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Binding between Responses is not Modulated by Grouping of Response Effects

COLLECTION: CORE MECHANISMS IN ACTION CONTROL: BINDING AND RETRIEVAL

RESEARCH ARTICLE

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ABSTRACT

Several action control theories postulate that individual responses to stimuli are represented by event files that include temporal bindings between stimulus, response, and effect features. Which stimulus features are bound into an event file can be influenced by stimulus grouping. Here, we investigate whether effect grouping moderates response feature binding. For this purpose, we used an adapted response-response binding paradigm introducing a visual effect after each response. These effects could either appear spatially grouped, i.e., close to each other, or non-grouped, thus far from each other. If effect grouping influences response representation, response-response binding effects should be larger for responses producing grouped effects than for responses producing non-grouped effects. In two experiments, we found no indication for a modulation of response-response binding by effect grouping. The role of effect grouping for binding and retrieval processes seems to differ from past evidence regarding stimulus grouping.

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grouped, thus far from each other.[1] If effect grouping affects binding and retrieval similar to what is known from stimulus grouping, RR-binding effects should be larger for responses producing grouped effects than for responses producing non-grouped effects.

In two experiments we investigated this question by introducing visual response effects in a grouped vs. non-grouped manipulation. In Experiment 1 effect grouping was varied block-wise while in Experiment 2 effect grouping was varied trial-wise. In an additional control experiment, validating our grouping manipulation (see Appendix A), participants rated to what extent they perceived effects in different spatial positions as being grouped. Anticipating results, we observed standard RR-binding effects but none of the experiments provided evidence for an impact of effect grouping on RR-binding.

EXPERIMENT 1

The aim of Experiment 1 was to investigate whether grouping of effects modulates integration of the corresponding responses. If grouping of effects has an influence on event-file integration, responses that elicit grouped effects should be more likely to be integrated than responses eliciting non-grouped effects. Anticipating that to some degree participants might perceive response effects as artificial, we took measures to increase the perceived relatedness between responses and effects. Previous research found that instructions can influence the way an effect is cognitively represented and can even overrule other influences of response-effect correspondence (Hommel, 1993). We designed the instructions to state that the participants actively make effects light up by giving correct answers. This should prompt the participants to represent the effects in terms of their action goals (making the effect appear; Hommel, 1993). To incentivize participants to attend to the effects, they were also instructed to use them as feedback for whether they answered correctly. To further ensure that responses and effects are perceived as cohesive (Kunde, 2001; Kunde et al., 2004), we presented effects on a horizontal line, similar to the response keys, which are aligned horizontally on the keyboard.

METHOD

Participants

Thirty students (22 women) from Trier University participated in the experiment. The samples' mean age was 22 years, with a range from 19 to 35 years. The participants were rewarded with partial course credit. Effect sizes in former studies on RR-binding (computed as t/sqrt(n)) were at least d = 0.63 (e.g., Moeller & Frings, 2019b: d = 0.63 and d = 0.88; Moeller & Frings, 2019c: d = 1.07; Moeller & Frings, 2019d: d = 0.74 and 1.07). A power-analysis with the program G*Power assuming α = .05 and a power of $1-\beta$ = .85 suggests that at least 25 participants were necessary (Faul et al., 2007).

Design

The design comprised three within-subjects factors, namely, effect grouping (grouped vs. non-grouped), response R1 relation (response repetition vs. response change from prime to probe), and response R2 relation (response repetition vs. response change from prime to probe).

Materials

The experiment was programmed in PsychoPy3/PsychoJS (2021.1.2; Peirce et al., 2019) and conducted online on Pavlovia (https://pavlovia.org/). For participation, a computer with a physical keyboard was required. Instructions were presented in white [RGB: 255, 255, 255] on a grey background [RGB: 128, 128, 128]. Stimuli were the letters A, B, C, and D and the digits 1, 2, 3, and 4, each with a height of 35 pixels and presented in white. Each display consisted of one letter or digit stimulus presented randomly on one out of 18 positions along an imaginary horizontal line drawn through the center of the screen.

Response effects were signified by blue [RGB: 0, 0, 255] squares with a white border and appeared on one of four positions on the same imaginary center screen line, depending on

1 We used the term 'grouping' not as spatial proximity in relation to other elements (see Wagemans et al., 2012), but in a sense that was implemented in studies on binding and retrieval processes in the past (e.g., Frings & Rothermund, 2011; Moeller et al., 2012).

the condition (coordinates in pixels, center of screen has coordinates [0, 0]: [–530, 0] and [530, 0] for non-grouped condition, and [–30, 0] and [30, 0] for grouped condition). Prime response effects disappeared after the prime, resulting in a maximum of two response effects visible at a time (see Figure 1a & b).

