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Brightness versus darkness: The influence of stimulus intensity on the distractor-response binding effect

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ABSTRACT

The intensity of a stimulus has been found to have a distinct impact upon response processes (e.g., response speed, response force, & response selection). For instance, reaction times are faster to bright than to dim stimuli (e.g., Kohfeld, 1971). In the present study, we investigated the possible influence of stimulus intensity on binding processes. According to binding theories, stimulus and response features are integrated together in short-lived memory traces, called event files (Hommel, 1998). Any re-encounter with one of these integrated features leads to the automatic retrieval of the previously constructed event file and thus of the response. Thereby bindings between stimuli (relevant and irrelevant) and responses have a direct impact on behavior. In the present experiment, we presented distractors with increasing stimulus intensity and found that intensity did exert an influence on binding processes. However, our results suggest that distractor intensity per se has no direct influence on the binding effect (the more intense a distractor is, the larger the binding effect), but that distractor intensity has an indirect effect on binding via grouping due to similarity between target and distractor intensity.

1. Introduction

The human cognitive system is provided with different mechanisms guiding action regulation (see Frings et al., 2020, for a recent framework on action control). One of these mechanisms is the binding of stimuli and responses. As proposed by the Theory of Event Coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001) perceived stimulus features and response features are integrated in loose networks of temporary associations, called event files. Event files are created at the time of responding to a stimulus and include binary bindings between individual stimulus and response features. Any reencounter with one of these integrated features leads to the automatic retrieval of the previously constructed event file and thus of the response (Hommel, 1998; Hommel, 2004).

Furthermore, not only features of stimuli we respond to, but also response irrelevant distractor stimuli can be integrated with a response in a short-lived memory trace (Frings, Rothermund, & Wentura, 2007; Rothermund, Wentura, & De Houwer, 2005). Likewise, the repetition of a distractor stimulus leads to the retrieval of the previously integrated memory trace and thus of the response. The so-called *distractor-response binding effect* is typically investigated using a sequential priming paradigm (e.g., Frings & Rothermund, 2011).

This sequential prime-probe design allows the orthogonal variation of response relation (i.e., whether the response is repeated or changed from prime to probe) and distractor relation (i.e., whether the distractor is repeated or changed from prime to probe), leading to four different trial conditions (see Table 1 for these conditions and example trials). The distractor-response binding effect arises in the interaction of the factors distractor relation and response relation: performance in response repetitions trials is facilitated if the distractor stimulus is repeated in the probe (e.g., repeating the distractor letter 'L', while the same response has to be executed to the target letter 'D' in prime and probe) in contrast to trials with a distractor change (e.g., presenting the distractor letter 'P' in the prime and 'L' in the probe, while the same response has to be executed to the target letter 'D' in prime and probe), while performance is impaired in response change trials if the distractor is repeated (e.g., repeating the distractor letter 'L' from prime to probe, while a different response has to be executed to the prime target 'J' and the probe target 'D'), in contrast to when the distractor is changed (e.g., presenting the distractor letter 'P' in the prime and 'L' in the probe, while the response is changed). The benefit of distractor repetitions in response repetition trials and the disadvantage of distractor repetition in response change trials together constitute the distractor-response binding effect.

Importantly, the term binding effect does not refer to the binding

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process (which is labelled integration process in the present study), but to the observed measurable effect (Frings et al., 2007). Furthermore, this measurable distractor-response binding effect can always been traced back to two processes – the stimulus-response integration process and the stimulus-response retrieval process (see Frings et al., 2020). A great number of studies has evidenced that modulating factors (such as attention and task relevance) have an exclusive influence on the retrieval process and thus lead to differences in the observable effect (e.g., Ihrke, Behrendt, Schrobsdorff, Herrmann, & Hasselhorn, 2011; Moeller & Frings, 2014). However, there is also evidence that factors such as grouping can modulate the integration process and thus can also be responsible for differences in the observable binding effect (e.g., Laub, Frings, & Moeller, 2018).

Overall, the distractor-response binding effect is a robust effect that has been replicated several times with different modalities and stimuli (e.g., Giesen & Rothermund, 2014; Moeller, Rothermund, & Frings, 2012; Singh, Frings, & Moeller, 2019). Furthermore, recent research has determined various modulating variables that have an influence on the binding of distractor stimuli, such as grouping and Gestalt principles (e.g., Frings & Rothermund, 2011, 2017; Laub et al., 2018), attention (e.g., Ihrke et al., 2011; Moeller & Frings, 2014), and task-relevance (e.g., Singh, Moeller, Koch, & Frings, 2018). In the present study, another potential modulating variable will be investigated that has been suggested to modulate distractor processing, namely stimulus intensity.

