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# Large Scale Event Segmentation Affects the Microlevel Action Control Processes

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How do we make sense of our surroundings? A widely recognized field in cognitive psychology suggests that many important functions like memory of incidents, reasoning, and attention depend on the way we segment the ongoing stream of perception (Zacks & Swallow, 2007). An open question still is, how the structure generated from a perceptual stream translates into behavior. To address this question, we combined the findings in event segmentation literature with another influential body of literature that analyzes mechanisms behind the control of individual actions (Frings et al., 2020). Specifically, we analyzed how two very basic mechanisms in action control (binding and retrieval) are affected by boundaries between events. Two comic scenarios with different characters were used to implement events and boundaries between events. In two experiments, we measured binding and retrieval between individually executed responses that could be part of the same or separate events. In Experiment 1, we found larger binding effects for responses that were integrated within an event than for responses that had to be integrated across an event boundary. In Experiment 2, we found that the effect of retrieval of a past response on further actions was hampered by an event boundary. Together, the experiments indicate that the structure we pick up from our environment can translate into ongoing action via modulation of the two basic mechanisms binding and retrieval.

## Public Significance Statement

This study suggests that one way our interpretation of the structure in our everyday surroundings is translated into our actions functions via modulation of the basic mechanisms binding and retrieval in action control. The perception of a boundary between two event segments impairs both binding and retrieval between actions on either side of the boundary.


**Keywords:** action control, event file, response–response binding, event segmentation

In our everyday life, we sometimes seem to engage in a seamless stream of activities. Say a researcher is typing at her computer. Even though it might look like continuous striking of keys, the same activities of finishing an essay and sending an email may belong to the same activity of cooperation (i.e., sending the finished essay to a coauthor) or to two different actions of finishing the article and then writing to a friend. On a smaller scale, typing the letters “e—s—s—a” may either belong to the one activity of spelling “essay” or the two

actions of typing “activities” and “say.” Can such differences in representation affect our responses while typing?

Making sense of our perceptions and actions is closely associated with forming representations of events. A couple of early examples for concepts of events are those in episodic memory (Tulving & Thomson, 1973) and event schemata that include semantic knowledge about how certain episodic events typically unfold (Kintsch, 1988). However, the event concept is not restricted to

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memory. Combining episodic representations of events with knowledge from event schemata, event models have been proposed to describe how we perceive our surroundings and other people acting in them (Radvansky & Zacks, 2014; Zacks et al., 2007). Intriguingly, the better a person is at segmenting events, the better their understanding, memory, and also performance is for these events (e.g., Bailey et al., 2013; Radvansky & Zacks, 2014). In fact, focusing on action execution rather than perception, the formation of an event representation can also be understood as forming an action plan (albeit on a different time scale; Frings et al., 2020; Hommel et al., 2001). These small scale events seem to rely on theta and beta band activity because low-frequencies oscillations are particularly suitable to integrate information across larger distances (Beste et al., 2023; Pastötter et al., 2021; Takacs et al., 2020). This is apparently also true for larger scale events (Prochnow, Zhou, Ghorbani, Wendiggensen, et al., 2024). Clearly, we rely on event representations to make sense of our surroundings, and this affects our actions. Which leads to the question, how exactly the understanding of the environmental structure is translated into our actions. Two influential but largely independent fields in cognitive psychology, that is, event segmentation and binding and retrieval in action control are relevant for this question with the former focusing on the way we segment our perceptions into sensible units, and the latter examining very basic processes underlying virtually all our actions.