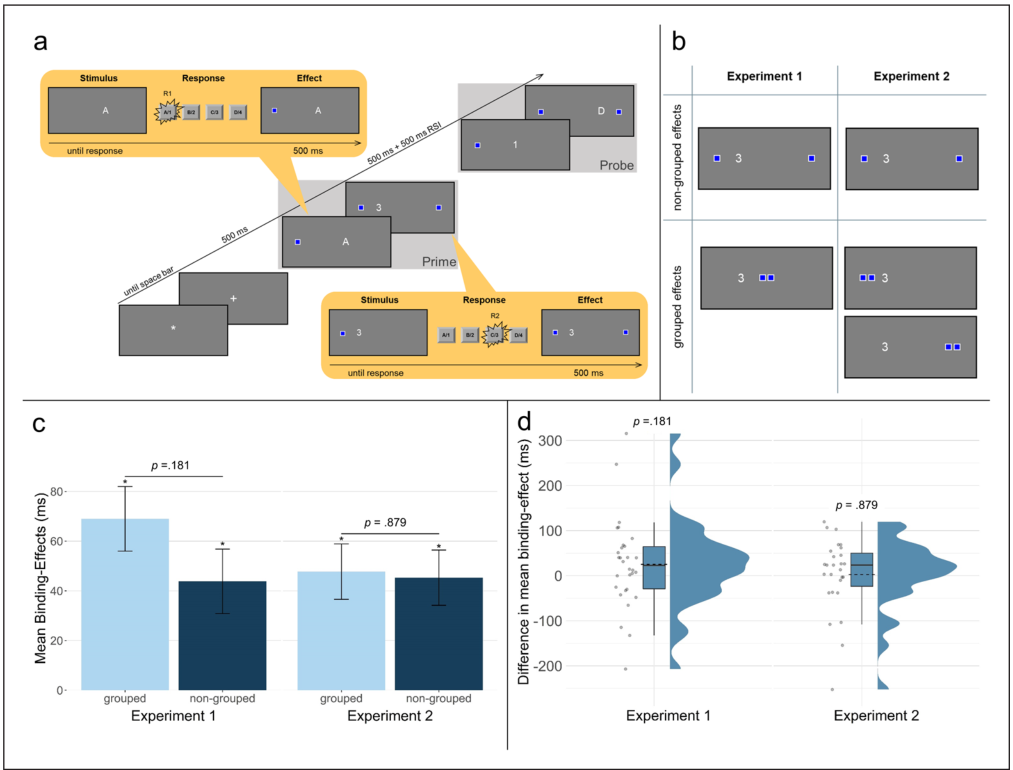

Figure 1 (a) Sequence of events in Experiments 1 and 2 in one example trial. Participants gave two successive responses, R1 and R2, both to the prime and to the probe. This is an example of a R1 repetition and R2 change trial in the non-grouped condition. The stimuli and effects are not drawn to scale. **(b)** Effect positions depending on effect grouping condition and Experiment. **(c)** Response-response binding effects in response times across Experiments 1 and 2 as a function of effect grouping (grouped vs. non-grouped). Binding effects were calculated as R1 repetition minus R1 change RTs for R2 change trials, subtracted from R1 repetition minus R1 change RTs for R2 repetition trials [(R1cR2r – R1rR2r) – (R1cR2c – R1rR2c)] **(d)** Distribution of difference in mean response-response binding effects between effect grouping conditions (calculated as [grouped]–[non-grouped] for each participant) for Experiment 1 and 2. Solid lines indicate medians; dashed lines indicate means.

Procedure

Before the experiment, participants gave informed consent regarding the recording of personal data and responses during the experiment and indicated their age and gender. Instructions were given on the screen. Participants were instructed to place their middle and index fingers on the keys D, F, J, and K. Each key corresponds to a letter and a digit (A/1, B/2, C/3, and D/4).

Their task was to press the key corresponding to the individually presented letters and digits. Each trial was started by pressing the space bar while an asterisk was presented in the middle of the screen (see Figure 1a). Then a plus sign appeared for 500 ms, followed by the first prime stimulus (letter or digit). Upon correct responses, a first response effect square lit up for 500 ms, upon incorrect responses, the trial continued without a response effect square appearing. Then the second prime stimulus appeared indicating prime response R2. Again, execution of a correct response resulted in the presentation of a second effect square for 500 ms while the response stimulus remained on screen. The position of response effect squares depended on condition (grouped vs. non-grouped, see Figure 1b). Afterwards, a blank screen appeared for 500 ms and was followed by the probe. The procedure in the probe was identical to that in the prime. Every 48 trials participants were allowed to take a short break, after which they resumed the task in their own time.