Previous research found that stimulus intensity not only influences sensory and perceptual processing but also has an influence on response processes (see Miller, Franz, & Ulrich, 1999; Nissen, 1977; Ulrich, Rinkenauer, & Miller, 1998). For instance, a long-time known effect of stimulus intensity is that responses are faster to bright or loud stimuli than to dim or soft stimuli (e.g., Kohfeld, 1971). Furthermore, evidence was found that the intensity of a stimulus (relevant and even irrelevant ones) has an influence on response force in choice reaction time task, thereby supporting the assumption that intensity can affect response processes (Miller et al., 1999).

With regard to the influence of stimulus intensity of irrelevant distractor stimuli on response selection processes, Houghton, Tipper, Weaver, and Shore (1996) postulated that more intense stimuli are activated to a higher degree and thus need to be inhibited more strongly, and therefore produce greater interference than comparable stimuli that are less intense. This assumption was tested using the negative priming paradigm (for a recent review on the negative priming effect see Frings, Schneider, & Fox, 2015). Houghton et al. (1996) used distractor stimuli that were presented in either dark grey (low intensity) or white (high intensity) on a black background, while the target stimuli were always presented in light grey. Yet, no reliable evidence for a modulating effect of distractor intensity was found. Comparable, Fox and De Fockert (1998) presented target and distractor stimuli either in white (high-contrast display) or in dark-grey (low-contrast display) against a black background. They found faster responses to high-contrast displays compared to low-contrast displays, but also evidence that high-contrast prime distractors produce more interference and in turn larger negative priming effects than low-contrast prime distractors.

In sum, aside from the obvious effects of target intensity, there is first evidence for an influence of distractor intensity on response selection processes, however, to the best of our knowledge, there is no study investigating the influence of stimulus intensity of irrelevant distractor stimuli on binding effects. Furthermore, different assumptions about the exact way distractor intensity might influence binding effects can be drawn.

The present study

The aim of the present study was to investigate the influence of distractor intensity on the distractor-response binding effect. Hypothetically, an influence of distractor intensity might be twofold. First, it could be assumed that increasing distractor stimulus intensity would lead to an increasingly stronger distractor-response binding effect due to its separate effect upon integration and retrieval (Frings et al., 2020). Theories such as the feature integration theory of attention (Treisman & Gelade, 1980) and the instance theory of automatization (Logan, 1988)

Table 1
Examples of the four different trial conditions underlying the distractor-response binding paradigm in the present study and the respective comparisons for the calculation of the distractor-response binding effect. Each of the four trial conditions was realized for each distractor intensity condition (examples are from the low distractor intensity condition).

		Prime	**Probe**	comparisons for the distractor-response binding effect
Response Relation	**Distractor Relation**			
Response Repetition	Distractor Repetition	L D L	L D L	benefit of distractor repetitions in response repetition trials
	Distractor Change	P D P	L D L	
Response Change	Distractor Repetition	L J L	L D L	disadvantage of distractor repetitions in response change trials
	Distractor Change	P J P	L D L	

assume that attention to a stimulus is necessary for the integration and the retrieval process. Furthermore, in the theory of event coding it is postulated that stimuli need to be activated to a certain degree (e.g. by being relevant for the task) to pass a specific integration threshold and become integrated into an event file (Hommel, 2004, 2005). Since high intensity distractor stimuli should receive more attention than low intensity stimuli and since more attention to a stimulus should facilitate its integration, it is at a theoretical level highly plausible to assume that high intensity distractor stimuli are more likely integrated in an event file than low intensity stimuli. Furthermore and in line with the theoretical assumptions, previous studies have evidenced that factors that prioritize the retrieval-starting stimulus have a greater chance to activate the retrieval process (Ihrke et al., 2011; Laub et al., 2018; Moeller & Frings, 2014). That is, high intensity distractor stimuli should have more potential to start the retrieval process than low intensity distractor stimuli. Both, the influence of intensity during integration, as well as the influence during retrieval should lead to stronger distractor-response binding effects with increasing distractor intensity (the increasement