## Event Segmentation

Event segmentation is a fundamental concept that involves the perceptual and cognitive process of dividing continuous experiences into meaningful units or events (Zacks, 2020). When viewing other peoples' behavior sequences, humans possess a remarkable ability to parse these streams of information into discrete segments that can be instructed to relate to coarse or fine-grained events (Newtson, 1973). This segmentation process is driven by various cues, such as changes in sensory inputs, temporal discontinuities, semantic coherence, and contextual information (Richmond & Zacks, 2017). By segmenting events, individuals can organize and remember information more effectively, facilitating higher-level cognitive processes such as attention, memory, and reasoning (e.g., Flores et al., 2017; Gold et al., 2017). Overall, event segmentation plays a crucial role in how we perceive and understand the world around us (Zacks, 2020). This understanding is also crucial for our interaction with the environment. The ability to segment ongoing perceptual streams into separable events indeed predicts superior action performance in naturalistic events (Bailey et al., 2013; Sebastian et al., 2017). For example, participants were first asked to view three different movies showing an actor in an everyday situation and press the spacebar every time they thought one meaningful unit of activity ended. In a second part of the experiment, participants performed a naturalistic action test, in which they packed a lunchbox and a schoolbag. Here, event segmentation ability in the first task (i.e., the correlation of participant's segmentation with the normative segmentation of the entire sample) predicted fewer errors in the naturalistic action test (Bailey et al., 2013). That is, segmentation of the surroundings into meaningful events seems to affect action control. While it is still unclear *how* such segmentation is translated into ongoing action,

there are unquestionable mutual effects between action and perception (e.g., Hommel et al., 2001; Müsseler & Hommel, 1997; Prinz, 1997; Witt & Proffitt, 2005). For example, performance in individual keypresses is affected by the repeated perception of recently encountered stimuli (e.g., Frings et al., 2007). However, while the observed activities in the discussed event segmentation tasks typically lasted between 2 and 10 min (e.g., Bailey et al., 2013; Gold et al., 2017), in the next section, it will become clear that mutual effects of perception and action have been measured in time frames of 0.5–5 s (e.g., Frings, 2011; Hommel & Frings, 2020). Hence, on the one hand, time units in event segmentation literature seem to be closer to real life experiences than those in action control literature. On the other hand, these differences in timing also mean that short-term action control processes should work within (and also across) individual event segments.

## Two Mechanisms in Action Control: Binding and Retrieval

The Binding and Retrieval in Action Control framework (BRAC; Frings et al., 2020; see also Beste et al., 2023; Frings, Beste, et al., 2024; Frings, Foerster, et al., 2024) is a recent and powerful framework to describe behavior in many classic effects in action control research. Crucially, it draws attention to two basic processes (binding and retrieval) that have been assumed to affect virtually every human action. For example, responding to a certain stimulus leads to integration or *binding* of all stimulus and response features into one common representation, that has been called an event file (Hommel, 2004). Evidence for the resulting short-term associations (also called bindings) between stimulus and response features, can be collected in a following response: If any of the bound features is repeated, it will *retrieve* the (representations of) associated features, affecting responding. For example, if the stimulus is repeated, it will start retrieval of the associated response, facilitating repetition of this response and impairing other/new responses. These binding and retrieval mechanisms have been used to explain result patterns in repetition priming tasks (Henson et al., 2014; Tenpenny, 1995), negative priming tasks (Frings et al., 2015; Mayr & Buchner, 2006), task switching tasks (Koch et al., 2018), congruency sequence tasks (Dignath et al., 2019), stimulus–response binding tasks (Frings et al., 2007; Hommel, 1998), and action panning tasks (Kunde, 2001). All these tasks have in common that they use a sequential structure of two responses per trial, where binding occurs during the first response and repetition of a feature at the time of the second response starts retrieval, affecting performance in this second response. Although both binding and retrieval are necessary to affect performance in a certain situation, these processes function independently. For example, color similarity between distractor and target stimuli affects binding of the distractor with a response and retrieval of a response via distractor repetition in opposite directions (with more binding for similarly colored distractors and more retrieval for dissimilarly colored/distractors; Laub et al., 2018).

Importantly, binding and retrieval does not only occur between stimulus and response in microevents that consist of an individual action, but also between individual responses of an ongoing action sequence (Moeller & Frings, 2019a, 2019b, 2019c; for some of the

underlying neurological mechanisms of binding regarding action features, see Dilcher et al., 2021; Takacs et al., 2021; Wendigensen et al., 2022). If participants respond to two sequentially presented stimuli, these two responses are integrated or bound to each other so that repetition of one of them at a later point in time also leads to retrieval of the other integrated response. Such retrieval will then affect performance in the following response. If the retrieved and the currently required response match, performance is improved, but if they do not match, performance is impaired. That is, in an ongoing stream of action, we have to expect binding between adjacent responses and also effects of retrieval from one response to the next (for binding and retrieval between nonadjacent responses see, Moeller & Frings, 2019a). Just as networks of stimulus-response bindings have been interpreted as the representation of an individual action (e.g., Hommel, 2004), binding between responses can be understood as a higher order representation of an individual action sequence (e.g., Moeller & Frings, 2021). The paradigm to measure response-response (RR) binding effects includes two prime and two probe responses and it is orthogonally varied whether the first and/or the second of these two responses repeats from prime to probe. The assumption is then that the prime responses are integrated so that repetition of the first response in the probe starts retrieval, affecting the second probe response.

