a particular stimulus and the response to it are stored in event files. If one of these features is repeated, then the entire event file is retrieved. Thus, in such a case, each of the individual features making up the concept of detailedness would have been stored within the event file. However, since none of the individual features were perceptually repeated, there could be no retrieval based purely on perceptual repetition of these features. What was however repeated, was the detailedness of the stimulus—each time, however, with a different set of individual features. Thus retrieval was due to the repetition of the concept itself, and not due to any of the individual features of the concept.

The present findings enhance previous studies on concept-binding. Using concrete concepts that referred to specific objects, had a well-defined set of features and clear labels Denkinger and Koutstaal (2009) and Frings and colleagues (2013) also found that concepts are integrated in event files and can retrieve responses. However, in the previous studies on binding, there was always repetition of some feature (like certain perceptual features or response features) which could have caused the retrieval. We can therefore not be sure whether retrieval was actually due to the repetition of the concept, or due to the repetition of certain features. In the present study however, such a repetition was avoided by not repeating any perceptual feature, and by not using a concept that has a clear label. Although concrete concepts have an advantage over abstract concepts in tasks such as sentence judgement and recall (e.g. Holmes & Langford, 1976; Nelson & Schreiber, 1992) they both seem to function in a similar manner in action control as both are integrated in event files and can retrieve the responses on repetition. However, one possible shortfall in the present experiment is that the simpler stimuli (i.e. with only one distractor feature) have slightly brighter luminance than the more complex stimuli, and the subjects might have used luminance in addition to detailedness for retrieval.

Since abstract concepts do not refer to specific objects, the individual set of features that they must contain is not as well defined as with concrete concepts. For instance, the concept of a table always includes a surface and legs. By contrast, the concepts used in the present study consisted of a number of individual features that made up the concept, while none of those specific features were necessary. That is, any feature combination would suffice, as long as feature co-occurrence of a certain number of features was secured. Despite this variability and in the absence of perceptual repetition, binding was observed. This might suggest that event files are flexible enough to incorporate and be activated by features belonging to a particular concept that might have been absent at the time of integration. One might therefore speculate, that S–R bindings

play a role in contingency learning. The *instance theory of automatization* (Logan, 1988) has been proposed to account for such learning (e.g., Schmidt, De Houwer, & Besner, 2010). Event files are not easily distinguishable from the central concept in this theory—the instance (Horner & Henson, 2009; Moeller & Frings, 2014, 2017) and both—instance and event file—have been discussed as being early steps in the learning process (Logan, 1988; Moeller & Frings, 2014). However, especially during this beginning of learning, it is important that event files are flexible enough to integrate concepts that are not well learned yet. It would also be beneficial to the learning process if they included and were retrieved by features that were not necessarily perceptually present at integration. Such a broad understanding of binding would allow features that do not occur regularly as well as concepts that are not yet learned to be integrated in the event file and retrieve responses, which might then enable S–R learning. In fact, Schmidt, De Houwer and Rothermund (2016) argue that the retrieval processes that lead to such short term binding effects, are the same processes that support learning.

There are other theoretical approaches that might be relevant for the data pattern observed in the present experiment. Firstly, the *episodic retrieval account of Negative Priming* (Neill, 1997; Neill & Valdes, 1992) that is actually an enhancement of the instance theory to irrelevant features (Logan, 1988). This account assumes that ignored features are stored in episodic traces as ‘to-be-ignored’ features and upon repetition might interfere with responding (since they retrieve a do-not-respond tag). Although there is evidence that the type of episodic retrieval assumed in Negative Priming research and binding research is the same (e.g., Henson et al., 2014) the present data cannot easily be explained by such a mechanism unless one assumes that a specific response is integrated with the concept and not an unspecific do-not-response tag (see e.g., Mayr & Buchner, 2006, the prime-response-retrieval account of Negative Priming and Rothermund, Wentura & De Houwer, 2005).

Another approach is the *bypass rule* (Fletcher & Rabbitt, 1978). The bypass rule suggests that, in binary tasks, if any part of the previous stimulus is repeated, then participants strategically repeat the previous response as well. If however nothing is repeated, they change their response. Yet, regarding binding effects in general, previous research has argued that these effects do not rely on the bypass rule. For example, Frings & Rothermund (2011) found binding effects (i.e., a significant interaction of response relation and distractor relation) even if participants completed an intervening task and made a different response between the prime and the probe—something that is not easily explained in terms of the bypass rule. Also regarding the present data, the bypass rule cannot explain the pattern of

results particularly in our RT data. The bypass rule explicitly states that upon repetition of perceptual features the same response is facilitated. Yet, we never repeated perceptual features between prime and probe other than the response feature color (irrespective of concept repetition). Thus, applying the strategic bypass rule would require participants to actively judge every stimulus as high vs. low detail despite being perceptually different and then decide to repeat the response if the level of detail repeats. In a nutshell, the bypass rule has to assume several extensions of the original theory to explain our result pattern.

In conclusion, the results indicate that abstract concepts function like concrete concepts within S–R binding paradigms. They are integrated with responses and can retrieve them upon repetition, even in the absence of perceptual repetition of any of the individual features.

#### Compliance with ethical standards

**Conflict of interest** Tarini Singh declares that she does not have any conflict of interest. Christian Frings declares that he has no conflict of interest. Birte Moeller declares that she has no conflict of interest.

**Ethical approval** All procedures performed in the study involving human participants were in accordance with the institutional ethical standards and in accordance with the 1964 Helsinki declaration and its later amendments.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

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## **8. May I Have Your Attention Please: Binding of Attended but Response Irrelevant Features.**

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RUNNING HEAD: Binding the Attended Feature

May I Have Your Attention Please: Binding of Attended but Response Irrelevant Features.

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**Abstract**

Stimuli can be integrated with the response made to them, and if a stimulus is repeated, it can retrieve the previously integrated response. Further, even irrelevant features can be integrated and, upon repetition, retrieve the response. Yet, the role of attention on feature binding is not clearly understood. Some theories assume a central role of attention (e.g., Treisman, & Gelade, 1980; Logan, 1988), while others find no influence of attention on feature binding (e.g., Hommel, 2005). In the present experiments the effect of attention on integration of two different response-irrelevant features of the same stimulus was examined. In two experiments participants responded to the colour (response feature) of word stimuli while two irrelevant features (word type and valence) of the words were systematically varied. Participants' attention was directed either to one or the other of the response-irrelevant features, by asking participants to report that feature at the end of the trial. Feature-response binding effects in the colour task were only observed for attended response-irrelevant feature. The results indicate that feature binding is not only very flexible, but also sensitive to attentional distributions. It is also automatic in the sense that as long as attention is available feature binding occurs, irrespective of task-specific demands.

Human action planning and execution is a central aspect of everyday life.

Understanding action control at the micro-level (e.g., at the level of feature integration and response selection) was a goal of cognitive psychology right from the beginning (e.g., Ach, 1910; James, 1890). In the last two decades, researchers have agreed on the idea that responding entails integration of stimulus and response features into short-lived episodic compounds (e.g., Hommel 1998; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Logan, 1988). These stimulus-response bindings enable retrieval of the response if the stimulus is repeated. According to the *Theory of Event Coding* (Hommel, 2004; Hommel et al., 2001), feature codes of the stimulus and the response are integrated into *event files* which are feature compounds, much like *object files* in perception research (see Kahneman, Treisman, & Gibbs, 1992), with the difference that response features are included. Should any of the feature codes be repeated, the entire event file is retrieved, resulting in response facilitation if all the features, including the response are repeated, and to response interference if some of the stimulus or response features change.

Interestingly, not only are the stimulus features we respond to integrated with the response, rather even irrelevant features and even entire irrelevant stimuli that occur simultaneously or in close temporal contiguity with the target stimulus are integrated with the response – a finding labelled *distractor-response binding* (Frings, Rothermund, & Wentura, 2007). The Stimulus-Response Retrieval model (Rothermund, Wentura, & De Houwer, 2005) postulates retrieval of the previously executed (and stored) response upon repetition of the distractor. This retrieval, however, has different effects on responding depending on whether the response remains the same or changes. If a distractor is repeated it retrieves the integrated response and facilitates responding in the case of a repeated response, since the retrieved response matches the response that is to be executed. However, distractor repetition hinders responding if the required response is changed, since the retrieved response does not match the response that must be executed. The distractor-response binding effect has been shown to

exist with a number of different types of distractors in the visual, auditory, and tactile modalities (e.g. Frings, et al., 2007; Mayr & Buchner, 2006; Moeller & Frings, 2011; Rothermund, et al., 2005), furthermore it has been shown to exist within as well as across modalities (Frings, Moeller, & Rothermund, 2013).

However, the role of attention for feature-response binding effects is still not clear. On the one hand, attention is assumed to be necessary for the integration process (e.g. Treisman & Gelade, 1980; Logan, 1988). According to the *Feature Integration Theory of Attention* (Treisman & Gelade, 1980) stimulus features are encoded separately and are later integrated together – a process which requires attention (Treisman & Gelade, 1980). The authors thus likened attention to “‘glue’ which integrates the initially separable features into unitary objects” (Treisman & Gelade, 1980, p. 98). Another integration theory, the *Instance Theory of Automatization* (Logan, 1988) is based on the assumption that “encoding into memory is an obligatory, unavoidable consequence of attention.” (Logan, 1988, p. 493). This suggests that attended stimuli are inevitably encoded, and upon repetition retrieve their previous instance – in short attention seems to be necessary for effects of instance retrieval. In line with this, spatial attention has been shown to be necessary for feature integration (Van Dam & Hommel, 2010) and integration of distractor stimuli (Moeller & Frings, 2015). For example, Moeller and Frings (2015) observed integration in a dual task setting, if both tasks were presented in the same spatial location, whereas presenting the tasks in two separate locations hindered integration between distractor stimuli and responses. Moreover, additional stimuli that are relevant due to a second task can also be integrated with responses in a choice reaction task (Moeller & Frings, 2014). Thus suggesting that additional stimuli can become integrated in a given event file, as long as these stimuli receive sufficient attention.

However, regarding different task irrelevant features of an individual stimulus, it is still unclear whether these are automatically integrated to similar degrees, or whether

attentional allocation also influences bindings within a single stimulus. Hommel (1998, 2004) suggested that only features that are relevant to the task or that are salient are likely to be integrated. In his experiments he observed stronger binding effects for the feature that was relevant to the response compared to those features that were not relevant to the response. Binding effects were observed for task irrelevant features as well, but they were strongest for the response relevant feature. Hence, Hommel and colleagues suggested that although integration is an automatic process there is an ‘attentional weighting’ system by way of which those features that are more relevant are more likely to retrieve an integrated response (Hommel, 2004; Hommel, Memelink, Zmigrod, & Colzato, 2014; Memelink & Hommel, 2013). Memelink and Hommel (2013) refer to this weighting of relevant features as ‘intentional weighting’. They argue that weighting in the perceptual domain may be referred to as ‘attentional weighting’, since it affects attentional processes; however, they further argue that such a weighting system also affects action selection in a similar manner, and thus use the term ‘intentional weighting’ to sum up weighting processes in both perception and action selection.

There is tentative evidence for intentional weighting of stimulus features from priming studies. Priming effects can be explained by episodic retrieval (e.g., Denkinger & Koutstaal, 2009; Horner & Henson, 2009, 2011). It has been suggested that, when a stimulus is responded to, an S-R episode (Waszak, Hommel, & Allport, 2003) or an event file (Hommel, et. al., 2001) is created, in which the stimulus and response information is stored. If the stimulus is repeated, it retrieves the response information with which it was integrated, thus resulting in shorter RTs to a repeated stimulus. Such binding effects have also been observed in task-switching contexts (e.g. Koch, Prinz, & Allport, 2005; Koch & Allport, 2006). These bindings do not have to be object specific, rather they can be of a conceptual or semantic nature as well (e.g., Denkinger & Koutstaal, 2009; Henson, Eckstein, Waszak, Frings, &

Horner, 2014). Interestingly, Spruyt, De Houwer, and Hermans (2009) found that when a stimulus had two semantic features, one affective and one non-affective semantic feature, priming effects were only found for that feature to which attention was directed via a second task. Attention was directed to either an affective feature or a semantic feature by requiring participants to classify the words on one of the two feature dimensions on 25 % or 75 % of the trials (i.e. either an affective semantic classification: positive–negative or non-affective semantic classification: animal–object). In the remaining trials, the authors observed significant priming effects only if attention was directed to the respective feature. The authors took this as evidence that feature-specific allocation of attention determined the extent to which that feature gets processed, and accordingly might reduce the extent to which other features might get processed. Thus features that receive attention (due to an additional task) are more likely to be processed to a greater extent and might thus reduce the amount of processing for other features.

Based on these assumptions one might also expect larger binding effects for attended task irrelevant features than for unattended task irrelevant features. Such a pattern may be seen as analogous to the phenomenon of ‘*overshadowing*’, as observed in forms of associative learning like classical conditioning. Overshadowing refers to the observation that, when more than one stimulus is present, the more salient of them may decrease or prevent the forming of associations between the less salient stimulus and the response (Mackintosh, 1975). Due to the attentional manipulation in the current experiments one of the stimulus features is made more salient, and stronger retrieval effects are expected for this feature.

On the other hand, however, experiments by Hommel and Colzato (2004) seem to indicate that increased attention does not necessarily lead to increased integration. In order to increase attention, participants in an instructed attention condition were asked to report a feature of the stimulus (at random) after the trial. Even though participants generally had

longer reaction times in the attended condition, suggesting that the attention manipulation had taken effect, the integration of the reported features was not significantly strengthened. Thus although it has been shown that increased attention leads to increased processing of a particular feature (Spruyt, et al., 2009), it has not been shown to influence integration of task irrelevant features (Hommel & Colzato, 2004). It should be noted though that attention was not drawn to one specific feature while other features could be ignored in the study by Hommel and Colzato (2004). Rather, the authors aimed to increase attention generally for all features. Therefore, this study does not reveal information about varying degrees of integration concerning differently attended features in one stimulus.