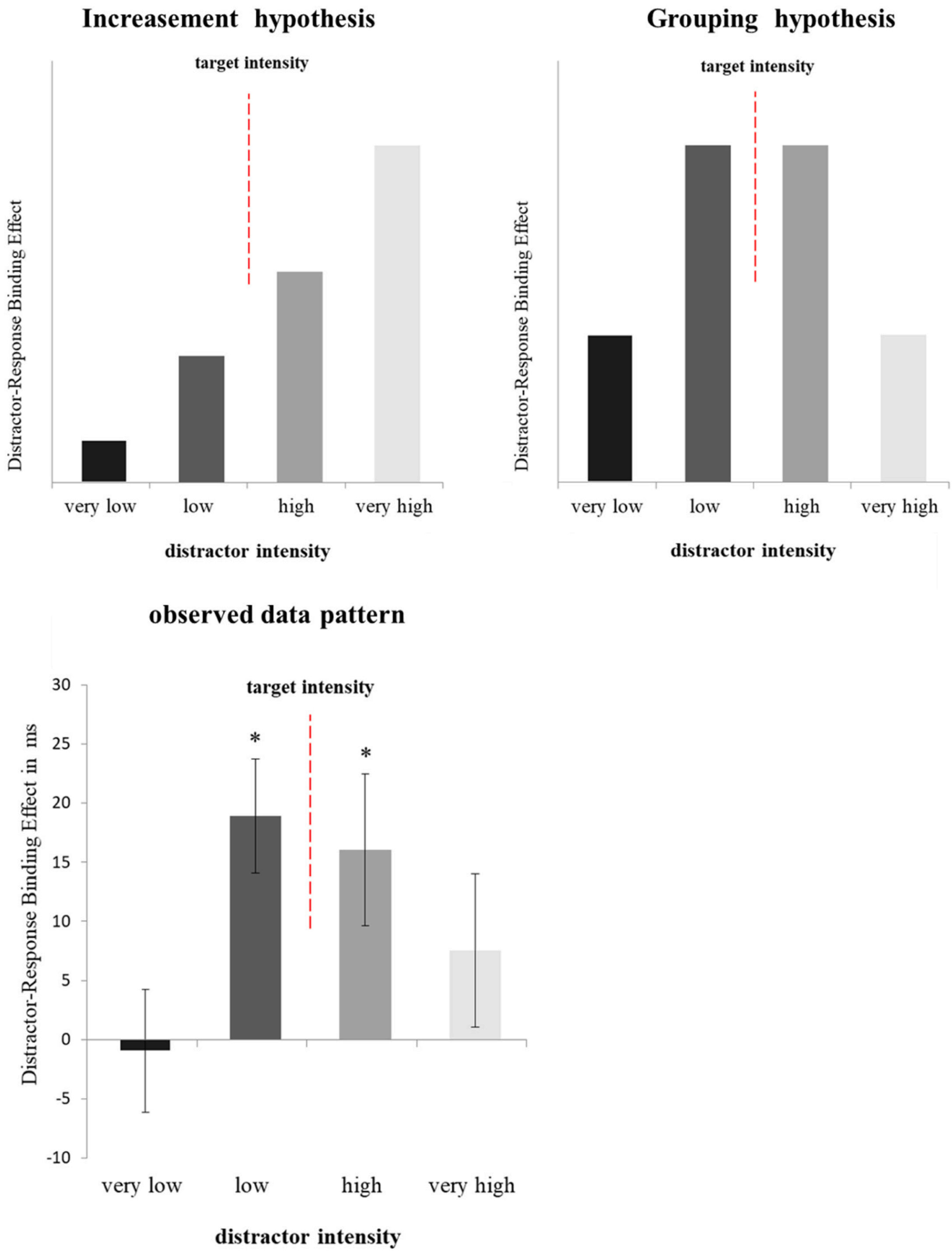

Fig. 1. Hypothetical and observed data pattern
Upper row: Hypothetical data pattern of the distractor-response binding effect as a function of distractor intensity assuming a mediating influence of stimulus intensity (left hand side) and assuming a mediating influence of grouping (right hand side).
Lower row: observed distractor-response binding effect in ms in the experiment, as a function of distractor intensity. * $p < .05$.

hypothesis; see Fig. 1, upper panel, left-hand side). It should be noted, that these predictions concerning the influence of intensity and attention on the integration and the retrieval process are based mainly on theoretical assumptions. However, previous studies are inconsistent about the role of attention with regard to the integration and retrieval process. More precisely, there is also evidence that the integration process is a highly automatic process that needs little or no attention (Hommel, 2005) and evidence that attention to the retrieval-starting stimulus is not sufficient to start the retrieval process (Huffman, Hilchey, Weidler, Mills, & Pratt, 2020; Schöpper, Hilchey, Lappe, & Frings, 2020).