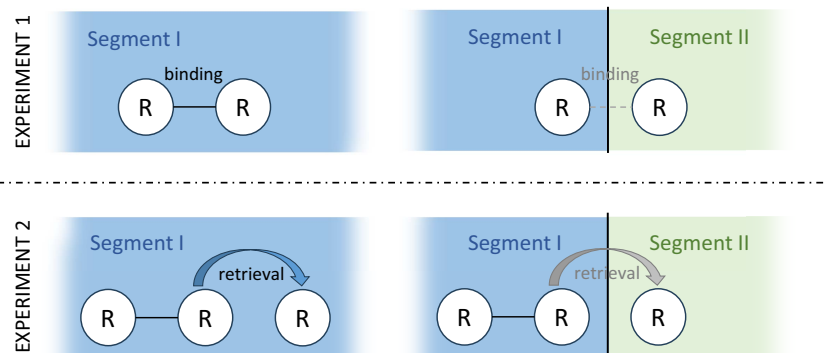
## The Present Study

Taken together, we continuously segment our surroundings into separable events to make sense of our environment. It is also clear that very basic mechanisms in action control affect individual responses in our ongoing stream of action. Even though event-files in action control and separated units in event segmentation are conceptually very close, behavior or interpretation of behavior in these fields is typically analyzed on very different time scales. While event segmentation investigates interpretations of everyday behavior that oftentimes include multistep actions of an observed actress, binding and retrieval in action control is usually concerned with very simple and individual stimulus-response instances in a laboratory setting. Therefore, a particularly intriguing question concerns a possible interface of both views. If we find effects of larger scale event interpretations on the control of individual small scale actions,

this might be a first step to unravel the translation process from the understanding of our everyday surroundings to the execution of our actions. In particular, in cases in which binding and retrieval relate to sequential features like individual responses, these basic mechanisms might be affected by event boundaries that separate items of the sequence (see Figure 1). In turn, these separated responses should be less likely integrated into the same representation of an action sequence. In fact, the BRAC framework suggests that both the binding and the retrieval process can be modulated by bottom up and top down influences of the current situation (Frings et al., 2020). Our making sense of the environment and the resulting structure of events that we perceive may be such top down influence. Here, we analyzed binding and retrieval effects (i.e., the result of binding followed by retrieval; referred to as “binding effects” in the following), between individual responses and manipulated whether to-be-bound responses (or retrieving and affected responses) were executed during the same event segment or were separated by a boundary between segments. If our perception of the structure of our surroundings is translated to our actions via modulation of the basic mechanisms of binding and retrieval, binding of two elements should be reduced when they belong to separated event segments.

The perception of event boundaries is associated with changes in perceptual features—for example, movement and color—and changes in conceptual features—for example, characters in a story and characters’ goals (Newton et al., 1977; Radvansky & Zacks, 2017; Zacks et al., 2009). Accordingly, to produce segmentation between different events, we devised two background scenarios that differed in main colors (blues vs. greens) and main character (fish vs. monkey). Each character moved from the left to the right side of the screen with the participant’s actions, reaching the goal of collecting a coin on the right hand side at the conclusion of each event. A complete movement of a character across the screen always required four responses by the participant. We measured binding effects within these four responses, treating the first two responses as prime and the second two as probe responses. It could then be assumed that the first two (prime) responses were integrated and that repetition of the first prime response as probe Response R1 would trigger retrieval of the second prime response, affecting performance in the second probe response (i.e., the last response of the sequence). Statistically binding effects between responses are indicated by an

**Figure 1**  
*Visualization of Conceptual Assumptions Regarding Binding and Retrieval Within and Across Event Segments in the Current Experiments*