The relation of R1 between prime and probe (repetition vs. change) was varied orthogonally to the relation of R2 (repetition vs. change). In R1 repetition trials (R1r), the same response was required to the stimulus indicating prime response R1 and the one indicating probe response R1. In R1 change trials (R1c), different responses were required to the stimulus indicating prime response R1 and the one indicating probe response R1. In R2 repetition trials (R2r), the same response was required to the stimulus indicating prime response R2 and the one indicating probe response R2. In R2 change trials (R2c), different responses were required to the stimulus indicating prime response R2 and the one indicating probe response R2. The factor effect grouping was varied block-wise with one block in each of the two conditions. The order of blocks was balanced across participants. Each experimental block included 96 trials, with 24 of each of the four conditions R1rR2r, R1rR2c, R1cR2r, R1cR2c. Stimuli indicating the R1 and R2 responses in prime and probe were selected at random, but in accordance to the requirements of the current condition. There were no stimulus repetitions within a trial. At the beginning of the experiment, participants passed a general practice block introducing both grouping conditions to avoid block order effects (4 trials). Before each experimental block started, they practiced their task for 16 trials (subsample of the experimental trials).

RESULTS

For the analysis of response times (RTs) we only included trials with correct responses R1 and R2 in both prime and probe. The rate of prime response errors (R1 or R2) was 12.9%. The probe error rates were 6.3% for R1 and 6.6% for R2 (only including trials with correct previous responses). Furthermore, we excluded RTs of more than 1.5 interquartile ranges above the third quartile of the probe R2 RT distribution of the participant (Tukey, 1977) and RTs shorter than 200 ms from the analysis. Due to these constraints, 26.0% of the trials were excluded from the RT analyses. For the mean RTs and error rates, see Table 1.

Table 1 Mean response times (in milliseconds) and mean error rates (in percentages) for probe responses R2, as a function of effect grouping, R1 relation and R2 relation between prime and probe.

	GROUPED EFFECTS		NON-GROUPED EFFECTS	
	R2 REPETITION	***R2 CHANGE***	***R2 REPETITION***	***R2 CHANGE***
R1 change	692 (9.1)	628 (2.4)	708 (9.6)	650 (5.4)
R1 repetition	668 (7.9)	672 (8.2)	690 (8.2)	676 (5.6)

The dependent variable of interest was performance in probe R2. If prime R1 and R2 are integrated, repeating prime R1 in the probe should trigger retrieval of the second prime response and thus influence performance in probe R2. In a 2 (R1 relation: repetition vs. change) × 2 (R2 relation: repetition vs. change) × 2 (effect grouping: grouped vs. non-grouped) analysis of variance (ANOVA) on probe R2 RTs, the main effect for R2 relation was significant, $F(1, 29) = 41.35$, $p < .001$, $\eta_p^2 = .59$, while the main effect for R1 relation was not, $F(1, 29) = 2.59$, $p = .118$, $\eta_p^2 = .08$. Additionally, the main effect for effect grouping was significant, $F(1, 29) = 4.59$, $p = .041$, $\eta_p^2 = .14$, with longer RTs in the non-grouped than in the grouped condition. More importantly, the two-way interaction of R1 and R2 relation was significant, $F(1, 29) = 29.01$, $p < .001$, $\eta_p^2 = .50$, indicating binding between the responses: The repetition of R1 facilitated performance only if R2 was repeated as well, $t(59) = 4.03$, $p < .001$, but impaired performance if R2 changed, $t(59) = -4.98$, $p < .001$. However, this was not further modulated by effect grouping, $F(1, 29) = 1.88$, $p = .181$, $\eta_p^2 = .06$, (see Figure 1c, for distributions of participants binding effects differences between grouping conditions, see Figure 1d). Bayes factors provided anecdotal evidence for an absence of the effect grouping modulation, $BF_{01} = 2.21$.