Second, alternatively it could be assumed that only the similarity of stimulus intensities of targets and distractors is decisive. Previous studies examined that grouping of stimuli or Gestalt principles can modulate the strength of binding effects, that is, distractors and targets that are perceived as belonging together or as belonging to the same event are more likely integrated with each other, leading to stronger distractor-response binding effects (Frings & Rothermund, 2011, 2017; Laub et al., 2018). More precisely, distractor stimuli that have a similar intensity as a simultaneously presented target stimulus are more likely perceived as belonging to the target/belonging together and thus are more likely integrated. With this in mind, one would expect stronger distractor-response binding effects if distractor and target are presented in similar stimulus intensities and thus are more likely grouped with each other (the grouping hypothesis; see Fig. 1, upper panel, right-hand side).

In the present experiment, we presented distractor stimuli in four different intensities. Stimulus intensity was implemented as the brightness of the stimuli against a black background (e.g., a white stimulus is more intense than a grey stimulus). The distractor intensity could either be very low (very dark grey), low (dark grey), high (light grey), or very high (very light grey) and was constant within a trial (i.e., the same distractor intensity was presented in the prime and in the probe), but could change in a trial-by-trial manner (e.g., prime and probe of trial n with high distractor intensity and trial n + 1 with low distractor intensity in the prime and in the probe). In contrast, the target was always presented in the same stimulus intensity (that was located in between the middle distractor intensities).

If distractor intensity modulates the binding effect in the sense of the increasement hypothesis, one would expect increasing distractor-response binding effects with increasing distractor intensity. Statistically, this would be indicated by a three-way interaction of response relation, distractor relation, and distractor intensity and more precisely, by evidencing a linear trend (see Fig. 1, upper panel, left-hand side).

However, if the distractor-response binding effect is modulated by distractor intensity in the sense of the grouping hypothesis, one would expect stronger (or solely) distractor-response binding effects for distractor intensities that are similar to the target intensity but not for distractor intensities that are dissimilar to the target intensity. This assumption would also be statistically indicated by a three-way interaction of response relation, distractor relation, and distractor intensity that should, however, follow a quadratic trend (see Fig. 1, upper panel, right-hand side).

Experiment.

2. Method

2.1. Participants

Previous studies investigating the distractor-response binding effect typically observe middle-sized effects (Cohen's $dz = 0.5$). An a priori power analysis (GPower 3.1.9.2; Faul, Erdfelder, Lang, & Buchner, 2007) revealed that a minimum of 27 participants is needed to detect a medium-sized effect ($dz = 0.05$) with a power of $1\text{-}ß = 0.80$ (assuming $\alpha = 0.05$, one-tailed). Thirty students (26 female, 4 male) from the University of Trier took part in the experiment. None of the participants reported deficiencies in color vision. All participants took part in exchange for partial course credit.

2.2. Design

The design of the experiment contained three within-subject factors: distractor intensity (very low, low, high, vs. very high), response relation (response repetition vs. response change), and distractor relation (distractor repetition vs. distractor change).

2.3. 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 (1680 × 1050 pixels). The stimuli were eight letters of the German alphabet. All stimuli were presented on a black background. Each letter had a horizontal visual angle of 0.6° and a vertical visual angle of 0.6° at an approximate viewing distance of 50 cm. The red target letter (D, F, J, or K; according to the color model RGB: red = 255, green = 0, and blue = 0; lightness = 128 according to the HSL model; averaged luminance = 40 cd/m^2) was always presented at the center of the screen. Two identical distractor letters (G, H, L, or P) always flanked the target letter on both sides. Dependent on the factor distractor intensity, the distractor stimuli were either presented in very dark grey (very low intensity; according to the color model RGB: red = 26, green = 26, and blue = 26; lightness = 26 according to the HSL model; averaged luminance = 1 cd/m^2), dark grey (low intensity; according to the color model RGB: red = 92, green = 92, and blue = 92; lightness = 92 according to the HSL model; averaged luminance = 20 cd/m^2), light grey (high intensity; according to the color model RGB: red = 163, green = 163, and blue = 163; lightness = 163 according to the HSL model; averaged luminance = 60 cd/m^2), or very light grey (very high intensity; according to the color model RGB: red = 230, green = 230, and blue = 230; lightness = 230 according to the HSL model; averaged luminance = 130 cd/m^2).

2.4. Procedure

Each participant was tested individually in a soundproof chamber. Instructions were presented on the computer screen. The participants were instructed to place their left index finger on the "F"-key and their right index finger on the "J"-key of the computer keyboard. Their task was to always classify the identity of the central presented target letter by pressing the corresponding key (the "F"-key for the targets D and F; the "J"-key for the targets J and K). It was emphasized, that participants should respond as quickly and accurately as possible.