### *The present study*

In the present experiments, the effect of attention on the binding of responses with irrelevant features was examined. Participants responded to the colour of a word. Each word had three features; one task relevant feature - colour (yellow vs. green), and two features – an affective feature (valence: positive vs. negative) and a lexical feature (word type: adjective vs. substantive) – that were irrelevant to the colour task. The three stimulus features used, colour, word type, and valence, were selected since each of these features; colour, word type and, valence, are relatively automatically processed. Colour as a feature can be processed automatically and without focused attention (e.g. Treisman, 1988). Lexical features can be relatively automatically activated due to the automaticity of reading and language encoding (e.g. Roelofs, 1992; Pickering & Branigan, 1998), and valence as a feature can be relatively automatically processed, as evidenced by studies on affective priming (e.g. Fazio, Sanbonmatsu, Powell, Kardes, 1986). Only colour was relevant to the (RT) task and was therefore always attended. Depending on the experimental condition, one of the other two

## Binding the Attended Feature

features was relevant to a second task (and hence probably attended) but still irrelevant to the colour classification task. We expected to observe stronger binding effects for the response-irrelevant but attended features.

In particular, in one condition the lexical feature was attended to, and in the other condition the affective feature was attended to. This was achieved by asking the participants to report either the lexical or affective feature of the word (depending on the condition) at the end of some of the trials. Please note that these features were still irrelevant to the colour classification task that was used to measure binding effects. In each of the conditions, all three features of the word (colour, affective feature and lexical feature) were orthogonally varied, thus allowing us to compute the binding effect for each of the response-irrelevant features in both conditions. If the intentional weighting mechanism also influences integration of response-irrelevant features, we expected to see stronger binding effects for the attended irrelevant feature compared to the non-attended irrelevant feature.

## Experiment 1

### Method

*Participants.* Sixty students (13 male) from the University of Trier participated for partial course credit. The sixty participants were randomly assigned to one of two experimental groups. The median age was 22 years (range 18 – 33). All participants reported normal or corrected-to normal vision. The sample size was calculated according to previous distractor-based binding effects which typically lead to middle to large sized effects (Cohen's  $d$  between .4 and 1). Thus we planned to run  $N = 30$  participants in each group, leading to a power of  $1 - \beta = .96$  (assuming an  $\alpha = .05$ ) (GPower 3.1.9.2, Faul, Erdfelder, Lang, & Buchner, 2007).

*Design.* The experimental design consisted of a mixed design, with three within subjects' variables, namely, response relation (repetition vs. change), word type relation (repetition vs. change), valence relation (repetition vs. change) and one between subjects variable, namely, second task (word type relevant vs. valence relevant).

*Materials.* The experiment was run using the E-Prime Software, Version 2.0. The Stimuli were 48 German words taken from the Berlin Affective Word List, that were either positive or negative in valence and either adjectives or nouns, i.e. each of the 48 words had both features (**Table 1b and 1c**). **Table 1a** contains mean ratings for the lexical characteristics for the two valence groups. The words were presented centrally on a black background in 12 point Courier New font, subtending a visual angle of  $0.38^\circ$  in height, and  $1.24^\circ$  to  $4.39^\circ$  in width. The words were presented either in green (RGB Values: 144, 255, 0) or yellow (RGB Values: 228, 225, 0). Viewing distance was approximately 60cms.

*Procedure.* The participants were tested individually in soundproof chambers. The experimental instructions were presented on screen and summarized by the experimenter. The participants were asked to place their right hand index finger on the 'J' key and their left hand index finger on the 'F' key. The participants responded to the colour of the words. Half of the participants responded to the yellow colour with a right hand key press and the green colour with a left hand key press and the other half of the participants received the opposite mapping. One half of the participants were encouraged to attend to the valence of the words, and the other half was encouraged to attend to the word type. This was achieved by means of yes/no questions about either the word type or the valence of the words presented in that trial, which appeared at the end of 75% of the trials. Each trial started with a fixation cross for 1000 ms. Participants were instructed to fixate the cross as the stimuli would appear at that position. Then followed the prime and stayed on screen until a response was made. A blank screen then followed for 500 ms, after which the probe was presented and stayed on screen until a

response was made. Depending on the group, on 75% of the trials the participants were asked to report either the word type or valence of the prime and probe words in the present trial. The questions were yes/no questions and had to be responded to with the '4' and '6' keys on the number pad. Once they had answered the questions they could start the next trial by pressing the spacebar. The trial sequence is depicted in **Fig. 1**. It must be noted that no word was ever repeated from the prime to the probe. Before starting the test block the participants worked through a practice block of 32 trials. In the practice trials the participants received feedback on all trials. In the test block the participants received feedback only when they responded incorrectly. Within each condition the response relation, word type relation, and valence relation were manipulated. In response repetition (RR) trials the same colour (green or yellow) was repeated from the prime to the probe and in response change (RC) trials the colour was changed from the prime to the probe. Similarly in word type repetition (WR) trials the word type (either adjective or noun) was repeated from the prime to the probe and in word type change (WC) trials it was changed from the prime to the probe. In valence repetition (VR) trials the valence was repeated and in valence change trials (VC) the valence was changed for the prime to the probe.

## Results

Only trials with correct responses to both the prime and the probe were included in the analysis. Trials that had reaction times that were either shorter than 200 ms or longer than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant were not included in the analysis (Tukey, 1977). This resulted in a total of 10.5% of the data being excluded from the RT analysis. **Table 2** shows the mean RTs and error rates.

Probe response times were analysed in a 2 (response relation) x 2 (word type relation) x 2 (valence relation) x 2 (second task) mixed model MANOVA with group as the between

subjects factor and pillai's trace as the criterion. A significant main effect for response relation was observed,  $F(1, 58) = 135.02, p < .001, \eta_p^2 = .70$ , suggesting faster responses when the same response was to be repeated ( $M = 574$  ms,  $SD = 198$  ms) compared to when the response had to be changed ( $M = 627$  ms,  $SD = 198$  ms). Significant main effects for word type relation,  $F(1, 58) = 5.44, p = .023, \eta_p^2 = .09$ , and valence relation,  $F(1, 58) = 4.22, p = .044, \eta_p^2 = .07$ , suggested faster responses in general when either word type was repeated ( $M = 598$  ms,  $SD = 195$  ms) than when it changed ( $M = 603$  ms,  $SD = 200$  ms) and faster responses when valence was repeated ( $M = 597$  ms,  $SD = 191$  ms) compared to when the valence was changed ( $M = 604$  ms,  $SD = 205$  ms). However the main effect of valence was further modulated by the second task,  $F(1, 58) = 4.80, p = .033, \eta_p^2 = .08$ , suggesting that only in the second task in which valence was relevant the responses were faster when valence was repeated but not in the group in which word type was relevant. The response relation and valence relation interaction (which signifies the overall DRB effect for valence, independent of the second task) was also significant,  $F(1, 58) = 6.17, p = .016, \eta_p^2 = .10$ , suggesting that when both response and valence were repeated the responses were faster. The significant main effect of word type relation was not further modulated either by second task,  $F(1, 58) = 1.05, p = .310, \eta_p^2 = .02$  or response relation,  $F(1, 58) = 1.44, p = .235, \eta_p^2 = .02$ . The three-way interactions of response relation x valence relation x second task,  $F(1, 58) = 2.79, p = .100, \eta_p^2 = .05$ , and response relation x word type relation x second task,  $F(1, 58) = 1.44, p = .235, \eta_p^2 = .02$ , were not significant.

*Error rates.* The same analysis were run for the error rates. A significant interaction of response relation and word type relation,  $F(1, 58) = 13.08, p = .001, \eta_p^2 = .18$ , was observed which was further modulated by second task resulting in a significant three-way interaction of response relation x word type relation x second task,  $F(1, 58) = 11.39, p = .001, \eta_p^2 = .16$ , suggesting that only in the second task in which word type was relevant did binding between

## Binding the Attended Feature

response and word type occur. The important three-way interaction of response relation x valence relation x second task was also significant,  $F(1, 58) = 6.72, p = .012, \eta_p^2 = .10$  suggesting that, similar to word type, only in the second task in which valence was relevant did any binding of response and valence occur.

*Distractor-Response Binding Effects.* The distractor-response binding (DRB) effects were calculated for reaction times and error rates with the following formula (RRVC – RRVR) – (RCVC – RCVR) for the Valence Binding effect and (RRWC – RRWR) – (RCWC – RCWR) for the Word type Binding effect. DRB effects were calculated individually for both distractors in both second task conditions i.e. for the condition in which the distractor was relevant and the condition in which it was not relevant (**Fig. 2**). There was no significant difference in the reaction time DRB effects for word type when word type was the relevant feature (19 ms) and when it was not the relevant feature (-1 ms),  $t(58) = -1.27, p = .208$ , nor for the valence DRB effect when valence was the relevant feature (54 ms) and when it was not the relevant feature (10 ms)  $t(58) = 1.67, p = .100$ . For error rates however, there was a significant difference between the DRB effects for word type when word type was the relevant feature (4.4% errors) and when it was not the relevant feature (0.19% errors),  $t(58) = -3.38, p = .001$ , and for valence when valence was the relevant feature (2.69% errors) and when it was not the relevant feature (-0.68% errors),  $t(58) = 2.57, p = .013$ , indicating larger effects for the attended feature, respectively.

## Discussion

The aim of Experiment 1 was to test whether attending to one response-irrelevant feature of a stimulus would result in stronger binding effects for that feature. The participants were encouraged to attend to one of two irrelevant stimulus features and the binding effects were measured for both the irrelevant attended feature and the irrelevant non-attended feature.

Distractor-response binding effects in the error data were significantly stronger in the condition in which the features received more attention, i.e. the DRB effect for word type was stronger in the condition in which word type received attention, and the DRB effect for valence was stronger in the condition in which valence received attention. This pattern was also observed in the RT data, even if only at a descriptive level. Together the results of Experiment 1 indicate that, if more than one response-irrelevant feature is present, only the feature that is attended will be integrated with the response. It can be argued that when participants were encouraged to attend to one of the features by asking them to report that feature, the weights for that dimension were set higher than for the other dimension. In Experiment 1, attention to one or the other feature was treated as a between-subjects factor. That is, participants did not need to shift attention between features during the experiment. In such a rather stable attentional situation, differences in attention to response-irrelevant stimuli apparently influence integration. In the following experiment we aimed to examine the flexibility of the intentional weighting. Therefore, attention to the response-irrelevant features was treated as a within-subjects factor.

## **Experiment 2**

The aim of Experiment 2 was to examine the effect of attentional manipulation in situations that require more flexible attentional shifts. Attention to one or the other irrelevant feature was varied within-subject either in two separate blocks (Experiment 2A) or in a trial by trial manner (Experiment 2B). If the internal system of intentional weighting is flexible and can respond very quickly to changes in attentional requirements, then we would expect to see the three-way interaction of response relation x valence relation (word type relation) x second task (valence or word type as relevant), and we would not expect this interaction to be further modulated by the manner in which attention was varied (either in two blocks or trial

by trial). If, however, it is not flexible enough to respond to faster changes (as in the trial by trial variation), we would expect the three-way interaction to be further modulated by the manner in which attention was varied. Specifically we would expect to see the significant three-way interactions in the blocked condition, but not in the trial by trial condition<sup>1</sup>.

## Method

*Participants.* Sixty two participants (15 male) from the University of Trier participated for partial course credit (32 in Experiment 2A and 30 in Experiment 2B). The median age of the participants was 21 years (range 18 – 31). The age data was not logged for one participant due to a technical error, the data of this participant have been included. Two participants (Experiment 2B) were excluded from the analysis due to interruptions in the experiment. All participants reported normal or corrected-to-normal vision.

*Design.* The experimental design consisted of four within subjects' factors, namely, response relation (repetition vs. change), word type relation (repetition vs. change), valence relation (repetition vs. change), second task (word type relevant vs. valence relevant), and one between subjects factor; attentional manipulation type (block wise or trial by trial).

*Materials and Procedure.* Materials and procedure was the same as in Experiment 1 except for the following changes; in Experiment 2A, attention was manipulated in a blocked manner, and in Experiment 2B it was done so trial by trial, by presenting a cue before each

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<sup>1</sup> Experiment 2 was in fact run in two slightly different versions that we here present as Experiments 2A and 2B. In one version the attention of the subjects was manipulated in a blocked manner, and the participants had to report the relevant feature on 33.33% of the trials, and in the other version, the attention was manipulated in a trial-by-trial manner, and participants reported the relevant feature on 75% of the trials. Furthermore, five words were changed in Experiment 2B, due to their similarity to other words. The changes are noted in Tables 1b and 1c. All analyses reported below were run with attentional manipulation type as a further independent variable.

trial. In Experiment 2A, the participants were asked to report the feature on 33.3% of the trials and in Experiment 2B they did so after 75% of the trials.

## Results

*Reaction Times.* Only trials with correct responses to both the prime and the probe were included in the analysis. Trials that had reaction times that were either shorter than 200ms or longer than 1.5 interquartile ranges above the third quartile of the RT distribution of the participant were not included in the analysis (Tukey, 1977). This resulted in a total of 11.45% (Exp 2A) and 10.5% (Exp 2B) of the data being excluded from the RT analysis.

**Table 2** shows the mean RTs and error rates.

Probe response times were analysed in a 2 (response relation) x 2 (word type relation) x 2 (valence relation) x 2 (second task) x 2 (attentional manipulation type) MANOVA with pillai's trace as the criterion. A significant main effect of response relation was observed,  $F(1, 58) = 113.03, p < .001, \eta_p^2 = .66$ , suggesting faster response times when the response was repeated ( $M = 566$  ms,  $SD = 118$  ms) compared to when the response was changed ( $M = 621$  ms,  $SD = 128$  ms). The main effect of word type relation was marginally significant,  $F(1, 58) = 2.87, p = .096, \eta_p^2 = .05$ , suggesting faster response times when the word type was repeated ( $M = 591$  ms,  $SD = 121$  ms) compared to when the word type was changed ( $M = 595$  ms,  $SD = 124$  ms). The three-way interaction of second task x response relation x valence relation was marginally significant,  $F(1, 58) = 3.91, p = .053, \eta_p^2 = .06$ , suggesting the integration of valence and response, but only when valence was the relevant feature. The response relation x word type relation interaction was marginally significant,  $F(1, 58) = 3.22, p = .078, \eta_p^2 = .05$ . No other effects were significant,  $F_s < 2.5, p_s > .152$ .