In the same analysis on error rates, the main effect of R2, $F(1, 29) = 15.36$, $p < .001$, $\eta_p^2 = .35$, was significant, while the main effect of R1, $F(1, 29) = 2.23$, $p = .146$, $\eta_p^2 = .07$, was not. However, the interaction of R1 and R2 was significant, $F(1, 29) = 11.14$, $p = .002$, $\eta_p^2 = .28$, again indicating binding between the responses: The repetition of R1 did not facilitate performance if R2 was repeated as well, $t(59) = 1.36$, $p = .18$, but impaired performance if R2 changed, $t(59) = -3.05$, $p = .003$. The relation was not further modulated by effect grouping, $F(1, 29) = 2.82$, $p = .10$, $\eta_p^2 = .09$, $BF_{01} = 1.47$. Taken together, results from both, RT and error rate data, indicate that RR-binding effects are not modulated by grouping of response effects.

DISCUSSION

Results from Experiment 1 indicate that responses are integrated and thus, they clearly replicate previous findings on RR-binding. However, RR-binding effects were not modulated by effect grouping. Three factors might explain the results: Firstly, it stands to question whether the grouping manipulation itself was actually successful, i.e., whether the participants perceived the two effects as more grouped in the spatially close condition than in the far condition. We used a grouping manipulation for our effects that was similar to the one used before to investigate stimulus grouping on binding and retrieval processes (e.g., Frings & Rothermund, 2011; Moeller et al., 2012). Yet, it is unclear whether such a modulation is perceived the same way when used on response effects. Thus, we conducted a manipulation check experiment (see Appendix A), where participants rated the perceived grouping between response effects. The results were very clear and indicated that participants perceived the effects as significantly more grouped in the spatially close condition than in the far condition. Secondly, one can argue that grouping manipulations might rely on a subjective frame of reference: To perceive two effects as grouped, we need to establish a stable representation of what grouped means in comparison to non-grouped. Since we manipulated grouping block-wise, variance on the factor effect grouping may have lacked to draw sufficient attention to it and to provide a constant comparison of grouped effects for the non-grouped trials and vice versa (for a similar argument regarding the influence of perceptual grouping of stimuli - via figure ground segmentation - on binding, see Frings & Rothermund, 2017). Even though we shortly introduced both conditions at the beginning of the experiment through a general training, this might not have been sufficient to ensure an ongoing representation of the grouped vs. non-grouped manipulation. Thus, introducing a trial-wise manipulation might help establish a proper frame of reference regarding the distance of effects. Thirdly, we cannot be entirely sure that effects were perceived as being related to the responses rather than just being perceived as random. Here a manipulation check would be necessary.

EXPERIMENT 2

In Experiment 2, conditions were varied trial-wise instead of block-wise. To avoid additional complexity of the display with changing effect positions in a trial-wise manipulation, we decided to adjust the effect positions, so that the same four possible positions were used in both conditions. Additionally, we ran a short manipulation check questionnaire at the end of the experiment asking about the participants' impression on the relatedness between responses and effects.

METHOD

Participants

Twenty-seven students (20 women) from Trier University participated in the experiment. The samples' mean age was 23 years, with a range from 19 to 36 years. The participants were rewarded with partial course credit. Three additional participants were excluded due to extremely high error rates (more than 90% of trials had to be excluded).

Design

The design comprised three within-subjects factors, namely, effect grouping (grouped vs. non-grouped), response R1 relation (response repetition vs. response change from prime to probe), and response R2 relation (response repetition vs. response change from prime to probe).

Materials and procedure

Materials and procedure were identical to those in Experiment 1, except for the following differences. Unlike Experiment 1, the factor effect grouping (grouped vs. non-grouped) was variated trial-wise. Thus, the part of the training introducing the two conditions separately was omitted. Additionally, response effects appeared in one of four possible positions (in pixels, screen center has coordinate [0, 0]: [–540, 0], [–480, 0], [480, 0] and [540, 0], see Figure 1b). For the grouped condition, response effects in each trial appeared in either the two left side or the two right side positions, while response effects in the non-grouped condition always appeared on opposite screen side positions, while maintaining a fixed distance (either [–540, 0] and [480, 0], or [–480, 0] and [540, 0]). At the end of the experiment, participants had to fill out a short questionnaire (six items; see Appendix B) judging whether they perceived their responses and the effects as related (forced choice; 4 items) and rating the strength of that relation (7-point rating scale; 2 items).

RESULTS

On a questionnaire regarding the perceived relation of responses and effects, the majority (79.8%) of participants reported perceiving the effects as being related to the responses[2] and rated the strength of this relation with M = 5.75 (SD = 1.25) on a seven-point scale with 1 being not related and 7 being strongly related. Furthermore, the strength of perceived grouping

2 Mean across four forced choice items. Frequency distributions did not differ between items, $\chi^2(3) = 3.04$, p = .385.

and the difference in binding effects between both conditions (calculated as [grouped]-[non-grouped] for each participant) did not correlate significantly, $r(23) = -.07$, $p = .736$ (7-point scale), and $r(23) = -.04$, $p = .842$ (forced choice items).