A single trial consisted of the following events: a plus sign was presented for 500 ms as a fixation mark at the center of the screen. After that, the prime target, flanked by two distractors, was presented at the center of the screen. The stimuli were presented until a response was given by pressing one of the keys. A fixation mark was then presented for 500 ms, followed by the probe target and distractor letters, which were again presented at the center of the screen until the participant responded by pressing one of the two keys. After the participants executed the probe response, a blank screen was presented for 500 ms after which the next trial started. Thus, each trial was characterized by the same prime-probe structure and furthermore, the trials were clearly separable from each other due to presenting the blank screen after each probe display. In case of an error in the prime or in the probe, a feedback display appeared for 1000 ms reminding the participant to respond as quickly as possible, but without making errors.

In response repetition trials, the same response was required in the prime and in the probe. In response change trials, a different response had to be made in the probe than in the prime. 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 in the probe was different from those in the prime. The orthogonal variation of response relation and distractor relation resulted in four different conditions (see also Table 1): response repetition / distractor repetition, response repetition / distractor change, response change / distractor repetition, and response change / distractor change. Each of these four conditions was realized 40 times for each of the four distractor intensity conditions, leading to a total of 640 trials (the distractor intensity was always the same within a trial, but could change between trials). Every 82 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. The sole difference to the experimental block was that participants received feedback both for incorrect and correct responses.

3. Results

Only probe reactions in trials with correct answers to both the prime and probe were considered. Moreover, only reaction times (RTs) slower than 200 ms and faster than 1.5 interquartile ranges over the third quartile of the reaction time distribution of each person were used for the analysis (Tukey, 1977). According to these constraints, 12.69% of the trials were discarded; 4.15% of the trials were excluded because of erroneous responses in the prime, 3.72% of the trials were excluded because of erroneous responses in the probe, and 4.82% due to the RT outlier criteria. Mean RTs and error rates on the probe are depicted for the different levels of distractor intensity in Table 2.

A 4 distractor intensity (very low, low, high, vs. very high) × 2 response relation (response repetition vs. response change) ×2 distractor relation (distractor repetition vs. distractor change) multivariate analysis of variance (MANOVA) on probe RTs, with Pillai's trace as criterion, yielded a significant main effect of distractor intensity, $F(3, 27) = 8.92, p < .001, \eta_p^2 = 0.50$. Participants responses were faster in the condition with a very low distractor intensity ($M = 525$ ms, $SD = 69$ ms), than in conditions with low distractor intensity ($M = 533$ ms, $SD = 69$ ms), high distractor intensity ($M = 534$ ms, $SD = 70$ ms), and very high distractor intensity ($M = 534$ ms, $SD = 67$ ms). The main effect of response relation was also significant, $F(1, 29) = 100.97, p < .001, \eta_p^2 = 0.78$. Participants responded faster if the response was repeated ($M = 506$ ms, $SD = 64$ ms), than if they had to change their response from prime to probe ($M = 557$ ms, $SD = 75$ ms). The main effect of distractor relation did not reach significance, $F(1, 29) = 2.66, p = .114, \eta_p^2 = 0.08$. Furthermore, the analysis revealed an interaction between response relation and distractor relation, $F(1, 29) = 13.29, p = .001, \eta_p^2 = 0.31$, indicating a general distractor-response binding effect. Importantly, the distractor-response binding effect was further modulated by distractor intensity, as indicated by the significant three-way interaction, $F(3, 27) = 3.40, p = .032, \eta_p^2 = 0.27$. Polynomial contrast analysis revealed that the three-way interaction followed a quadratic trend, $F(1, 29) = 9.26, p = .005, \eta_p^2 = 0.24$. Furthermore, post-hoc analyses revealed that the distractor-response binding effect was significant in the low distractor intensity condition, $t(29) = 3.92, p < .001, d = 0.72$, and in the high distractor intensity condition, $t(29) = 2.50, p = .019, d = 0.46$, but not in the very low distractor intensity condition, $t(29) < 1, p = .856, d = 0.03$, and not in the very high distractor intensity condition, $t(29) = 1.16, p = .254, d = 0.21$ (see Fig. 1, lower panel). None of the other effects reached significance, all $Fs(1, 27) < 1, ps > 0.635$.