*Error rates.* The same analysis was conducted for the error rates. The interaction of response relation and valence relation was significant,  $F(1, 58) = 10.82, p = .002, \eta_p^2 = .16$ , suggesting that overall participants were more accurate when both valence and response were repeated. This interaction was further modulated by attentional manipulation type,  $F(1, 58) = 4.95, p = .030, \eta_p^2 = .08$ , suggesting that responses were more accurate when both response and valence were repeated, but only in the blocked attentional manipulation type. The interaction of second task x response relation x valence relation was not significant,  $F(1, 58) = 2.53, p = .117, \eta_p^2 = .04$ , and was not modulated by attentional manipulation type,  $F(1, 58) = 0.13, p = .719, \eta_p^2 = .00$ . Similarly for word type, the response relation x word type relation was significant,  $F(1, 58) = 23.58, p < .001, \eta_p^2 = .29$ , suggesting more accurate responses if both response and word type were repeated. This interaction was further modulated by attentional manipulation type,  $F(1, 58) = 4.66, p = .035, \eta_p^2 = .07$ , the effect was stronger in the blocked attentional manipulation type. The crucial three-way interaction of second task x response relation x word type was significant,  $F(1, 58) = 10.84, p = .002, \eta_p^2 = .16$ . This interaction was not further modulated by attentional manipulation type,  $F(1, 58) = 1.97, p = .166, \eta_p^2 = .03$ .

*Distractor-Response Binding Effects.* As in Experiment 1, the DRB effects were calculated for both valence and word type in both conditions (**Figure 2**). The DRB effects were analysed in a mixed model ANOVA with one within subject factor (DRB effect: for the relevant feature vs the irrelevant feature) and one between subjects factor (attentional manipulation type: block wise vs. trial by trial). In RTs DRB the effect for valence was significantly different when valence was the relevant feature (20 ms) compared to when it was not the relevant feature (-3 ms),  $F(1, 58) = 4.00, p = .050, \eta_p^2 = .06$ . The DRB effects for word type when word type was the relevant feature (14 ms) compared to when it was not the relevant feature (1 ms) did not differ significantly,  $F(1, 58) = 1.54, p = .219, \eta_p^2 = .03$ . For

error rates, the DRB effects for valence when valence was the relevant feature (2.57% errors) was marginally different from when valence was not the relevant feature (1.00% errors),  $F(1, 58) = 2.76$ ,  $p = .102$ ,  $\eta_p^2 = .05$ . For word type the difference when word type was the relevant feature (3.65% errors) compared to when it was not the relevant feature (0.55% errors) was significant,  $F(1, 58) = 11.09$ ,  $p = .002$ ,  $\eta_p^2 = .16$ .

## Discussion

The pattern of results in Experiment 2 are identical to that observed in Experiment 1, thus providing further evidence that only if a response-irrelevant feature received attention, it is integrated with the response. This is the case even when the attentional shifts occur within subjects, and even when the attentional shifts occur relatively quickly (in this case on a trial by trial basis<sup>2</sup>). The DRB effects for both irrelevant features were significantly stronger when they were the relevant feature compared to when they were not relevant. For valence this significant difference was evident in the RTs and (marginally) in the error rates, and for word type it was found in the error rates.

## General Discussion

The aim of the present experiments was to test whether attention modulates binding effects of response-irrelevant features. In order to investigate this question, we compared

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<sup>2</sup> A control analysis of possible carry over effects in Experiment 2B was conducted in a 2 (cue relation) x 2 (response relation) x 2 (valence relation) x 2 (word type relation) MANOVA. Neither the cue relation x response relation x valence relation interaction,  $F(1, 29) = 0.37$ ,  $p = .548$ ,  $\eta_p^2 = .013$ , nor the cue relation x response relation x word type relation,  $F(1, 29) = 0.67$ ,  $p = .419$ ,  $\eta_p^2 = .023$ , were significant, suggesting no significant carry over effects. A similar analysis for Experiment 2A to examine carry over effects from one block to the next was not possible, due to the design of the experiment, which did not allow for a separation of trials into separate bins (and thus analyse, for e.g. the first 25% of the trials, to investigate possible carry over effects).

binding effects of response-irrelevant features that received attention due to a second task and response-irrelevant features that did not receive attention due to a second task. Our results show that irrelevant features produce binding effects but that attention modulates binding effects of response-irrelevant features.

In the present experiments the stimuli had three features, of which two were irrelevant to the RT task (namely; valence and word type). Significant binding effects were found only for that feature which was attended to (in this case by asking the participants to report the feature at the end of a proportion of trials), but not for the other feature. This pattern replicated in a blocked design and in a trial to trial design.

The present results are in accordance with other studies that have examined the influence of attention on feature binding and retrieval. For instance Spruyt et al. (2009) found priming effects only for the feature which was attended to. In that study, participants carried out a word pronunciation task, but were required to make an affective judgement or a semantic classification, depending on condition, on a particular number of trials (75%, these trials were not included in the analysis). The authors found affective priming effects only when the participants affectively classified the words and not when the semantic classification task was done. Similarly, significant semantic priming was only observed when the participants carried out the semantic classification task. Thus significant priming effects were only observed when the feature received enough attention. However, in that study, the relevant feature was response relevant. The participants had to make either a semantic or affective classification, instead of pronouncing the word, on a certain number of trials. Thus by virtue of the task attention was directed to the affective feature of the stimulus on the classification trials. The participants had to evaluate the stimulus on a particular dimension in order to make a response. In the present experiments, however, the valence and word type were always irrelevant to the RT task, they only had to be reported at the end of the trial (75%

or 33.33% of the trials) but that response was not a speeded response task. The affective and semantic features never had to be processed in order to make a response in the RT task. Thus the present results suggest that when a feature is attended to, even when it is irrelevant to the response, it still influences responding.

The present results are also in accordance with integration theories, which suggest that attention influences what gets integrated. For instance the *Feature Integration Theory of Attention* (Treisman & Gelade, 1980) argued that attention is necessary for feature integration, the *Instance Theory of Automatization* (Logan, 1988) argued that encoding stimuli into memory was a consequence of attention directed towards it, suggesting that attention was necessary for a stimulus to be encoded into memory.

However, the present results may be seen to be in conflict with results of other studies that found no effect of attention on integration and retrieval. For instance Hommel and Colzato (2004) found that asking participants to report one of the three stimulus features at the end of a trial did not increase the strength of the integration and retrieval for the reported feature. This difference, however, might be due to differences in procedure. In the study by Hommel and Colzato, participants were asked to report one of three features at random. In Experiment 1 of the present experiments, however, the participants consistently reported either one or the other feature. In Experiment 2 of the present study participants either reported one feature consistently in one block, or they were asked to report either one or the other feature on a trial-by-trial basis. Thus the trial-by-trial condition is more similar to the procedure used in the Hommel and Colzato study, however, there is still one important difference; in the trial-by-trial condition of the present study a cue appeared before at the beginning of each trial which indicated toward which feature attention should be directed. Thus in the present study attention was specifically directed to one or the other feature, rather than just a general increase of attention to the stimulus as a whole.

Notably, we found that even a relatively salient feature (in this case valence) does not get integrated with the response if it does not receive attention. According to Spruyt et al. (2009) the allocation of feature-specific attention determines the extent to which stimulus features are processed, and not whether they are processed at all or not. Applied to the present results, it would mean that the feature which received attention was processed to a higher level than the other feature. Thus even though the other feature may have been processed, it was not enough to ensure it was integrated with and retrieved the response. Such a pattern was observed in the results. In the condition in which attention was instructed towards word type, we observed larger binding effects for word type than in the condition in which attention was not instructed toward word type. The result pattern for valence was similar. One process which might result in such a feature specific allocation of attention is intentional weighting (Hommel & Memelink, 2013). The mechanism of intentional weighting serves to weight feature codes based on the intent of the actor. Thus features that are considered necessary or task relevant will be weighted more heavily and will thereby become more salient, and receive more attention. The present results would suggest that the intentional weighting system is quite flexible and is able to cope with attentional shifts within a stimulus and in a short span of time. In Experiment 2 the attentional manipulation type (whether attention was directed to one feature or the other in a blocked manner or in a trial by trial manner) did not seem to have an effect on integration as the three way interactions were not further modulated by the factor attentional manipulation type. This suggests that when attention is directed to one feature consistently over a specific period of time as well as when the attention shifts from one feature to another very quickly, the system of intentional weighting still functions efficiently, to allow for stronger integration of and retrieval due to that feature which is more relevant to the actors goal intentions. Further, intentional weighting applies even to response-irrelevant features. Most interestingly, it does not matter whether a feature is relevant to the

task at hand or relevant due to a different task. As long as a feature is attended at all, it seems to be weighted heavier and integrated with any current response.

The present result pattern is also reminiscent of the phenomenon of overshadowing, as observed in forms of associative learning, like classical conditioning. Overshadowing is observed when, if more than one stimulus is present, then the more salient stimulus will reduce or prevent conditioning for the less salient stimulus (Mackintosh, 1975). In the present experiments, attention was directed to one of the two response-irrelevant stimulus features, thereby increasing the salience of that feature. The result pattern conforms to the observations of overshadowing in associative learning. Binding effects were observed only for the feature toward which attention was instructed. This finding might be seen as a further similarity between such short term distractor-response bindings and learning forms such as classical conditioning. Giesen and Rothermund (2014) were able to show similarities in the structure of distractor-response bindings and classical conditioning. They compared the unconditioned stimulus (US) to a target, the conditioned stimulus (CS) to the distractor, and the response to the unconditioned response (UR). Pairing the target (US) and distractor (CS) and the response (UR) leads to an associating between the distractor (US) with the target (CS) and the response (UR), and subsequent presentations of the distractor (CS) can retrieve the response (CR). The present findings, which might be considered to be analogous to overshadowing, could be seen as evidence of further similarity between such short term binding effects and long-term forms learning (see also Moeller & Frings, 2017).

At first sight, it may seem surprising that the feature valence was integrated with and retrieved responses just as the non-affective feature word type did. In affective priming studies an RT advantage is usually observed if the prime is of the same valence as the target or if the valence remains the same on two consecutive trials. This has been the case even if valence is completely irrelevant to the task. Valence has thus been considered a feature that is

automatically processed and affective priming is considered to occur unconditionally, irrespective even of its relevance (e.g., Fazio et al., 1986; Hermans, De Houwer, & Eelen, 1994) and has even been observed to bypass the bottleneck in the PRP paradigm (Fischer & Schubert, 2008). Furthermore, evidence for automatic processing of valence in the DRB paradigm has also been observed (Giesen & Rothermund, 2011). In the present study however, valence was only integrated with and retrieved the response when it received sufficient attention. Thus it would appear that the inherent salience of valence is not enough for it to get integrated with and retrieve responses. When valence is an irrelevant feature, it does not get integrated with and later retrieve the response unless attention is intentionally directed towards it, thus functioning like any other feature. Indeed other studies have shown that valence processing might not be as unconditional as has been assumed (e.g. Klauer & Musch, 2001, Exp. 3; Spruyt, Hermans, De Houwer & Eelen, 2002; Spruyt et al., 2009). In tasks where valence was not relevant, no evidence for affective priming was found (e.g. Hermans, Van den Broeck, & Eelen, 1998; De Houwer, Hermans, Rothermund & Wentura; 2002).

In conclusion, the results of the present experiments suggest that attention plays a role in binding of response-irrelevant stimulus features. Even within a single stimulus, response-irrelevant features that are allocated more attention due to an additional task are more likely to be integrated, with responses and able to retrieve them on repetition, compared to features that are not allocated attention.

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**Table1a.** Mean ratings on Valence, Arousal, Word length, Word Frequency and Orthographic Neighbours

	Valence	Arousal	Word length	Frequency	Orthographic Neighbours
Positive	2,46	2,85	6,17	41,47	1,17
Negative	-2,44	3,96	6,33	33,74	1,13

**Table 1b.** Negative Words (English translations in parenthesis)

GIFTGAS (Poison Gas)	SCHLIMM (Evil). In Exp. 2a Tot (Dead)
WELTKRIEG (World War)	KRANK (Sick). In Exp. 2a Lieblos (Uncharitable)
PEST (Plague). In Exp. 2a Nazi (Nazi).	LEBLOS (Lifeless)
ALPTRAUM (Nightmare)	GRAUSAM (Gruesome)
FOLTER (Torture)	EINSAM (Lonely)
MASSAKER (Massacre)	TREULOS (Faithless)
MORD (Murder)	PERVERS (Perverse)
TOD (Death)	ANGST (Anxiety)
ATOMBOMBE (Atom Bomb)	QUAL (Agony)
GEWALT (Violence)	PANISCH (Panic)
BRUTAL (Brutal)	NUKLEAR (Nuclear)
ILLEGAL (Illegal)	TRAURIG (Unhappy)

**Table 1c** Positive Words (English translations in parenthesis)

SPAß (Fun)	LEBENDIG (Lively). In Exp. 2a Sonnig (Sunny)
FREIZEIT (Leisure Time)	EHRlich (Truthful)
URLAUB (Vacation)	LIEB (Endearing)
SOMMER (Summer)	TOPFIT (Fit)
FERIEN (Holidays)	GENIAL (Genial)
HEILUNG (Cure)	WOCHENENDE (Weekend). In Exp. 2a Liebe (Love)
SEX (Sex)	BELIEBT (Popular)
SONNE (Sun)	OPTIMAL (Optimal)
GLÜCK (Luck)	PERFEKT (Perfect)
FREUDE (Happiness)	WARM (Warm)
PARADIES (Paradise)	KREATIV (Creative)
MUTIG (Courageous)	GESUND (Healthy)

**Table 2.** Mean Reaction Times and Error Rates (in parenthesis) for Experiment 1 as a function of second task (Word type relevant vs. Valence relevant), Response Relation (RR vs. RC), Valence Relation (VR vs. VC) and Word type Relation (WR vs. WC).

		VR		VC	
		WR	WC	WR	WC
<i>Word type relevant</i> <i>condition</i>	RR	537(1.0)	552(3.9)	540(1.5)	559(2.7)
	RC	592(3.1)	592(1.0)	588(3.5)	584(1.1)
<i>Valence relevant</i> <i>condition</i>	RR	582(1.3)	580(1.1)	619(2.8)	628(4.2)
	RC	668(2.9)	673(2.9)	658(2.0)	658(2.9)

**Table 3.** Mean Reaction Times and Error Rates (in parenthesis) for Experiment 2 as a function of relevance second task (Word type relevant vs. Valence relevant), Response Relation (RR vs. RC), Valence Relation (VR vs. VC) and Word type Relation (WR vs. WC).