*Note.* R = response. See the online article for the color version of this figure.

interaction of Response R1 relation from prime to probe and Response R2 relation from prime to probe: the repetition of R1 from prime to probe improves performance if R2 is repeated as well, but impairs performance, if R2 changes from prime to probe. In two experiments we measured this baseline binding effect within an event and compared it with the same effect for either binding (Experiment 1, Figure 1, upper part) or retrieval (Experiment 2, Figure 1, lower part) across an event boundary. Hence, in Experiment 1, the experimental condition included an event boundary between the two prime responses and in the experimental condition of Experiment 2 event boundaries occurred between the two probe responses. We expected both binding and retrieval to be affected by the switch from one event to another. This would be indicated statistically by diminished binding effects in the experimental conditions. To anticipate the results, we did find smaller binding effects both if to-be-bound responses were separated by an event boundary (Experiment 1), and also if the response to-be-affected by retrieval was separated from the retrieving response by an event boundary (Experiment 2).

## Transparency and Openness

The study was not preregistered. Study materials, analysis codes, and raw data of the reported experiments can be found on Open Science Framework at [https://osf.io/s36wm/?view\\_only=9b8b9b0933184626bd51752b89332f75](https://osf.io/s36wm/?view_only=9b8b9b0933184626bd51752b89332f75).

## Experiment 1

Our objective was to investigate whether two consecutive responses executed within the same event demonstrate a greater tendency or efficiency in being bound together compared to responses executed within two separate events. To distinguish between events, we employed two distinct scenarios. One scenario involved a fish navigating through an underwater environment, encountering water plants, and collecting a coin. The other scenario featured a monkey traversing a forest setting, passing tree stumps, and also collecting a coin. To examine the influence of event boundaries on the binding mechanism, we consistently presented two responses to be integrated, followed by two responses to measure binding. These responses were either given within the same scenario (underwater or woods), with the transition between scenarios always occurring before the first to-be-integrated response. Alternatively, the switch between scenarios occurred after the first to-be-integrated response, and we measured binding in the subsequent responses. We expected a larger binding effect when the to-be-integrated responses were executed within the same scenario compared to conditions where responses were separated by a change in scenarios.

## Method

### Participants

We were interested in at least a medium sized effect for the difference between binding effects within and across event segments. Thirty-nine participants (30 female, nine male) from the Trier University took part in the experiment. According to a power analysis with the program G\*Power (Faul et al., 2007), this size was sufficient to find an effect of  $d = 0.48$ , with  $\alpha = .05$  (one-tailed) and a power of  $1 - \beta = .90$ . The median age of the sample was

22 years (19–35). One additional participant was excluded from the analyses because he participated via iPad, that is, without a physical keyboard. All participants received partial course credit for their participation. The experiment was in accordance with ethical standards at Trier University.

### Design

The design was adjusted from previous studies, investigating RR-bindings (e.g., Moeller & Frings, 2019c, 2021) and included three within-subjects factors: Response R1 relation from prime to probe (response repetition vs. response change), Response R2 relation from prime to probe (response repetition vs. response change), and event boundary (before to-be-integrated responses vs. between to-be-integrated responses).

### Materials

The experiment was programmed using PsychoPy3/PsychoJS (2020.2.6; Peirce et al., 2019) and conducted online on Pavlovia (<https://pavlovia.org/>). Instructions were shown in white on grey background. Backgrounds during the experiment were either a woods or an underwater landscape including either a monkey and four tree stumps (in the woods) or a fish and four water plants (under water) that were arranged horizontally in the lower part of the screen (see Figure 2). Stimuli were the digits 1, 2, 3, and 4 and the letters A, B, C, and D. All digits and letters were presented in red. Participants responded by pressing one of four keys (D, F, J or K) on the computer keyboard.