Since response repetition trials can be subdivided into response repetition/target repetition and response repetition/target change trials, additional analyses were ran to investigate the role of target repetition/changes. Using the same 4 distractor intensity (very low, low, high, vs. very high) × 2 response relation (response repetition vs. response change) ×2 distractor relation (distractor repetition vs. distractor change) MANOVA, we found a significant distractor response binding effect when including only target repetition trials, $F(1, 29) = 4.78, p = .037, \eta_p^2 = 0.14$, as well as when including only target change trials, $F(1, 29) = 12.59, p = .001, \eta_p^2 = 0.30$. Importantly, these two effects did not differ from each other, $t(29) = 1.45, p = .158, d = 0.26$. Furthermore, the additional analyses revealed that the relevant three-way interaction of distractor intensity, response relation, and distractor relation is significant when including only target repetition trials, $F(3, 27) = 3.08, p = .044, \eta_p^2 = 0.26$, and when including only target change trials, $F(3, 27) = 4.57, p = .010, \eta_p^2 = 0.34$.

In the same analysis on error rates the main effect of response relation just missed significance, $F(1, 29) = 4.12, p = .052, \eta_p^2 = 0.12$. By trend, participants made less mistakes if the response was repeated ($M = 3.44\%$, $SD = 3.52\%$), than if the response changed from prime to probe ($M = 4.45\%$, $SD = 4.99\%$). The interaction of distractor intensity and distractor relation was not significant, $F(3, 27) = 2.75, p = .062, \eta_p^2 = 0.23$. Descriptively, the main effect of distractor relation was only observed in the low distractor intensity condition ($M = 0.83\%$), but not in the other distractor intensity conditions (all $Ms < 0$). The interaction of response relation and distractor relation missed significance, $F(1, 29) = 3.32, p = .079, \eta_p^2 = 0.10$. However, the data pattern is descriptively in line with the occurrence of a distractor-response binding effect. Less mistakes were made in response repetitions trials if the distractor was also repeated ($M = 3.31\%$, $SD = 2.54\%$), compared to when the distractor changed ($M = 3.55\%$, $SD = 2.32\%$), while more errors were made in response change trials if the distractor repeated ($M = 4.90\%$, $SD = 4.63\%$), compared to when the distractor changed ($M = 4.02\%$, $SD = 3.32\%$). None of the other effects reached significance, all $Fs(1, 27) < 1, ps > 0.374$.

Discussion

The aim of the present study was to investigate the influence of distractor intensity on the distractor-response binding effect. Previous studies found evidence for an influence of distractor intensity on response selection processes (e.g., Fox & De Fockert, 1998). To investigate whether binding processes are also modulated by stimulus intensity, we used a distractor-response binding paradigm and presented distractor stimuli in four different intensities (i.e., the brightness of the stimuli). Importantly, target intensity was constant and in between the middle distractor intensities.

Different assumptions about the way distractor intensity might modulate the distractor-response binding effect can be drawn. On one side, it could be assumed that increasing distractor intensity would lead to an increasingly stronger distractor-response binding effect (the

Table 2

Mean RTs (in milliseconds) and error rates (in percent) of probe responses in the experiment, as a function of distractor intensity, response relation, and distractor relation.

		Distractor Intensity			
		very low	low	high	very high
Response Relation	**Distractor Relation**				
Response Repetition	Distractor Repetition	497 (3.6)	505 (2.5)	504 (3.6)	505 (3.7)
	Distractor Change	501 (3.1)	515 (4.1)	512 (3.6)	512 (3.5)
Response Change	Distractor Repetition	548 (4.4)	561 (4.9)	564 (5.3)	560 (5.0)
	Distractor Change	553 (4.0)	553 (4.9)	555 (3.6)	559 (3.6)

increasement hypothesis). Theoretically, it could be assumed that the more intense a stimulus, the more attention should it receive, which in turn should facilitate the integration of this stimulus with the response. Furthermore, a stimulus that receives more attention might be more likely to initiate the retrieval process (e.g., Ihrke et al., 2011). On the other side, it could be assumed that the similarity between target intensity and distractor intensity is decisive for the distractor-response binding effect (the grouping hypothesis). Distractor and target stimuli with similar stimulus intensities should be more likely perceived as belonging together and thus should be more likely integrated with each other, resulting in a stronger distractor-response binding effect.

In the present experiment, we found a significant distractor-response binding effect as indicated by the interaction of response relation and distractor relation. Furthermore, the distractor-response binding effect was modulated by distractor intensity. Importantly, the three-way interaction followed a quadratic trend. This pattern of results clearly fits with the grouping hypothesis (see Fig. 1, lower panel). Furthermore, the distractor-response binding effect was only significant for those distractor intensities that were similar to the target intensity (i.e., low and high distractor intensity), but not for those distractor intensities that were dissimilar to the target intensity (i.e., very low and very high distractor intensity). Thus, a significant distractor-response binding effect was only observed if the distractor stimuli were perceived as belonging to the target or as belonging to the same event as the target. This observation is in line with previous research evidencing a modulating effect of grouping on binding effects (e.g., Frings & Rothermund, 2011, 2017). Moreover, the observed pattern of results is clearly inconsistent with the increasement hypothesis. According to this hypothesis, an increasingly stronger distractor-response binding effect with increasing distractor intensity would be assumed. That is, a linear trend and the strongest distractor-response binding effect for very high distractor intensity would be expected. This was clearly not the case (see Fig. 1). Thus, the present results suggest that higher intensity does not automatically lead to stronger integration and/or retrieval of distractors.