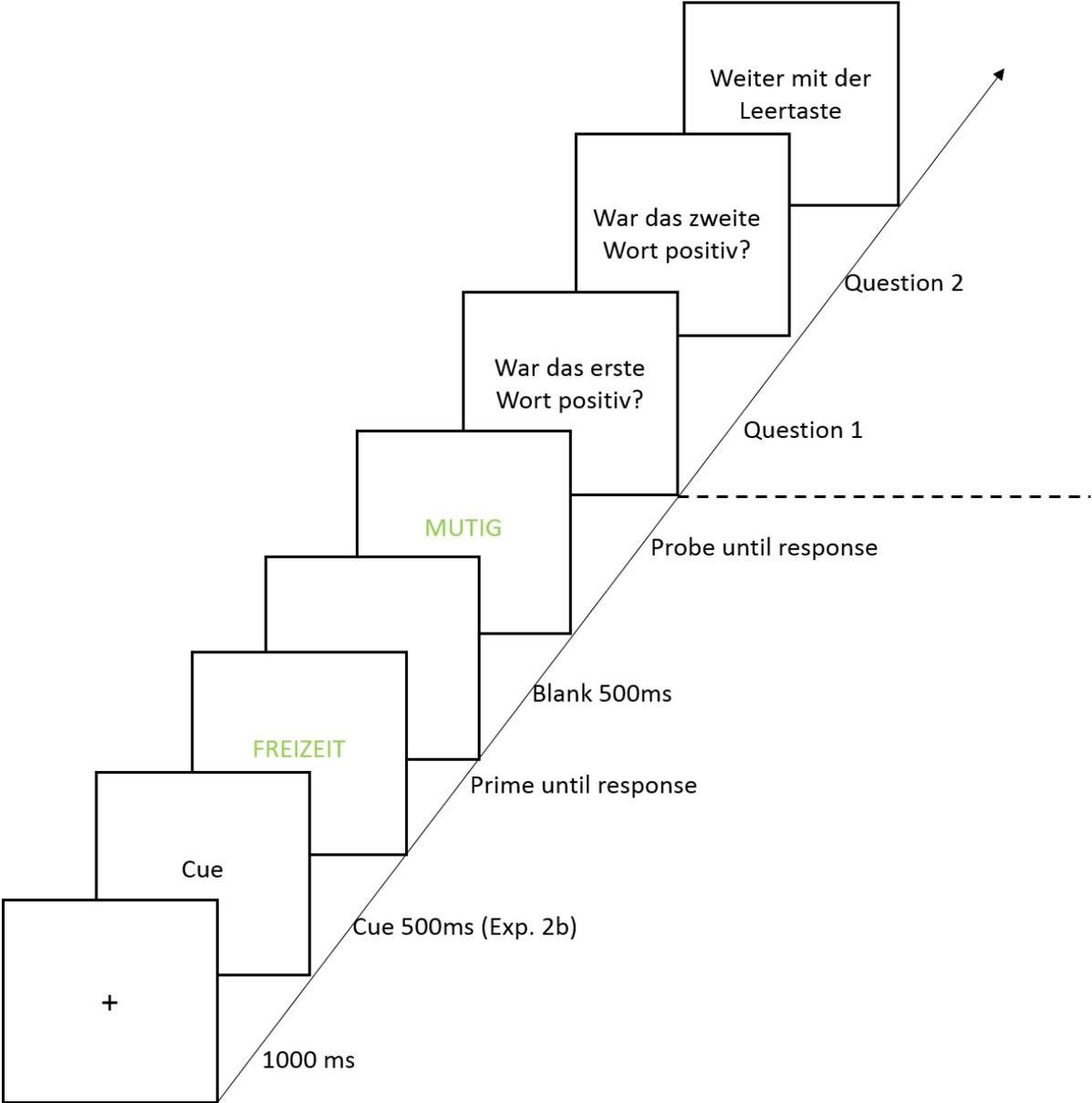
		VR		VC	
		WR	WC	WR	WC
<i>Word type relevant</i>	RR	564(1.6)	572(3.3)	559(2.0)	578(4.5)
<i>Condition</i>	RC	622(4.4)	616(2.4)	621(3.7)	625(2.6)
<i>Valence relevant</i>	RR	558(2.3)	556(1.8)	567(3.3)	574(3.6)
<i>Condition</i>	RC	622(4.3)	624(3.3)	617(2.8)	617(2.4)

**Figure Legends.**

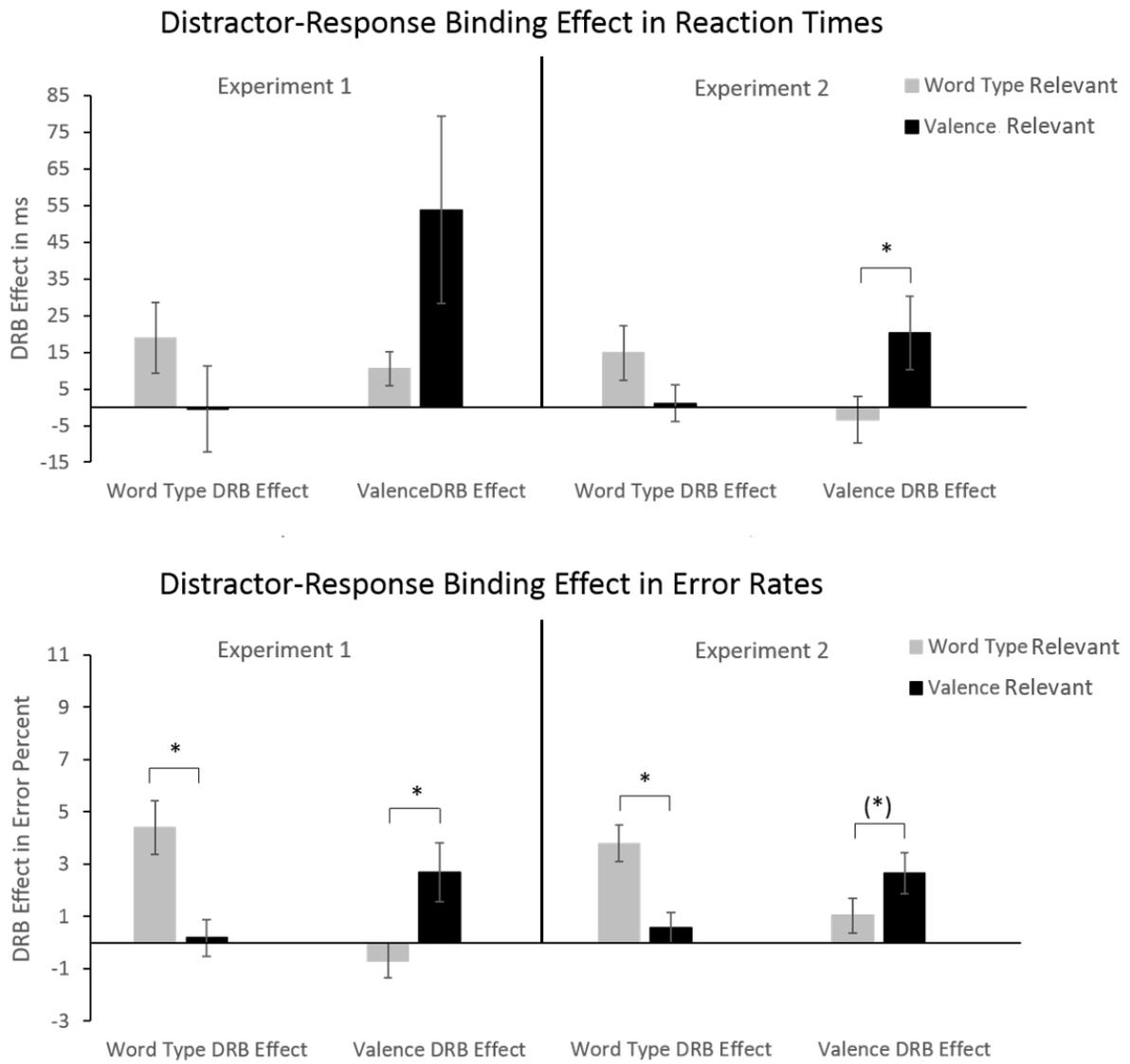
**Figure 1.** Trial sequence - portions after the broken line only appeared on 75% (2b) or 33.3% (2a) of the trials. Depending on the condition, participants had to report either the valence or word type of the prime word in response to question 1 and the valence or word type in response to question 2. The first question always pertained to the prime word; participants responded with a 'yes' or 'no' response to whether the prime word was positive (or negative) or an adjective (or a noun). The second question always pertained to the probe, participants responded with a 'yes' or 'no' response to whether whether the prime word was positive (or negative) or an adjective (or a noun).

**Figure 2.** Distractor-Response Binding Effects for Reaction Times (upper panel) and Error Rates (lower panel) in Experiment 1 and Experiment 2 as a function of relevance condition. Error bars indicate the Standard Error of the Mean.

Figure 1.



**Figure 2.**



## **9. Disentangling Inhibition-based And Retrieval-based After-Effects of Distractors: Cognitive Versus Motor Processes.**

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**Disentangling Inhibition-based And Retrieval-based After-Effects of Distractors: Cognitive Versus Motor Processes**

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### **Abstract**

Selective attention refers to the ability to selectively act upon relevant information at the expense of irrelevant information. Yet, in many experimental tasks, what happens to the representation of the irrelevant information is still debated. Typically, two approaches to distractor processing have been suggested, namely distractor inhibition and distractor-based retrieval. However, it is also typical that both processes are hard to disentangle. For instance, in the Negative Priming literature (for a review Frings, Schneider, & Fox, 2015) this has been a continuous debate since the early 1980ies. In the present study we attempt to prove, that both processes exist, but that they reflect distractor processing at different levels of representation. Distractor inhibition impacts stimulus representation, while distractor-based retrieval impacts mainly motor processes. We investigated both processes in a distractor priming task, which enables an independent measurement of both processes. For our argument, that both processes impact different levels of distractor representation, we estimated the exponential parameter ( $\tau$ ) and Gaussian components ( $\mu$ ,  $\sigma$ ) of the Ex-Gaussian reaction time distribution, which have previously been used to independently test the effect of cognitive and motor processes (e.g., Moutsopoulou & Waszak, 2012). The distractor-based retrieval effect was evident for the Gaussian component, which is typically discussed as reflecting motor processes, but not for the exponential parameter, while the inhibition component was evident for the exponential parameter, which is typically discussed as reflecting cognitive processes, but not for the Gaussian parameter.

### **Statement of public significance**

This study provides evidence for two distinct processes involved in the processing of irrelevant stimuli: inhibition and retrieval. Both processes occur at different levels, cognitive and motor level respectively. Furthermore they are independent of each other. At a cognitive level irrelevant stimulus representations are inhibited, allowing us to select only those stimuli that are relevant to our goals, while distractor-based motor retrieval, may provide the first step to building behavioral routines.

## Introduction

In a world full of sensory input we must selectively process and respond to only the (currently) relevant input. The literature on selective attention reflects our knowledge on how the human cognitive systems handles this task (see Houghton & Tipper, 1994; Styles, 2006). Obviously, humans can selectively attend and selectively ignore information very well. What actually happens to the not selected information or the actively ignored information has been discussed in the literature for decades. Prototypical for this debate is the literature on Negative Priming (for reviews see Fox, 1995; Tipper, 2001; Neill & Valdes, 1996; Frings, Schneider, & Fox, 2015; D'Angelo, Thomson, Tipper, & Milliken, 2016). Negative Priming refers to the phenomenon, that a to be ignored item (distractor) on a prime trial, that is repeated as targets in a subsequent probe trial, leads to worse performance in terms of reaction times and error rates. A coarse-grained differentiation is to argue, that two types of processes contribute to this effect. The first one is distractor inhibition (Tipper, 1985; Houghton & Tipper, 1994), that is, actively ignoring the distractor leads to some kind of inhibited representation of this stimulus. This inhibition lingers from one stimulus display to the next, leading to worse performance if one has to respond to a-previously-inhibited stimulus. The second process is distractor-based retrieval (Neill, 1997; Rothermund, Wentura, & De Houwer, 2005; Mayr & Buchner, 2006), that is, the distractor is encoded with a “do-not-respond” tag during prime processing or with the prime response itself and through the distractor repetition in a subsequent trial, the retrieved information conflicts with the currently demanded response. These two processes describe after-effects of ignoring a stimulus, which can also be found outside the scope of the Negative Priming paradigm (Frings et al., 2015). In this article, we argue that both processes, the distractor inhibition and the distractor-based retrieval, can be separated using one task and further can be associated with different levels of processing.

*Distractor-based retrieval*

Binding theories assume that a stimulus and the response made to it are integrated into an *event file* (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Hommel, 2004) or a *Stimulus-Response episode* (S-R episode; Waszak, Hommel, & Allport, 2003). Event files and S-R episodes are short lived episodic traces. A re-encounter with one or more of the stored stimulus features leads to automatic retrieval of the previously constructed event file. This integration is not restricted to relevant stimuli, even irrelevant stimuli, *distractors*, can be integrated with responses. Thus even repeating the distractor can retrieve the previously integrated file and hence the response. The effect of distractor repetition depends upon whether the response is repeated or changed. If the distractor repeats while the response changes, performance is impaired as in the case of a distractor-to-target repetition in Negative Priming (Rothermund et al., 2005). If both the response and the distractor are repeated, performance is enhanced because the distractor retrieves a compatible response.

Distractor-based retrieval might retrieve bindings at different levels of processing/representations. In the previous research, it has been suggested, that bindings between a stimulus and a response exist at multiple levels of representation, e.g., conceptual, motor, decisional (Frings, Moeller, & Rothermund, 2013; Henson, Eckstein, Waszak, Frings, & Horner, 2014; Horner & Henson, 2009 Neill & Valdes, 1996). In particular, a paper by Giesen and Rothermund (2014) suggests, that bindings between a distractor and the response exist independently of bindings, at the level of stimulus associations (between the distractor and the target). In other words, although distractors might retrieve other levels of representation (e.g., even decisions under uncertainty; Nett, Bröder, & Frings, 2015), it seems safe to conclude, that in typical priming tasks with a small and defined set of stimuli mapped to particular responses, repeating a distractor will retrieve the previously encoded response. This argument is further supported by studies showing that repeating a distractor can lead to specific errors namely to prime-response-retrieval errors: participants erroneously respond with the previous encoded response, since the distractor repeats while no

stimulus to which this response was assigned is displayed. This finding can only be explained in terms of response retrieval (Mayr & Buchner, 2006; Wiswede, Rothermund, & Frings, 2013).