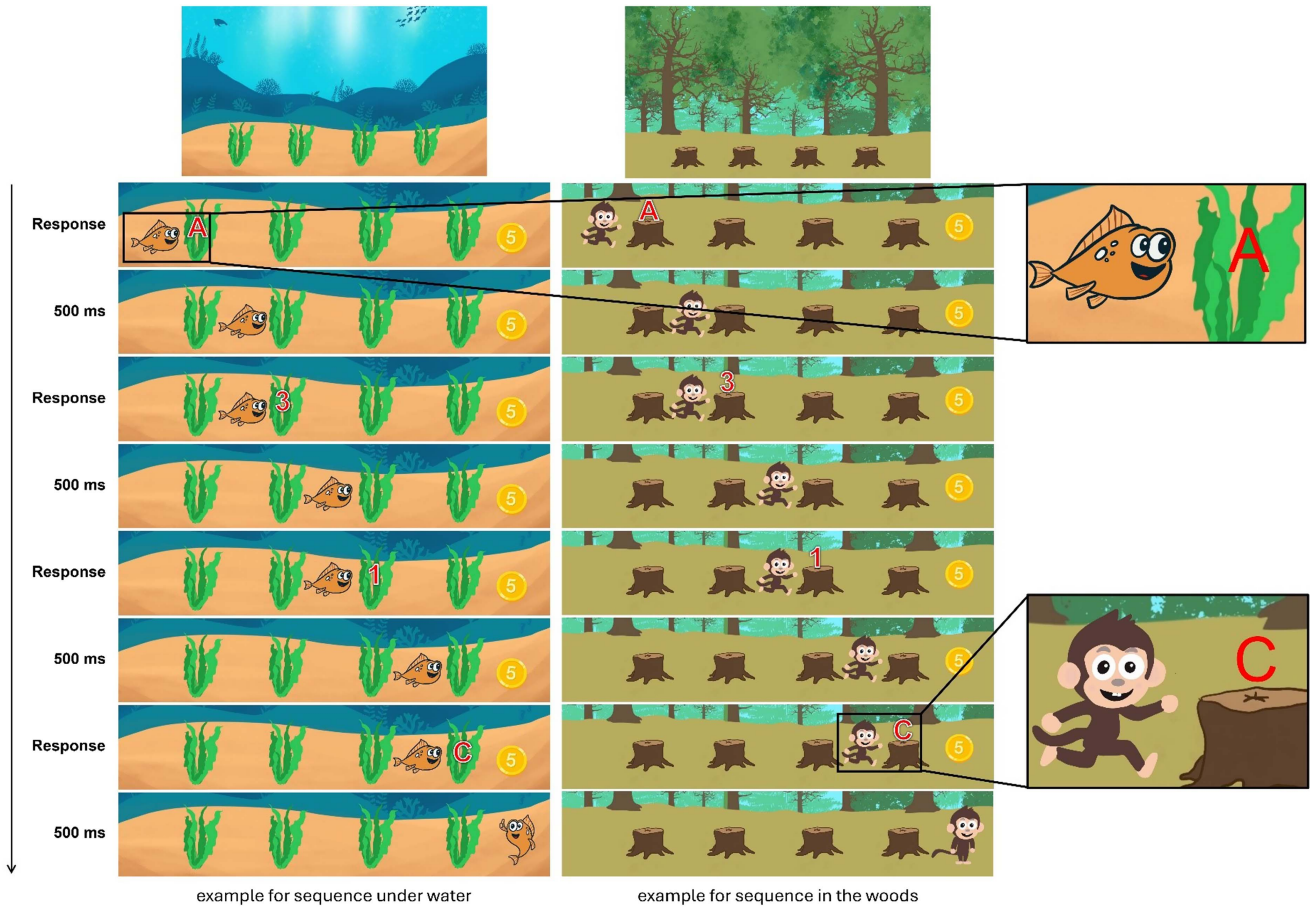
### Procedure

Participants were tested online and instructions were given via screen. Participants were instructed to place middle and index fingers of both hands on the keys D, F, J, and K of their keyboard and that their left middle finger was mapped to the Stimuli A and 1, their left index finger to the Stimuli B and 2, their right index finger to the Stimuli C and 3, and their right middle finger to the Stimuli D and 4. Their task was always to press the key corresponding to individually presented digits and letters. This task was self-paced with no timeout: the stimuli and respective background remained on the screen until participants responded. They were told that they would see either a monkey or a fish “move” through woods or water, respectively, and that their responses helped to get the letters or digits out of the way for the fish and the monkey. In turn, these would be able to pass the obstacle (water plant or tree stump, respectively). Four water plants or four tree stumps and a yellow coin were arranged horizontally in the lower part of the screen, the coin being located at the far right end of the line of plants/stumps (see Figure 2). In one block, all responses of one trial were given in the same scenario (i.e., event, either under water or in the woods). Here, the trial started with the animal—that faced to the right side—being presented left of the obstacle farthest to the left and a letter or digit (i.e., the first prime stimulus) presented to the top of and somewhat overlaying this obstacle. This gave the impression of the animal waiting in front of the obstacle. Upon responding to the stimulus, the stimulus vanished and the animal changed location and appeared to the left of the next obstacle to the right, again as if it was waiting before the obstacle. After a period of 500 ms, the next