Importantly, our findings are not dependent on the factor target relation, that is, on whether the response repetition included a target repetition or a target change (which is both possible due to the two-to-one mapping of targets and responses). As the theory of event coding states, event files consist of binary bindings between the different stimulus and response features, that is, a distractor stimulus can be bound to a target, as well as to a response (Hommel et al., 2001). A study by Giesen and Rothermund (2014) found that both bindings exist and that a repeated distractor stimulus can retrieve both the target and the response. In line with that, evidence was found that the repetition of the distractor stimulus in the present study likewise leads to the retrieval of the target stimulus and the response and that the present findings are not dependent on whether the target is repeated or changed.

It should be noted that the present study provides no insight into the respective influence of distractor intensity regarding the different processes contributing to the binding effect. Distractor-response binding effects can always been traced back to two different processes: stimulus-response integration and stimulus-response retrieval (see Frings et al., 2020; Hommel, 2004, 2005; Hommel, Memelink, Zmigrod, & Colzato, 2014). Furthermore, past research has evidenced that grouping can have a separate influence on either one of these processes (Laub et al., 2018). Against the background of previous studies one might argue that the integration process is influenced by intensity in the present study, since the integration process has been evidenced to benefit from a grouped stimulus arrangement, while the retrieval process was evidenced to benefit from a non-grouped stimulus arrangement (Laub et al., 2018). However, these considerations are purely speculative at this point and further studies need to be conducted to draw any conclusions about the influence of grouping via stimulus intensity on the process of stimulus-response integration and stimulus-response retrieval.

Furthermore, it should be noted that the role of stimulus intensity for the distractor-response binding effect might be dependent on the manner distractor intensity is implemented. In the present study, the distractor intensity was always constant within one trial, that is, the same distractor intensity was presented in the prime and in the probe. To investigate a possible separate influence of stimulus intensity on the stimulus-response integration process and the stimulus-response retrieval process, distractor intensity need to be individual varied during prime-integration and probe-retrieval. However, a recent study by Laub and Frings (2020) suggests that the similarity between prime and probe is decisive for the occurrence of the distractor-response binding effect. More preciously, evidence was found that the distractor-response binding effect is encoding specific and thus that the retrieval process is dependent on the similarity between prime and probe. Thus, it is possible that distractor-response binding effects are only observed if the distractor intensity is similar in the prime and in the probe. Furthermore, by varying the target intensity simultaneously with the distractor intensity (e.g., presenting target and distractor both in low intensity vs. presenting target and distractor both in high intensity), it might be possible to shed light on the general role of stimulus intensity with regard to response selection processes in the present context. However, these considerations need to be clarified by future studies.

Previous research showed that stimulus intensity has an influence on response speed and force, as well as on the degree to which a stimulus could interfere with processing – depending on the ‘role’ (target vs. distractor) a stimulus has. The present study extends these findings as the effects of distractor intensity (at least in the binding paradigm used here) had no such influences. Instead, distractor intensity exerts only indirect effects on responding via grouping with the particular target intensity.

In sum, the present study suggests that the intensity of an irrelevant distractor stimulus plays no crucial role for the distractor-response binding effect per se; instead intensity exerts influences on this binding effect only indirectly via grouping due to similarity between distractor and target intensity. In other words, intensity might just like color be one of many features with which a distractor becomes more similar to the target and hence is grouped with the target, leading ultimately to larger observable distractor-response binding effects.

Ethical approval

All procedures performed in the studies involving human participants were in accordance with the institutional ethical standards and in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

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

CRediT authorship contribution statement

Ruth Laub: Conceptualization, Methodology, Software, Formal analysis, Data curation, Visualization, Writing - original draft. **Christian Frings:** Conceptualization, Resources, Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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References

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191.

Fox, E., & De Fockert, J. W. (1998). Negative priming depends on prime-probe similarity: Evidence for episodic retrieval. *Psychonomic Bulletin & Review, 5*, 107–113.