### *Distractor inhibition*

As stated above, distractor after-effects are also discussed in terms of distractor inhibition (e.g., Frings, Wentura, & Wühr, 2012; Houghton & Tipper, 1994; Wühr & Frings, 2008). That is, repeating the same distractor from trial n-1, as a distractor in trial n typically leads to a benefit, because the distractor is still inhibited and thus selection against a still inhibited distractor is easier (e.g., Neumann & DeSchepper, 1991). In the Negative Priming task a distractor-to-target repetition leads to worse performance as the target suffers from previous inhibition. Interestingly, previous research showed that distractor-based event-file retrieval and distractor inhibition are independent (Giesen, Frings, & Rothermund, 2012). In addition, while it is clear that inhibition can impact different levels of representation in the Negative Priming task, it is typically assumed to impact a central level of stimulus representation, and not the response (Houghton & Tipper, 1994). Again, this is not specific for Negative Priming, in other tasks analysing inhibition, it is also assumed that inhibition impacts a central level of stimulus representation and that not just a specific response is inhibited (e.g., in the retrieval-induced-forgetting task, Anderson, 2003). In addition, using stimulus-logged lateralized readiness potentials in a distractor priming paradigm, Pramme, Schächinger, and Frings (2015) yielded evidence for inhibition at the level of stimulus representation while inhibition, at the level of responses as indexed in stimulus-logged lateralized readiness potentials, was not observed.

### *The Present Study*

We investigated and separated distractor-based retrieval and distractor inhibition processes in one paradigm, while at the same time suggesting that both processes impact upon different levels of

representation as outlined above. We used a distractor-to-distractor priming task (Frings, Rothermund, & Wentura, 2007), in which response relation and distractor relation were orthogonally varied and hence distractor inhibition and distractor-based retrieval could be independently measured (Giesen et al., 2012; Moeller & Frings, 2014). This task design allows the disentanglement of distractor inhibition and distractor-based retrieval processes, in contrast to the Negative Priming task, where this is not possible. In the present study participants responded on each display to a target flanked by two distractors. Distractor inhibition is measured as the main effect of distractor relation (i.e. repeating the same distractor from prime to probe display should make probe selection easier, due to still inhibited distractors). Distractor-based retrieval is measured by the distractor-response-binding effect; that is, repeating a distractor should lead to facilitation, if the response is repeated too, but to impairment, if the response changes – in other words this binding effect is reflected in the interaction of response relation and distractor relation (Frings et al., 2007; Frings & Rothermund, 2011; Giesen & Rothermund, 2014; Moeller & Frings, 2014; Moeller, Frings, & Pfister, 2016).

We used a method of data analysis that was initially suggested by Hohle (1965) and that has been shown to be effective in analysing the effects of cognitive processes and motor processes independently, by estimating the Ex-Gaussian reaction time (RT) distribution (e.g., Hohle, 1965; Townsend & Ashby, 1983). The shape of the Ex-Gaussian RT distribution is a convolution of three parameters: an exponential parameter ( $\tau$ ), which reflects the skewness and thickness of the tail and the Gaussian components ( $\mu$ ,  $\sigma$ ), of which  $\mu$  reflects the leading edge of the distribution and  $\sigma$ , the variance of the Gaussian distribution (see Moutsopoulou & Waszak, 2012). The two parameters,  $\tau$  and  $\mu$ , have been shown to describe conflict and retrieval effects on different levels,  $\tau$  reflects conflict in higher cognitive processes and  $\mu$  reflects conflict in motor processes (Hohle, 1965; Heathcote, Popiel, & Mewhort, 1991; Steinhauser & Hübner, 2009; Moutsopoulou & Waszak, 2012). For instance, Moutsopoulou & Waszak (2012) used an across-task associative priming paradigm in which response congruence and task congruence were varied. They observed that the

effect of manipulating response congruence was evident in the  $\mu$  parameter, and the effect of task congruence was evident in the  $\tau$  parameter. This finding stands in accordance with results from previous studies applying the same logic that the exponential parameter ( $\tau$ ) reflects cognitive processing, while the Gaussian components ( $\mu$ ,  $\sigma$ ) reflect motor processes (Hohle, 1965; Heathcote et al., 1991; Schmiedek, Oberauer, Wilhelm, Süß, & Wittman, 2007; Steinhauser & Hübner, 2009).

For the data analysis, the three parameters of the Ex-Gaussian RT Distribution, were estimated and analysed separately, in addition to the standard RT analysis using means. We expected to observe evidence for distractor inhibition and distractor-based retrieval in the RT mean analysis, reflected in the interaction of distractor relation and response relation and the main effect of distractor relation. We also assumed that retrieval reflects representations at the response level and hence we expected the interaction to be observed in the Gaussian  $\mu$  parameter. In contrast, we expected distractor inhibition to occur at a stimulus representation level, reflected in a significant main effect of distractor relation in the exponential  $\tau$  parameter.

## **Method**

### *Participants.*

Fifty students (36 female, 14 male) from the University of Trier took part in the Experiment. Their median age was 21 years with a range from 18 to 35 years. None of the participants reported deficiencies in color vision. All participants took part in exchange for partial course credit. Note that we ran more participants (and had much higher trial numbers, see below), than what is typically done in distractor priming tasks (e.g., according to a priori power-analysis, one would need fewer participants to reliably detect binding and inhibition effects). Previous studies on distractor-based retrieval processes typically found these effects to be middle to large sized (Cohen's  $d$  between .4 and 1). Thus, normally such an experiment can be run with  $N = 30$  participants, leading to a power of  $1 - \beta = .96$  (assuming an  $\alpha = .05$ ) (GPower 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007).

However, in order to accurately estimate the Ex-Gaussian parameters, a larger number of trials per condition and a larger sample of participants (e.g., Lacouture & Cousineau, 2008) are required. For instance, when re-analyzing existing data sets from our own laboratory (with around 30 participants and less trials per condition), for most participants an accurate estimation that fits the Kernel density function, could not be achieved.

*Design.*

The design of the Experiment contained two within-subject factors: response relation (response repetition vs. response change) and distractor relation (distractor repetition vs. distractor change).

*Materials and apparatus.*

The experiment was conducted using the E-Prime software (version 2.0). Instructions and stimuli were shown on a standard color monitor. The stimuli were the letters D, F, J, and K, presented on a black background. Each letter had a horizontal visual angle of  $1.1^\circ$  and a vertical visual angle of  $1.0^\circ$  at an approximate viewing distance of 50 cm. The distractors (green) and the targets (red) were of the same stimuli set (the letters D, F, J and K). The stimuli were arranged in a flanker formation: the target was always presented in the center of the screen and was flanked by two identical distractor. Please note that the targets were always presented in red color and in the middle, while the distractors were always presented in green, flanking the target. This was kept the same for all conditions throughout the entire experiment.

*Procedure.*

Each participant was tested individually in a soundproof chamber. Instructions were given on the computer screen. The participants were instructed to place their left middle finger on the “D”-key, the left index finger on the “F”-key, the right index finger on the “J”-key and the right middle finger on the “K”-key. Their task was always to classify the identity of the red target letter by pressing the corresponding key with the respective finger. It was emphasized that participants should

respond as quickly and as accurately as possible to the identity of the target letter. The distractor-response binding effect was investigated in a prime-probe design. A single trial consisted of the following events: a plus sign was presented for 500 ms as a fixation mark at the centre of the screen. After that the prime display was presented, consisting of a central presented target letter and two flanking distractor letters. This flanker formation was presented until a response was given by pressing one of the four keys. In case of an error, a feedback display appeared for 1500 ms, reminding the participant to respond as quickly as possible, but without making errors. A fixation mark then was presented for 500 ms, followed by the probe target and distractor letters, that were again presented at the centre of the screen, until the participant responded by pressing one of the four keys. The distractor's and the target's identity could change between the prime and the probe. After the probe display a fixation mark appeared for 500 ms and the next trial started.

In response repetition trials, the same response was required in the prime and in the probe. In response change trials, different responses had to be given to the target in the prime and to the target in the probe. Orthogonally to the response relation, the distractor relation was varied. In distractor repetition trials, the prime distractor identity was repeated in the probe, whereas in distractor change trials, the distractor identity changed from prime to probe.

All participants worked through a training block and an experimental block. Each trial condition (response repetition/distractor repetition (RRDR); response repetition/distractor change (RRDC); response change/distractor repetition (RCDR), and response change/distractor change (RCDC)) was realized 300 times and hence the experimental block consisted of 1200 trials. Every 80 trials participants had the possibility to take a break. Prior to the experimental block all participants had to work through a practice block, consisting of 20 trials.

## **Results**

### *Analyses of Reaction Times and Error Rates*

Only probe reaction times (RT) in trials with correct answers to both the prime and the probe were considered. Moreover only reaction times slower than 200 ms and faster than 1.5 interquartile ranges over the third quartile of the reaction times of each person were analyzed (Tukey, 1977). According to these constraints 14.38 % of the trials were discarded<sup>1</sup>. Mean reaction times and error rates on the probe are depicted in **Table 1** for the factors response relation and distractor relation.

A 2 response relation (response repetition vs. response change) × 2 distractor relation (distractor repetition vs. distractor change) MANOVA on the probe RTs yielded a significant main effect of response relation,  $F(1, 49) = 524.84, p < .001, \eta_p^2 = .92$ . Participants responded faster if the response had to be repeated ( $M = 478$  ms,  $SD = 43$  ms) than if the response had to be changed ( $M = 639$  ms,  $SD = 72$  ms). In addition, the main effect of distractor repetition was significant,  $F(1, 49) = 34.91, p < .001, \eta_p^2 = .42$ . Participants responded faster if the distractor was repeated ( $M = 555$  ms,  $SD = 56$  ms) than if the distractor identity changed ( $M = 559$  ms,  $SD = 60$  ms). Most importantly the analyses revealed an interaction between response relation and distractor relation,  $F(1, 49) = 46.41, p < .001, \eta_p^2 = .49$ , indicating an average distractor-response binding effect.

The same analysis on error rates yielded a significant main effect of response relation,  $F(1, 49) = 131.79, p < .001, \eta_p^2 = .73$ . However the main effect of distractor relation was not significant,  $F(1, 49) = 0.47, p = .497, \eta_p^2 = .01$ . The interaction of response relation and distractor relation was again significant,  $F(1, 49) = 6.37, p = .015, \eta_p^2 = .12$ .

#### *Analyses of the Ex-Gaussian parameters*

The same analysis was conducted for the Ex-Gaussian RT distribution, consisting of the exponential parameter  $\tau$  and the Gaussian parameters  $\mu$  and  $\sigma$ . The parameters were estimated using maximum likelihood theory. The Ex-Gauss distribution is derived via a convolution of normal and exponential probability density functions. Its density is

$$f(x \mid \mu, \sigma, \tau) = \frac{1}{2\tau} e^{\frac{1}{2\tau}(2\mu + \frac{\sigma^2}{\tau} - 2x)} \operatorname{erfc}\left(\frac{\mu + \frac{\sigma^2}{\tau} - x}{\sqrt{2}\sigma}\right),$$

with

$$erfc(x) = 1 - erf(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} dt.$$

being the complementary error function. The mean of the Ex-Gauss distributed random variable is  $\mu + \tau$  and the variance  $\sigma^2 + \tau^2$ . We employed maximum Likelihood to estimate the parameter of the Ex-Gauss distribution. The log-likelihood function to be maximized is:

$$\sum_{i=1}^n \left( 2\mu + \frac{\sigma^2}{\tau} - 2x_i \right) + \log(erfc(x_i)) + \log\left(\frac{1}{\tau}\right)$$

This likelihood, however, is very difficult to maximize, as the likelihood is very flat in many regions and very steep at the borders of the parameter space. We used the quasi-Newton L-BFGS-B optimization algorithm proposed by Byrd, Lu, Nocedal, & Zhu (1995). This allows for box-constrained optimization. This leads to the following mathematical optimization formulation

$$\underset{\mu, \tau, \sigma}{\operatorname{argmin}} \sum_{i=1}^n \left( 2\mu + \frac{\sigma^2}{\tau} - 2x_i \right) + \log(erfc(x_i)) + \log\left(\frac{1}{\tau}\right)$$

As starting values the following setting was used:  $\mu := \operatorname{median}(x)$ ,  $\sigma := \operatorname{sd}(x)$ ,  $\tau := \operatorname{mean}(x)$ . If the the resulting variances from the inverse Hessian were negative the boxes where set wider. Otherwise, if these variance were very high a different set of starting values was used

$$\tau := 0.8 \operatorname{sd}(x), \mu := \operatorname{mean}(x) - \tau, \sigma := \sqrt{\operatorname{var}(x) - \tau^2}^{0.5}$$

This way all Parameter sets converged. In order to see whether the Boxes had an influence on the parameter sets, each parameter set was checked manually for optimality in a wider radius, without encountering need for changes.

In **Figure 1** the fit of the Ex-Gaussian distribution is compared to the fit from a Gaussian distribution. Especially in case of response repetitions the Gaussian distribution fits the data poorly whereas the Ex-Gaussian fits considerably well. In **Figure 2**, the contribution of the Gaussian and the Exponential component of the Ex-Gaussian distribution to the total reaction time is depicted (exemplarily for Subject 1). In the case of response repetition the exponential component has a major

impact on total reaction time and the scale and location of the Gaussian component shifts considerably. This indicates, together with the much better fit shown in **Figure 1**, that the Ex-Gaussian distribution is in this context more appropriate for the analysis of response times.

A 2 response relation (response repetition vs. response change)  $\times$  2 distractor relation (distractor repetition vs. distractor change) MANOVA on the  $\mu$  parameter yielded a significant main effect of response relation,  $F(1, 49) = 683.72, p < .001, \eta_p^2 = .93$ . That is, participants responded faster if the response had to be repeated ( $M = 399$  ms,  $SD = 30$  ms) than if the response had to be changed ( $M = 599$  ms,  $SD = 50$  ms). The main effect of distractor relation was not significant,  $F(1, 49) = 0.11, p = .737, \eta_p^2 = .01$ . Most importantly the interaction between response relation and distractor relation was marginally significant,  $F(1, 49) = 3.45, p = .069, \eta_p^2 = .07$ , evidencing that the distractor-response binding is represented in the  $\mu$  parameter, which supposed to reflect motor processes.

The 2 response relation (response repetition vs. response change)  $\times$  2 distractor relation (distractor repetition vs. distractor change) MANOVA on the  $\tau$  parameter revealed a significant main effect of response relation,  $F(1, 49) = 5.17, p = .027, \eta_p^2 = .10$ , and a significant main effect of distractor relation,  $F(1, 49) = 13.63, p = .001, \eta_p^2 = .22$ . The interaction of response relation and distractor relation was not significant,  $F(1, 49) = 0.76, p = .386, \eta_p^2 = .02$ .