For the analysis of RTs, we considered only trials with correct responses R1 and R2 in both prime and probe. The error rate for prime responses (R1 or R2) was 10.6%. The probe error rates were 5.7% for R1 and 5.1% for R2 (only including trials with correct previous responses). Due to the same constraints as in the previous experiments, 20.0% of the trials were excluded from the RT analyses. For the mean RTs and error rates, see Table 2.

Table 2 Mean response times (in milliseconds) and mean error rates (in percentages) for probe responses R2, as a function of effect grouping, as well as R1 relation and R2 relation between prime and probe.

	GROUPED EFFECTS		NON-GROUPED EFFECTS	
	R2 REPETITION	*R2 CHANGE*	*R2 REPETITION*	*R2 CHANGE*
R1 change	677 (7.4)	619 (2.1)	675 (8.5)	622 (3.9)
R1 repetition	664 (6.0)	653 (4.5)	654 (6.3)	646 (6.5)

In a 2 (R1 relation: repetition vs. change) × 2 (R2 relation: repetition vs. change) × 2 (effect grouping: grouped vs. non-grouped) ANOVA on probe R2 RTs, the main effect for R2 relation was significant, $F(1, 26) = 55.85$, $p < .001$, $\eta_p^2 = .68$, while the main effect for R1 relation was not, $F(1, 26) = 1.58$, $p = .220$, $\eta_p^2 = .06$. Additionally, the main effect of effect grouping was not significant, $F(1, 26) = 1.02$, $p = .321$, $\eta_p^2 = .04$. More importantly, the two-way interaction of R1 and R2 relation was significant, $F(1, 26) = 24.72$, $p < .001$, $\eta_p^2 = .49$, indicating binding between the responses: The repetition of R1 facilitated performance only if R2 was repeated as well, $t(53) = 3.49$, $p < .001$, but impaired performance if R2 changed, $t(53) = -4.29$, $p < .001$. However, this was not further modulated by effect grouping, $F(1, 26) = 0.02$, $p = .879$, $\eta_p^2 < .01$, (see Figure 1c, for distributions of participants binding effects differences between grouping conditions, see Figure 1d). This is supported by a Bayes factor of $BF_{01} = 4.86$, indicating that the data are more than four times more likely under the null hypothesis that assumes no modulation by effect grouping than under the alternative hypothesis.

In the same analysis on error rates, the main effect of R2, $F(1, 26) = 9.67$, $p = .004$, $\eta_p^2 = .27$, was significant, while the main effects of R1, $F(1, 26) = 0.45$, $p = .507$, $\eta_p^2 = .02$ and effect grouping, $F(1, 26) = 3.83$, $p = .061$, $\eta_p^2 = .13$, were not. However, the interaction of R1 and R2 was significant, $F(1, 26) = 12.15$, $p = .002$, $\eta_p^2 = .32$, again indicating binding between the responses: The repetition of R1 facilitated performance if R2 was repeated as well, $t(53) = 2.00$, $p = .050$, but impaired performance if R2 changed: $t(53) = -3.31$, $p = .002$. The relation was not further modulated by effect grouping, $F(1, 26) = 0.16$, $p = .69$, $\eta_p^2 < .01$, $BF_{01} = 4.55$. In sum, results from RT and error rate data do not indicate modulating effects of response effect grouping on RR-binding effects.

DISCUSSION

We again replicated binding between responses but found no modulation by grouping of response effects. Introducing a trial-wise instead of a blocked manipulation to establish a frame of reference regarding grouping did neither impact RR-binding nor the grouping manipulation. This was the case, even though results from a manipulation check questionnaire suggest that participants indeed perceived responses and effects as related in the present experiment. This again indicates that grouping of effects has no influence on whether they are integrated in the same action representation.

GENERAL DISCUSSION

In two experiments, we investigated the role of effect grouping on event-file integration. Using an adapted RR-binding task (Moeller & Frings, 2019b), we manipulated whether responses produced grouped vs. non-grouped effects. If grouping influenced whether effects are integrated in the same representation, we expected grouped effects to lead to stronger RR-binding than non-grouped effects. In sum, we could replicate standard RR-binding effects in both experiments. However, these remained unaffected by the effect grouping manipulation. For an overview of binding effects across both experiments, see Figure 1c.