Frings, C., Hommel, B., Koch, I., Rothermund, K., Dignath, D., Giesen, C., … Philipp, A. (2020). Binding and retrieval in action control (BRAC). *Trends in Cognitive Sciences*, 1–13. https://doi.org/10.1016/j.tics.2020.02.004

Frings, C., & Rothermund, K. (2011). To be or not to be … included in an event file: Integration and retrieval of distractors in stimulus-response episodes is influenced by perceptual grouping. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 1209–1227.

Frings, C., & Rothermund, K. (2017). How perception guides action: Figure-ground segmentation modulates integration of context features into S-R episodes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43*, 1720–1729.

Frings, C., Rothermund, K., & Wentura, D. (2007). Distractor repetitions retrieve previous response to targets. *The Quarterly Journal of Experimental Psychology, 60*, 1367–1377.

Frings, C., Schneider, K. K., & Fox, E. (2015). The negative priming paradigm: An update and implications for selective attention. *Psychonomic Bulletin & Review, 22*, 1577–1597.

Giesen, C., & Rothermund, K. (2014). Distractor repetitions retrieve previous responses and previous targets: Experimental dissociations of distractor–response and distractor–target bindings. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 645–659.

Hommel, B. (1998). Event files: Evidence for automatic integration of stimulus-response episodes. *Visual Cognition, 5*, 183–216.

Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in Cognitive Sciences, 8*, 494–500.

Hommel, B. (2005). How much attention does an event file need? *Journal of Experimental Psychology: Human Perception and Performance, 31*, 1067–1082.

Hommel, B., Memelink, J., Zmigrod, S., & Colzato, L. S. (2014). Attentional control of the creation and retrieval of stimulus–response bindings. *Psychological Research, 78*, 520–538.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brian Sciences, 24*, 849–878.

Houghton, G., Tipper, S. P., Weaver, B., & Shore, D. I. (1996). Inhibition and interference in selective attention: Some tests of a neural network model. *Visual Cognition, 3*, 119–164.

Huffman, G., Hilchey, M. D., Weidler, B. J., Mills, M., & Pratt, J. (2020). Does feature-based attention play a role in the episodic retrieval of event files? *Journal of Experimental Psychology: Human Perception and Performance, 46*, 241–251.

Ihrke, M., Behrendt, J., Schrobsdorff, H., Herrmann, J., & Hasselhorn, M. (2011). Response-retrieval and negative priming - encoding- and retrieval-specific effects. *Experimental Psychology, 58*, 154–161.

Kohfeld, D. L. (1971). Simple reaction time as a function of stimulus intensity in decibels of light and sound. *Journal of Experimental Psychology, 88*, 251–257.

Laub, R., & Frings, C. (2020). Distractor-based retrieval in action control: The influence of encoding specificity. *Psychological Research, 84*, 765–773.

Laub, R., Frings, C., & Moeller, B. (2018). Dissecting stimulus–response binding effects: Grouping by color separately impacts integration and retrieval processes. *Attention, Perception, & Psychophysics, 80*, 1474–1488.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review, 95*, 492–527.

Miller, J., Franz, V., & Ulrich, R. (1999). Effects of auditory stimulus intensity on response force in simple, go/no-go, and choice RT tasks. *Perception & Psychophysics, 61*, 107–119.

Moeller, B., & Frings, C. (2014). Attention meets binding: Only attended distractors are used for the retrieval of event files. *Attention, Perception, & Psychophysics, 76*, 959–978.

Moeller, B., Rothermund, K., & Frings, C. (2012). Integrating the irrelevant sound. Grouping modulates the integration of irrelevant auditory stimuli into event files. *Experimental Psychology, 59*, 258–264.

Nissen, M. J. (1977). Stimulus intensity and information processing. *Perception & Psychophysics, 4*, 338–352.

Rothermund, K., Wentura, D., & De Houwer, J. (2005). Retrieval of incidental stimulus-response associations as a source of negative priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31*, 482–495.

Schöpper, L. M., Hilchey, M. D., Lappe, M., & Frings, C. (2020). Detection versus discrimination: The limits of binding accounts in action control. *Attention, Perception, & Psychophysics, 82*, 2085–2097.

Singh, T., Frings, C., & Moeller, B. (2019). Binding abstract concepts. *Psychological Research, 83*, 878–884.

Singh, T., Moeller, B., Koch, I., & Frings, C. (2018). May I have your attention please: Binding of attended but response-irrelevant features. *Attention, Perception, & Psychophysics, 80*, 1143–1156.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Tukey, J. W. (1977). *Exploratory data analysis*. Reading, Massachusetts: Addison-Wesley.

Ulrich, R., Rinkenauer, G., & Miller, J. (1998). Effects of stimulus duration and intensity on simple reaction time and response force. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 915–928.