The 2 response relation (response repetition vs. response change)  $\times$  2 distractor relation (distractor repetition vs. distractor change) MANOVA on the  $\sigma$  parameter revealed a significant main effect of response relation,  $F(1, 49) = 243.40, p < .001, \eta_p^2 = .83$ , again showing an advantage for repeated responses. Neither the main effect of distractor relation,  $F(1, 49) = 0.01, p = .964, \eta_p^2 = .01$ , nor the interaction of response relation and distractor relation reached significance,  $F(1, 49) = 0.65, p = .423, \eta_p^2 = .01$ .

## Discussion

The aim of the present experiment was to test the after-effects of distractor repetition, namely distractor-based retrieval and distractor inhibition, within one paradigm and to disentangle these effects, so as to see whether the underlying processes affect different levels of representation. In a distractor-to-distractor priming paradigm, it was possible to test for both distractor-based retrieval and inhibition, by orthogonally varying response relation and distractor relation. The disentanglement of the two effects was achieved by estimating and separately analysing the two Ex-Gaussian parameters  $\mu$  and  $\tau$ . A number of studies have used the Ex-Gaussian distribution analysis to disentangle the effects of cognitive and motor processes in different paradigms (e.g., Steinhauser & Hübner, 2009; Moutsopoulou & Waszak, 2012). Task or stimulus-based manipulations have been reflected in the  $\tau$  parameter and response-based manipulations in the  $\mu$  parameter. Further Schmiedek et al. (2007) have linked higher cognitive functions to the  $\tau$  parameter.

In the traditional RT analysis of the means of the Gaussian distribution, we found a significant main effect of distractor relation, which is generally interpreted as the distractor inhibition effect. We also observed a significant interaction of response relation and distractor relation, which is believed to reflect distractor-based retrieval. In the separate analysis of the two Ex-Gaussian components, we found a marginally significant interaction of response relation and distractor relation only in the  $\mu$  parameter while this interaction was completely absent in the  $\tau$  parameter. Since the interaction is only evident in the  $\mu$  parameter, this would suggest that, in a flanker like task, distractor-based retrieval is driven by motor processes. For the main effect of distractor relation it was exactly the other way round, that is this effect was significant only in the  $\tau$  parameter, which is typically believed to reflect retrieval/conflict on a cognitive level, thus suggesting, that distractor inhibition is driven by cognitive processes (see **Figure 3**).

A closer look at the pattern of the interaction of response relation and distractor relation in the current data shows that it is not exactly as predicted by the stimulus-response retrieval model. The

model predicts a distractor repetition advantage in response repetition trials and a disadvantage in the response change trials. In the current data – as in many published studies on distractor-based retrieval – the advantage in the response repetition trials is evident, however, the disadvantage predicted in the response change trials is not observed (the effect here is 0 ms). The reason is that in response change trials distractor-based retrieval (here leading to a cost effect) and distractor inhibition (here leading to a benefit effect) cancel each other out, leading to a non-significant net effect. Therefore it has been argued that one must always interpret the interaction of response relation x distractor relation and not solely interpret the response change condition, as the main effect of distractor inhibition may overshadow the retrieval effect (e.g. Frings & Rothermund, 2011). Importantly, the method of analysing the parameters of the exponentially modified Gaussian distribution is well suited to circumvent this issue as by using this method both effects can be disentangled, and the strength of the effects can be measured independently.

It should also be noted that in our experiment retrieval presumably comprises response and target retrieval; Giesen and Rothermund (2014) have shown that distractor-based retrieval typically involves two independent processes, one retrieving the prime target stimulus and one retrieving the prime response. This fits the logic of the *Theory of Event-Coding* (Hommel et al., 2001), stating that repetition of a feature (here the distractor) will result in retrieval of the whole S-R episode including all feature bindings (concerning the response as well as the target). Disentangling and separating these two types of retrieval processes requires complex methodological procedures (see Giesen & Rothermund, 2014). Even eliminating identical target repetitions within the response repetition condition will not eliminate the possibility that retrieval effects are mediated by a retrieval of the target stimulus rather than by a direct retrieval of the response that was executed during the prime (since all targets are mapped onto a specific response, repetition of the distractor might retrieve the prime target, which is then translated into a matching response during the probe). It is thus highly likely that retrieval effects in our study reflect a mixture of distractor-stimulus and distractor-

response bindings. For the main point of our study, however, separating S-S from S-R retrieval is irrelevant. The essential finding of our study relates to the fact that distractor-based retrieval processes (of targets and/or responses) can be disentangled from distractor inhibition via an Ex-Gaussian approach and furthermore can be assigned to different levels of processing.

Finally, one may wonder whether using an unequal number of features for target discrimination (two colors) and response selection (four identities) had an influence on the parameter estimation (for instance, color discrimination was easier as only two colors had to be selected). We ran control simulations with artificial RT distributions that were based on the original RT distributions. For this purpose, we simulated data on the assumption that increasing the number of colors would make target discrimination more difficult. We increased the RT distributions individually for each participant and then estimated the Ex-Gaussian parameters again using the artificial RT distributions (we ran two simulations with artificially increased RT distributions of 5 % and 10% increase of the participants' average RT). The results remained exactly the same, in that the distractor-based retrieval was present only in the  $\mu$  parameter while distractor inhibition was present only in the  $\tau$  parameter. Thus, factors influencing the average RT level seem to be irrelevant for the disentanglement of distractor-based retrieval and distractor inhibition via Ex-Gaussian parameter estimation.

With respect to distractor-based retrieval, the current finding, that retrieval is driven by motor processes, would seem to be in accordance with the current position in the literature. This interpretation is in line with previous studies showing a direct link between the distractor and a motor response (e.g., Giesen & Rothermund, 2014) or a stimulus and a response in general (Dobbins, Schnyer, Verfaellie, & Schacter, 2004). Giesen and Rothermund (2014) found that repeating a distractor can retrieve the previously executed motor response, even if the target is changed. The present finding strengthens this assumption, and provides evidence for the underlying process of distractor-based retrieval. However, previous studies have shown that distractors can retrieve

responses at different levels of representation e.g., decisional, or conceptual level (Frings et al 2013; Henson et al., 2014; Nett et al., 2015). Our results do not exclude the possibility of retrieval on stimulus level, and furthermore, these different kinds of retrieval are not contradictory. The level of retrieval, stimulus (e.g., target) retrieval or response retrieval, is surely task-dependent. In addition, one might argue that different features have different processing times and that therefore the retrieval function of these features differ (we varied shape, colour, and location of the distractors). However, previous research on distractor-based binding effects clearly suggests that the retrieval function is not feature-dependent (e.g., Hommel, 1998) and further that response-feature bindings are typically binary and independent (Moeller et al., 2016). For our purpose, we assume that repeating a distractor in the same location, with the same colour and shape will start a retrieval process which results in retrieving the prime response – whether and how the different repeated features modulate or enhance each other is beyond the concern of the present research.

In the present experiment there was only a small set of distractors, each of which was mapped to a specific response. The task was a simple identification task, and therefore further processing of the stimuli was not required. In situations where the task requirements differ, it is likely that cognitive processes are also involved and that the distractor is further processed to a different/higher level, e.g., to a conceptual level. It may however still be argued, that although the distractor is processed to a higher (conceptual, instead of identity) level, the retrieval occurs at a motor level. For instance, in the study by Frings, Moeller, & Rothermund (2013), distractors could be presented in different modalities, without changing their identity; e.g., the distractor ‘frog’ could be presented as a picture or as a sound. In this case the distractor would have to be processed at a conceptual level, but once the distractor has been processed, it may still retrieve the motor response associated with it in the previous instance.

With respect to distractor inhibition, interestingly, the main effect of distractor relation, which is assumed to reflect distractor inhibition independent of binding effects, was significant only in the  $\tau$

parameter; thus according to the typical interpretation of Ex-Gaussian parameters in RT analyses, our results suggest that inhibition took place at the stimulus selection and not at the motor level. This finding is also in accordance with literature on negative priming (Frings, et al., 2015; Houghton & Tipper, 1994) and findings of other tasks involving inhibition processes (Anderson, 2003). Inhibition theories generally assume, that the internal representation of the distractor is actively suppressed, and that the inhibition lingers on to the next trial. Thus, when a distractor is repeated as a target, responding is slower, e.g., as is the case in Negative Priming. Applying distractor inhibition to the present results, we expected general performance facilitation if the distractor is repeated, since inhibiting and selecting against an already suppressed distractor is easier, than selection against a new distractor. Since the effect of distractor inhibition is reliant on the identification (and the following inhibition) of the distractor (Frings et al., 2015), the present results fit perfectly. Analyzing the estimated Ex-Gaussian components, we were able to provide further confirmation that the inhibition of the distractor occurs at the level of stimulus identification.

Furthermore binding and inhibition – both observed in the standard RT analysis – are exclusively driven by different parameters of the Ex-Gaussian function. This aspect of the data pattern speaks to the independence of distractor-based retrieval on the one hand and to distractor inhibition on the other hand (see Giesen et al., 2012). In their study, Giesen et al., (2012) were able to show that distractor-based retrieval and distractor inhibition are two separate and independent processes. They found that distractor inhibition effects were stronger for distractors that were incompatible than for distractors that were neutral. However, the strength of the distractor-based retrieval effects were not affected by the incompatibility/neutrality of the distractors. The present results confirm this finding and furthermore specify the level at which the processes underlying distractor-based retrieval and distractor inhibition work. The inhibition process, which is predominantly discussed as a process that enhances stimulus selection, allowing the selection of relevant stimuli by inhibiting any other irrelevant stimuli, was observed to operate on a cognitive

level. The retrieval process, which is discussed in relation with action planning, allows for fast and efficient responding to repeated stimuli by the retrieval of the response, was observed to operate on a motor level.

Inhibition theories usually discuss the inhibition process as a selection process that affects stimulus processing. Houghton and Tipper (1994, 1996) discuss a network model of selective attention, which includes a target field that describes the target, and a match/mismatch field that compares perceptual input to the target description. If perceptual input matches the target field then that stimulus representation is activated, if it does not, it is inhibited. Also, Neumann and DeSchepper (1991) discussed the spreading of inhibition in a manner similar to the spreading activation, which is usually discussed in priming literature. The main idea, that the larger the number of irrelevant stimuli, the less the amount of inhibition that each one receives, suggests that inhibition acts on stimulus representations. Another example is the paper of Neill, Lissner, and Beck (1990), who discussed the 'locus of inhibition', and whether a specific response was inhibited or a more central cognitive representation was inhibited. Some studies have found a transfer of inhibition to different stimuli, e.g., Tipper and Driver (1988) found transfer of inhibition between pictures and corresponding words. Tipper, MacQueen, and Brehaut (1988) found transfer of inhibition between manual and vocal responses. These findings together would suggest, that it is not a particular response that is inhibited, rather the cognitive representation of a stimulus is inhibited (or at least that inhibition is flexible in that it can be applied to every level of cognitive processing). The present results would seem to provide more evidence to such inhibition theories, since the inhibition in the present study was only observed in the parameter that reflects cognitive processing.

Binding theories on the other hand, discuss binary bindings between stimuli (relevant and irrelevant) and responses (e.g., Hommel, 1998; Frings et al., 2007). Repeating a stimulus would result in a retrieval of the response that was associated with it in the previous event. Evidence has been observed for direct bindings between distractors and stimuli (Giesen & Rothermund, 2013), for

conceptual mediation of such bindings (e.g., Frings et al., 2013), for retrieval of decisions (Nett et al., 2015) and retrieval of a specific response (Wiswede et al., 2013). Especially the findings of direct bindings between distractors and responses (Giesen & Rothermund, 2014) and the finding of the specific retrieval of the prime-response - which in the case of the probe was erroneous (Wiswede et al., 2013) would suggest, that such retrieval processes operate on a motor level. This is precisely the observation in the present study. Any evidence of retrieval was only observed in the parameter that reflects motor processes (the  $\mu$  parameter). Such stimulus-response bindings have often been discussed as a possible first step in the learning process (e.g., Logan, 1988; Frings, Moeller, & Horner, 2015), and the similarities in structure of distractor-response bindings and Pavlovian learning have been highlighted (Giesen & Rothermund, 2014). Not every single stimulus response pairing has a long term effect on behaviour. This would not be adaptive since then even wrong stimulus-response associations would be stored, which would lead to less efficient responding. However, contingencies can be recognised fairly quickly (Frings et al., 2015) and repeated stimulus-response pairings could translate into behavioural routines. Thus the retrieval of a motor response by a repeated stimulus might be the first step in the learning of behavioural routines.

Human behaviour in general and human selection in particular has to be highly adaptive. In day to day situations, human beings are confronted with a large number of stimuli at any given moment. In order to be able to respond efficiently, the relevant stimuli must be actively selected. Outside the laboratory, different (action) goals simultaneously affect top-down regulation of behaviour, while the relevance of goals (and accordingly of the related stimuli) can change from one second to the next. It is therefore *prima facie* plausible, that even irrelevant stimuli might be processed at different levels and with different processes (as here binding and retrieval and inhibition), thereby possibly adapting to different needs of successful behaviour. For instance, the binding and the retrieval of its motor component might be a first step of establishing a behavioural routine (e.g., Frings et al., 2015), while inhibition might be applied and relieved from an internal

stimulus representation just until a particular action is executed (and lingers on for a few milliseconds; Houghton & Tipper, 1994).

In conclusion, the present findings suggest that that the repetition of a distractor can lead to the direct retrieval of the motor-response (as seen in the interaction of distractor relation and response relation in the  $\mu$  parameter) and hence, that distractor-based retrieval effects mainly affect motor processes while distractor inhibition processes occur at a central stimulus representation level, as evidenced by a facilitated target selection against an already inhibited distractor, as seen in the main effect of distractor repetition in the  $\tau$  parameter.

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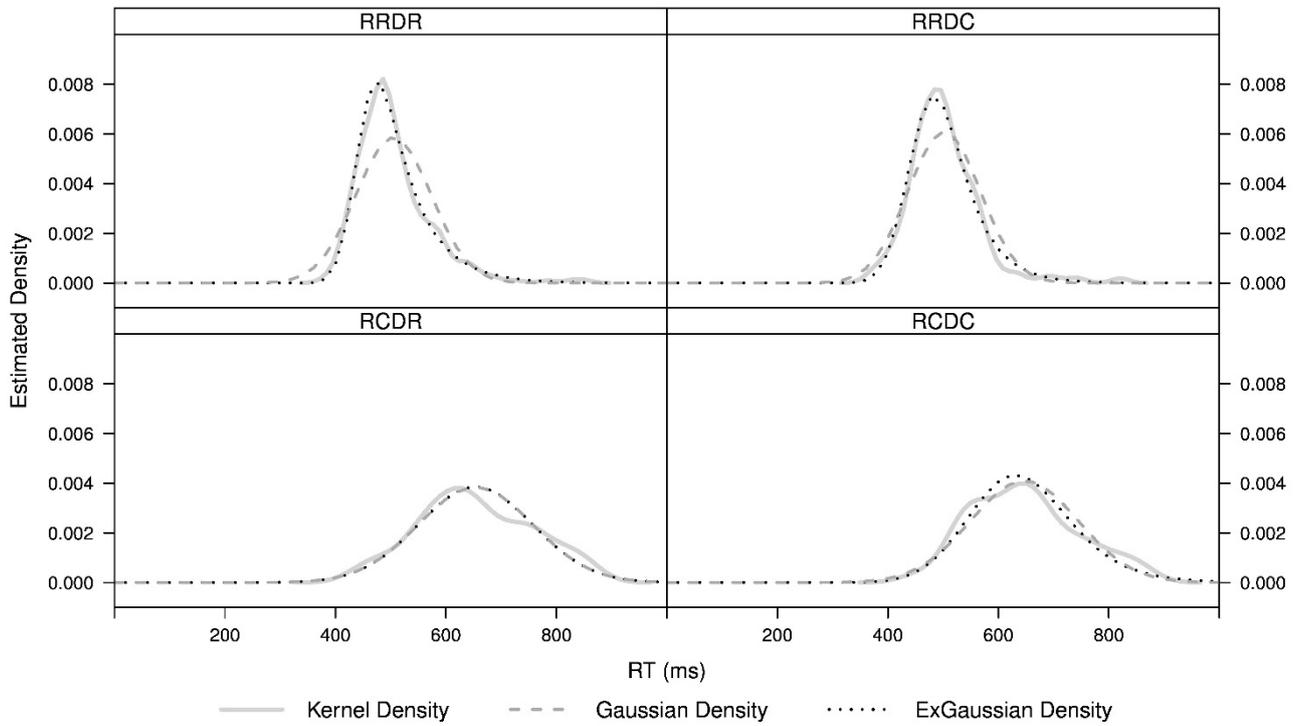
### Footnotes

<sup>1</sup> The results do not hinge on a particular outlier criterion. Using a less strict criterion (with a smaller loss of data) would not change the data pattern or results. In addition, the relatively high number of discarded trials was due to the fact, that only correct prime-probe response sequences were considered. Given that we were interested in the after-effects of processing the prime display on the probe, it is *lege artis* to only analyze correct probe responses that followed correct prime responses.

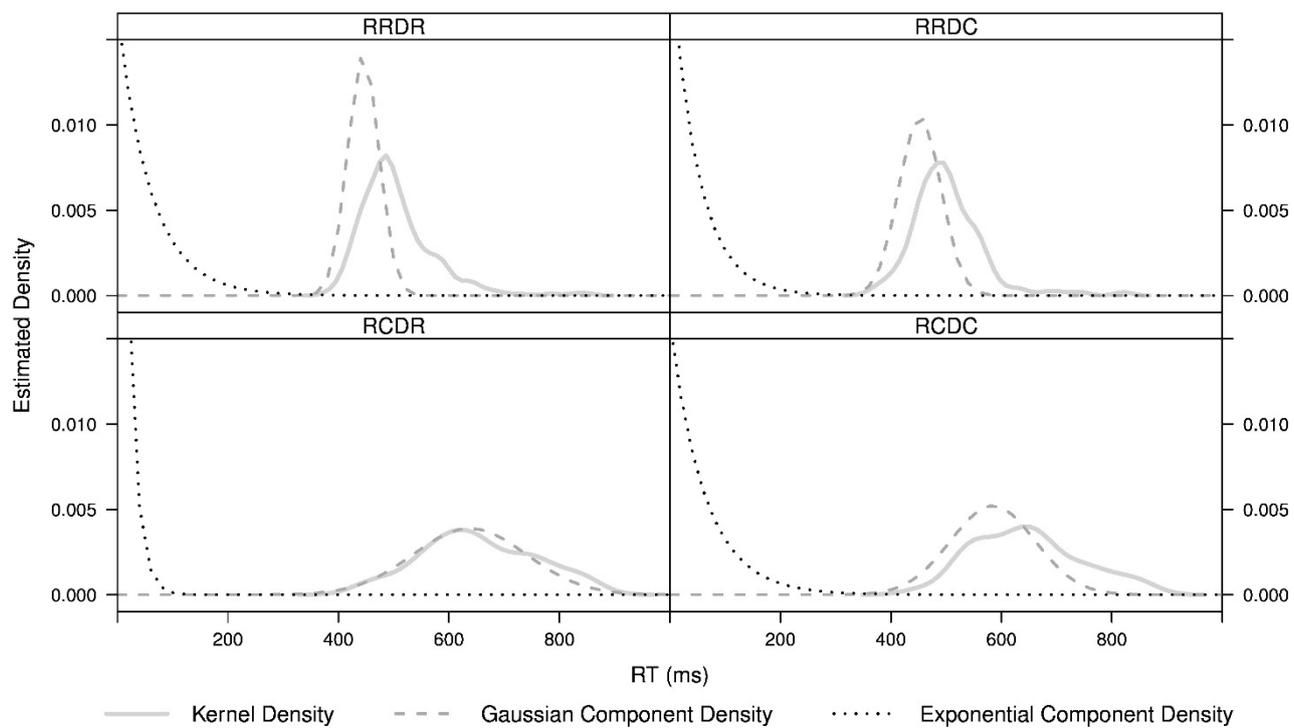
**Table 1.** Mean RTs and error rates in percentage (in parenthesis) of probe responses as a function of response relation and distractor relation.

<i>Response Relation</i>		
	Response Repetition	Response Change
<i>Distractor Relation</i>		
Distractor Repetition	471 (0.7)	639 (8.2)
Distractor Change	484 (1.1)	639 (7.6)

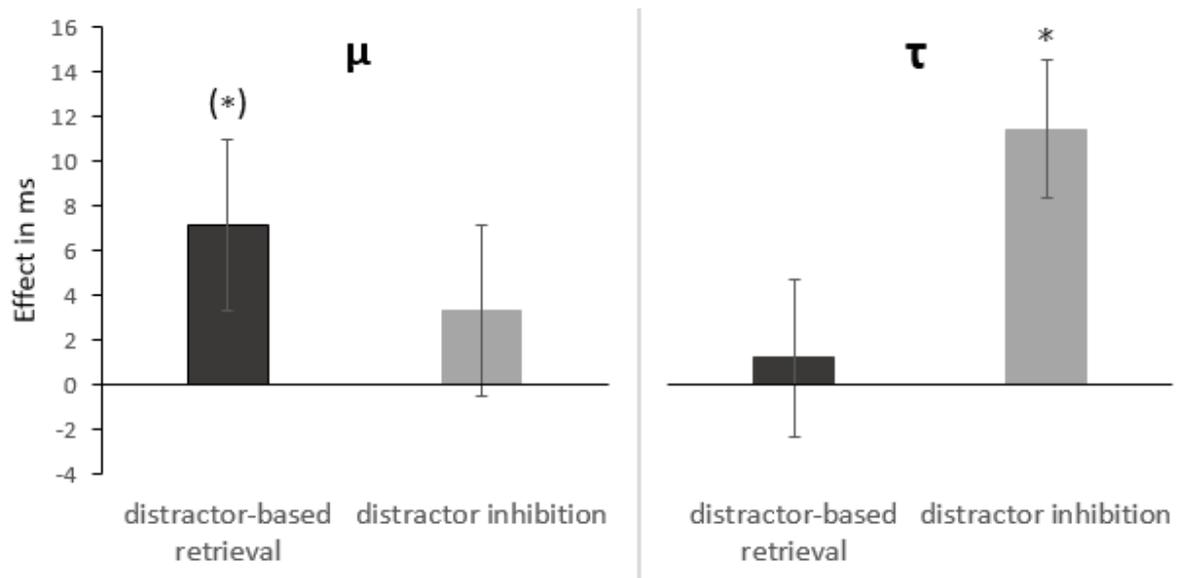
**Figure 1.** An exemplary comparison of the fit of the estimated density of the Gaussian distribution and of the Ex-Gaussian (exponential Gaussian) distribution to the empirical data, depicted for Subject 1.



**Figure 2.** The estimated components of the Ex-Gaussian distribution, exemplarily depicted for Subject 1.



**Figure 3.** Distractor-based retrieval effects and distractor inhibition effects in ms, respectively for the exponential parameter  $\tau$  and the Gaussian parameters  $\mu$ . Distractor-based retrieval effects were calculated as the difference between distractor repetition effects in response repetition and response change trials. Distractor inhibition effects are indicated by the main effect of distractor relation (distractor repetition benefits).



## 10. General Discussion

The studies presented in this work all aimed at understanding the influence of irrelevant stimuli on our actions and the conditions under which they occur. Irrelevant stimuli are all around us in our environment, and in order to function efficiently we must be able to ignore these irrelevant stimuli and select only those stimuli which are relevant to our actions. Ignoring a stimulus does not mean that it ceases to have any influence on our actions present, or future. Even if a stimulus is ignored, it still gets integrated with a response, and if it is repeated, it can retrieve the response with which it was integrated – distractor response binding. The studies reported in the present work attempted to further our understanding of the distractor-response binding effect; under what conditions such bindings occur and what is the extent of such bindings.

The first study, reported in chapter 6 (Singh, Moeller, & Frings, 2016), examined whether retrieval can extend to similar distractors. The results showed that even a similar distractor may retrieve the response, however the strength of the retrieval decreases with the decreasing similarity of the distractors.

The study reported in chapter 7 (Singh, Frings, & Moeller, 2017) examined whether distractor-response bindings extended to abstract concepts. The findings showed that like concrete concepts, even abstract concepts can be integrated with a response, and if repeated, they can retrieve the response.

The study in chapter 8 (Singh, Moeller, Koch, & Frings, submitted) looked at the influence of attention on the distractor-response binding effect. Bindings were observed only when attention was allocated to the distractor.

Chapter 9 (Singh, Laub, Burgard, & Frings, in press) examined two mechanisms that are often observed in the data and that exist independently of each other – distractor-response binding and distractor inhibition. Using an estimation and analysis of the Ex-Gaussian parameters of the reaction time distribution different processes were observed to underlie both effects. Motor processes were observed to underlie the distractor-based retrieval effect, and cognitive processes were observed to be underlying the distractor inhibition effect.

### 10.1. Retrieval in the absence of exact perceptual repetition

In most studies in the distractor-response binding literature, there are only two manipulations of the distractor, either a different distractor is presented in the probe, or exactly the same distractor is repeated. Repeating exactly the same distractor results in the

retrieval of the response. However, what would be the outcome if a similar, but not exactly the same distractor is presented in the probe - are distractor-response bindings so specific that absolutely no retrieval will occur even if there is a slight difference in the distractors or will at least some retrieval be observed if a similar distractor is repeated? Although only chapter 6 explicitly examined this question, evidence for retrieval without exact perceptual repetition of the distractor can be observed in the first three reported studies. In chapter 6 generalization to perceptually similar distractors was explicitly studied by manipulating the similarity between the distractors in 5 levels. The results showed the strongest distractor-response binding effect for exact repetitions and no retrieval for distractors with a difference of three levels between them. However, even for distractors that had a difference of one level (marginally) significant retrieval was observed, which suggests that retrieval can occur even if a similar distractor is presented. Similar results have been reported in related paradigms like repetition priming, e.g. Biederman & Cooper (1991), and stimulus-response binding studies, e.g. Denkinger & Koutstaal (2009). Both of those studies observed significant priming effects/retrieval effects when different exemplars of the same stimulus were presented. Both also found that the effects for the different exemplars were smaller than those for exact repetitions. Thus the first chapter delivered evidence that retrieval can occur even if the distractor is not exactly repeated.

In chapter 7 as well, there was evidence that perceptual repetition was not necessary for the retrieval of responses. In that study, the distractor (detailedness: high vs. low) was never perceptually repeated from the prime to the probe, rather only the concept of the detailedness was repeated, but each time with different features i.e. no distractor feature was ever repeated from the prime to the probe. Retrieval was observed even though there was absolutely no perceptual repetition of the distractor, only a repetition of the concept.

Similarly, in chapter 8, it was not necessary to repeat exactly the same stimulus, rather even a similar stimulus was able to retrieve the response. The experiments in chapter 8, in which word stimuli were used with valence and word type as distractors, could also be seen to point toward retrieval without exact repetition. In those experiments, although the valence (positive or negative) and word type (noun vs. adjective) were always either exactly repeated or completely changed, the words themselves were never repeated from the prime to the probe. Thus, for instance repeating the valence of the word (but changing the word itself) also led to retrieval (under the conditions of adequate attention). Again, studies in related paradigms have shown similar results. For instance studies on affective priming or semantic priming (e.g. Fazio, 2001; Hutchinson, 2003). In both of these types of priming, either the

same affect (valence) or the same semantic category is repeated in the probe, however, the stimulus itself is always changed, and faster responding is observed when both words are from the same category compared to when they belong to different categories. Thus, it is not necessary to repeat exactly the same stimulus, rather it suffices to repeat a semantically related one. It must be noted, however, that unlike in the chapter 6 similarity was not varied in a controlled increase/decrease of similarity, i.e. stimuli were either similar (belonged to the same category) or not. However, the implication still remains, it was not necessary to repeat exactly the same stimulus to retrieve the response. It was only necessary that the stimuli were from the same category. Thus throughout the first three studies, we find that exact (perceptual) repetition of a distractor is not a pre-requisite for retrieval to occur. Retrieval, even though to a lesser extent, will even occur if a similar distractor is presented. Retrieval is also observed if a perceptually different but conceptually related distractor is presented.

### **10.2. The influence of attention on distractor-response binding**

Although binding is, by and large, considered to be automatic, the influence of attention is still not clearly understood. While on the one hand some studies find binding only for spatially attended stimuli (Moeller & Frings, 2014) or for relevant features of a stimulus (Hommel, 1998) on the other hand conflicting evidence has been found in other studies. For instance, Hommel and Colzato (2004) found that increasing the attention to features of a stimulus did not increase the strength of their binding, and Hommel (2005) found that increasing attentional demands by making the task more difficult had no influence on binding effects.

Generally, distractor-response binding studies, unless explicitly studying the influence of attention, present only one distractor. In these studies the distractor-response binding effect is almost always observed. It would appear that in the absence of any competition, i.e. when only one distractor is presented, distractor based retrieval is observed (Chapters 6, 7, & 9), even if a slightly different distractor is presented (Chapter 5) or indeed if a perceptually different distractor is repeated (Chapter 7; see also Frings, Moeller, & Rothermund, 2013). It might therefore be argued, that in situations with only a single distractor, the single distractor, given spatial proximity to the target, receives enough attention (by virtue of it being the only distracting stimulus/feature) to enable it to cause binding and subsequent retrieval of the response if it is repeated. In studies with more than one distractor, however, binding is

generally strongest for the most salient or most relevant distractor, and for the other distractors very little to no binding at all is observed (Chapter 8; Hommel, 1998). In all the studies reported here, except the third (Chapter 8), there was always only one distractor presented, and distractor-response binding effects were always observed. Thus it would appear that in cases where a single distractor is presented, the distractor can retrieve the response.

In chapter 8 however, there were two distractors. In this case, significant binding was observed for the distractor that was made relevant via a second task, whereas very weak, if any, binding was observed for the other distractor. Similar results have been observed for a slightly different type of attentional manipulation. Whereas in chapter 8 attention was manipulated within one stimulus, i.e. the distractors were part of one single stimulus, Moeller and Frings (2014) found similar effects for manipulations of spatial attention. They used distractors at four different locations and cued the locations that were to be attended, they found binding for the attended distractors, but not for the unattended distractors.

However, other studies, using a slightly different paradigm found conflicting results. What accounts for the differences in the results observed in chapter 8 of this work and other experiments, which did not show any influence of attention on binding (e.g. Hommel, 2005; Hommel & Colzato, 2004)? In the Hommel (2005) study, the type of attentional manipulation was different. Whereas Hommel manipulated attentional load, the experiments in chapter 8 reported here manipulated feature based attention – i.e. attention was directed towards one or the other feature of the same stimulus. Thus, both studies tested two different types of attention.

The manipulation in the Hommel and Colzato (2004) study more closely resembles the manipulation used in chapter 8 reported here. In both of these studies, participants had to report one of the stimulus features at the end of a proportion of the trials. The difference, however, is that in the Hommel and Colzato study, the feature that the participants had to report was randomly selected, whereas in the studies in chapter 8, the to-be reported feature was cued. That is, the participants knew which feature they had to attend to before the trial began, and therefore had the chance to specifically attend to that feature, rather than simply increasing attention to all features in general. In such a scenario, significantly stronger binding is observed for the attended distractor, and little to no binding is observed for the unattended distractor.

This is the case even for seemingly salient distractors such as valence. Affective priming has been believed to be highly automatic, and occurs even when valence is irrelevant

(e.g. Fazio, 2001). However, in other studies, which required participants to name or categorize the stimuli based on some other criterion, affective priming effects were not observed, i.e. affective priming effects depend on whether valence is relevant to the task or not (Spruyt, De Houwer, & Hermans, 2009; De Houwer, Hermans, Rothermund, & Wentura, 2002). Thus it would seem that even affective priming is not completely immune to the influence of attention. The findings reported in chapter 8 are in agreement with such results. Binding effects were thus observed to be modulated by attentional allocation. In the presence of only a single distractor (Chapter 6, Chapter 7, & Chapter 9), repetition of the distractor generally leads to retrieval of the response. However if there is more than one distractor (e.g. Chapter 8), then stronger binding effects are observed for the attended distractor compared to the unattended distractor.

### **10.3. Distractor-response binding and learning**

A consistent theme in chapters 6 to 8 is the similarity between binding and learning. Whether binding is the first step in associative learning is still a matter of debate, however, what is undeniable, are the similarities between binding and learning, and, as shown in other studies, the influence that long term associations can have on binding under certain circumstances. In fact, short-term stimulus-response associations have been suggested as being early stages of the learning process. Logan (1988) postulated that instances as the first step in the learning processes. As more and more instances are stored, behaviour becomes increasingly memory based. Although it is as yet uncertain whether distractor-response bindings specifically can be a first step in the learning process, there are empirical findings that would at least suggest a couple of things; first, similarities between associative learning and short-term bindings (e.g. Giesen & Rothermund, 2014), and secondly, the influence of long-term associations on short-term stimulus response bindings (e.g. Moeller & Frings, 2014; Moeller & Frings, 2017). The studies reported in this work deliver evidence supporting the former claim, as shall be outlined below.

Evidence for similarities in associative learning and distractor-response binding came from a study examining the structure of distractor-response bindings. Giesen and Rothermund (2014) found that distractor-response bindings had a similar structure to Pavlovian conditioning. They found that the distractor had independent bindings with the target as well as with the response. They compared the distractor to the conditioned stimulus (CS), the target to the unconditioned stimulus (US), and the response to the target to the unconditioned

response (UR). Presenting the target (US) with the distractor (CS) results in associations between the distractor (CS) and the response (UR). When the distractor (CS) is repeated, it then elicits the response with which it was associated (CS).

The results reported here (Chapters 6, 7, & 8), provide evidence of further similarity between associative learning and distractor-response bindings. Chapter 6 showed that the phenomenon of generalization, which is typical of Pavlovian conditioning, can also be observed in distractor-response bindings. Repeating exactly the same distractor resulted in the strongest binding effects, presenting a similar distractor resulted in weaker binding effects, with the strength of the binding effect decreasing with the decreasing similarity of the distractors. These findings are in accordance both with generalization – the finding that responding can occur in circumstances that are similar but not exactly the same as in the learning stage – and the principle of generalization decrement – which is the finding that the strength of the generalization depends on the similarity of the stimuli (Pearce, 1987).

In chapter 8, the findings suggested evidence for another principle of Pavlovian conditioning – overshadowing. Overshadowing is the finding that if there is more than one stimulus present, then the more salient stimulus may prevent or decrease the formation of associations between the less salient stimulus and the response (Mackintosh, 1975). In chapter 8, two distractors were present, one of them was made more salient due to its relevance to a second task. Distractor-response bindings were stronger for the relevant distractor than for the irrelevant one. Thus again, we find an indication for a functional similarity between long-term learning and short-term bindings, overshadowing, a principle of Pavlovian conditioning was observed within short-term bindings. Another indication of similarity between distractor-response bindings and learning in general, might be the fact that attention can modulate distractor-response bindings. Attention has already been shown to be an influence in learning, (e.g. Mackintosh, 1975; Baddeley, Lewis, Eldridge, & Thomson, 1984; Haselgrove, Esber, Pearce, Jones, 2010) and chapter 8 provides evidence that attention has a similar influence on distractor-response bindings.

The results reported in chapter 7 can also be discussed with respect to learning. If it is assumed that short-term bindings are the first stage in the learning process (Logan, 1988), then the findings in chapters 7 are relevant even in the learning context. The study reported in Chapter 7 showed that perceptual repetition of a distractor was not necessary, rather the repetition of the distractor concept was enough to cause retrieval. Although this was not the first study to show concept based retrieval (see Frings, Moeller, & Rothermund, 2013) it was the first to show concept based retrieval with abstract concepts. The difference between

abstract concepts and concrete concepts is not trivial. Whereas concrete concepts have the advantages of larger number of sensory representations (e.g. visual, auditory, olfactory, etc.), and well defined features (e.g. prototypes), abstract concepts have none of these. The distractor concept of detailedness used in chapters 7, had neither a large number of sensory representations, nor is there any prototype of a detailed object (in this case a banana). Still, when the concept was repeated, it retrieved the response, even though none of the individual features were ever repeated. Considering these findings in the context of learning, if learning is an accumulation of instances as Logan suggested (1988), then retrieval without perceptual repetition might be advantageous. Logan (1988) postulated that repeat encounters with stimuli, in time, resulted in the automatization of behaviour. He suggested that every encounter with a stimulus is stored in an instance. Upon reencountering the stimulus, two processes are initiated, one algorithmic process to compute the appropriate response to that stimulus, and one automatic retrieval process, which retrieves the last stored instance from memory. With the accumulation of instances, the retrieval process becomes more likely to win the race against the algorithmic processing, thus making behaviour more retrieval based. Given that not every encounter with a stimulus will occur in the exact same manner, it would be beneficial if even a conceptually related stimulus could retrieve the instance. This way, behaviour can be adapted more quickly to slightly different situations. This kind of flexibility might be beneficial in the early stages of learning, when concepts are not fully learned. It would also imply the ability for retrieval to occur even when perceptually different (but conceptually same) features/stimuli are presented. Thus even features that were not necessarily present at the time of integration can retrieve the response with which the concept was associated.

A second line of evidence that might indicate that long-term learning and short-term bindings are not wholly independent of each other comes from studies that examine the influence of long-term associations on distractor-response bindings. For instance Moeller and Frings (2014; 2017) were able to show that when stimuli already have long term associations with a response, short-term bindings with another response are hindered. For instance, if a left pointing arrow is paired with a right-hand response, short-term binding is unlikely to be formed, however, if the response is compatible (left pointing arrow and left-hand response) then short-term-bindings are more likely to be formed (Moeller & Frings, 2014).

Similarly, if on the onset of a word, a different word has to be pronounced, bindings between the presented word and the pronounced word will not be formed. If however, the

pronunciation takes place at the onset of a non-word, then the non-word will be associated with the pronunciation (Moeller & Frings, 2017). Thus if stimuli are already strongly associated with a response, formation of short-term bindings with new incompatible responses will be hindered.

Although the exact relation, if any, between distractor-response bindings and long-term learning is a matter of dispute, and although the differences between them are abundantly clear, in light of the available empirical evidence, there does seem to be at least some similarity in the structure and the function of short-term bindings and long-term learning, and the results presented in the current work provide further indication of similarity.

#### **10.4. Distractor-based retrieval and distractor inhibition**

The study presented in chapter 9 provides evidence for the processes that underlie the mechanisms of distractor-based retrieval and distractor inhibition. In most distractor-response binding studies apart from retrieval, distractor inhibition is also observed since the distractor-inhibition effect is inherent to the paradigm used in distractor-response binding studies. Nearly all distractor-response binding studies use a distractor-to-distractor priming paradigm, where the distractor from the prime can be either repeated or changed in the probe. When a distractor is inhibited in the prime this inhibition gets carried over to the probe, and causes less interference in target selection (e.g. Houghton & Tipper, 1996).

This is generally also the reason why the result patterns sometimes do not exactly match those predicted by the Stimulus-Response retrieval model (Rothermund et al., 2005). The model suggests that distractor repetition should benefit response repetition and thus predicts faster responding when both the response and the distractor are repeated compared to when the response is repeated but the distractor is changed. This part of the prediction is generally always observed since both inhibition and retrieval predict similar outcomes.

The model also predicts that distractor repetition is a hindrance when the response is changed and thus responding is slower when the response is changed but the distractor is repeated compared to when both are changed. This part of the prediction is not always observed, since here retrieval and inhibition predict differing outcomes and might cancel each other out. Retrieval predicts slower responding because the retrieved response does not match the response that is to be executed, and inhibition predicts responding benefits, since the inhibited distractor should not interfere with target selection.

Previous studies have shown that distractor-based retrieval and distractor inhibition are two independent processes (Giesen, Frings, & Rothermund, 2012). In chapter 9, the mean reaction times of the Gaussian distribution were analysed, followed by an estimation and analysis of the parameters of the Ex-Gaussian distribution. This analysis suggested that the process underlying the distractor-based retrieval effect, observed only in the parameter  $\mu$ , was of a motor nature, and the process underlying the distractor inhibition effect, observed in the parameter  $\tau$ , was of a cognitive nature. The attribution of the processes to the observed effects also concur with findings in the literature. Distractor inhibition has been postulated to be at a cognitive level, i.e. the stimulus representation is inhibited (Neuman & DeSchepper, 1991; Tipper & Driver, 1988). In the case of retrieval, on the other hand, direct bindings between a distractor and a response have been observed, suggesting a motor process (Giesen & Rothermund, 2014). Thus, in addition to the knowledge that both effects exist independently of each other, the chapters 9 showed that they are driven by two different processes.

The results of experiment 1 reported in this work (chapter 6) would also seem to suggest motor processes as underlying retrieval. Structural similarities between Pavlovian conditioning and distractor-response binding have been discussed in the literature, suggesting that the repetition of the distractor directly retrieves the motor response, similar to the manner in which a conditioned stimulus would elicit the conditioned response (Giesen & Rothermund, 2014). Evidence of further similarities between distractor-response bindings and Pavlovian conditioning have been provided in chapter 6 (generalization and generalization decrement) and chapter 8 (overshadowing). In Pavlovian conditioning a conditioned stimulus is believed to directly elicit the conditioned response. Thus considering the similarities between Pavlovian conditioning and distractor-response bindings, one might argue that distractors do indeed directly retrieve a motor response.

## 10.5. Conclusions

The reported studies provided evidence of further similarities between distractor-response bindings and learning. Chapters 6 and 8 showed that generalization and overshadowing respectively, both effects typical of Pavlovian conditioning, can also be observed in distractor-based response retrieval. These results extend previous findings of similarities in the structure of distractor-response bindings and Pavlovian conditioning. Chapter 7 provided evidence for the binding of abstract concepts and retrieval in the absence of perceptual repetition. Even if there is no perceptual repetition of a distractor, rather only the

concept is repeated, binding was observed. Such a flexibility in the integration and retrieval of short term bindings, might be beneficial to the learning process, given that they have been discussed as early stages on the learning process. Evidence was also provided for the modulation of the distractor-response binding effect through attentional allocation. Chapter 8 showed that the binding effect for those distractors towards which attention was directed was stronger than for those towards which no attention was directed. This finding again suggests further similarity between distractor-response bindings and learning. Attention has been shown to be necessary for learning. And finally, chapter 9 threw light upon the process underlying two effects generally observed in distractor-response binding studies – distractor-based retrieval and distractor-inhibition. The distractor-response binding effect was observed to be driven by motor processes and distractor-inhibition by cognitive processes. Specifically the finding that retrieval occurs on a motor level, can be discussed in relation to learning, specifically Pavlovian conditioning, where the presentation of a conditioned stimulus (the distractor in distractor-response binding) elicits the associated conditioned response (the associated response in distractor-response binding). Taken together, the reported studies contribute to furthering our understanding of the conditions under which distractor-response bindings can be observed, and the relationship between distractor-response bindings and learning.

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## Irrelevant Influences

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## **Declaration of Authorship**

I hereby certify that this thesis has been composed by me and is based on my own work, unless stated otherwise. No other person's work has been used without due acknowledgement in this thesis. All references have been quoted and all sources of information have been specifically mentioned.

Trier, \_\_\_\_\_

Date

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Signature