**Figure 2**

*Sequence of Events in Two Trials, Visualized via Cuttings of Scenarios Similar to the Presented Slides*

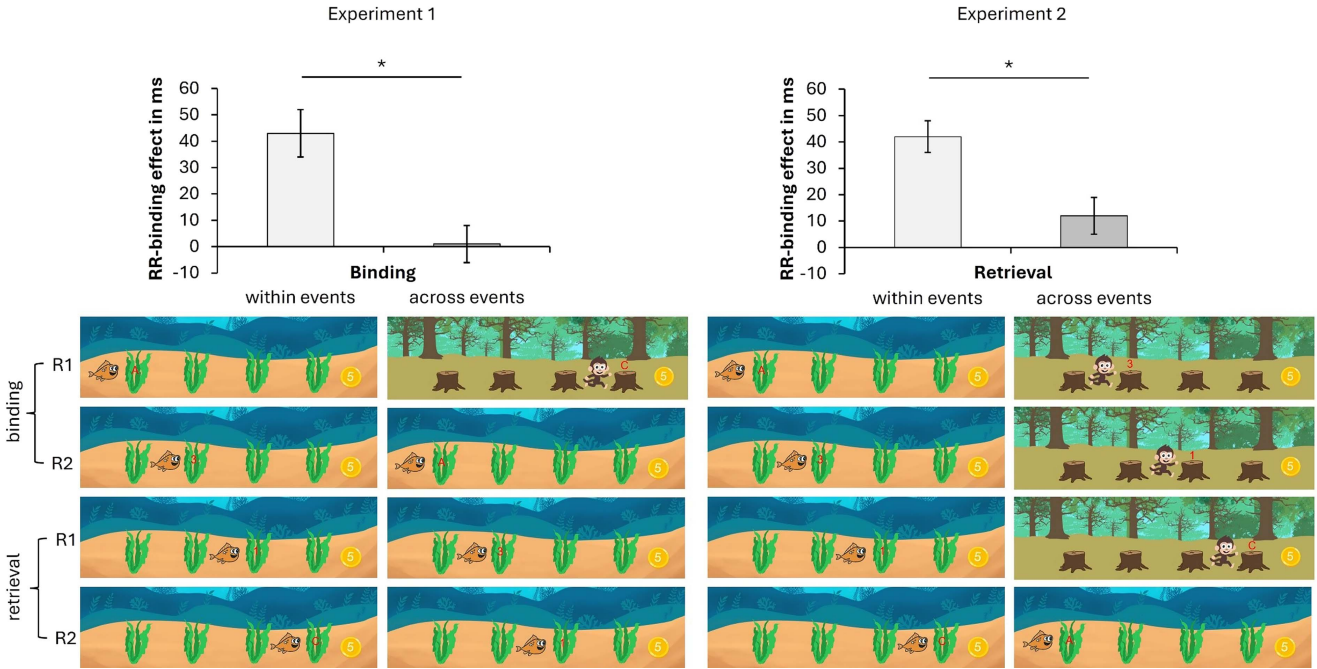


*Note.* Full scenarios are shown at the top of each trial sequence and details of the characters and stimuli on the right hand side. Participants responded with their index and middle fingers to the identity of individually presented digit and letter stimuli. Each response resulted in the animal being presented one step further to the right. After four responses in one scenario and the arrival of the animal at the goal position, the scenario switched with the other animal starting at the far left position. Response stimulus interval was always 500 ms. These are two examples of a Response R1 repetition and Response R2 repetition trial. The snippets from comics for this figure were created by Stephanie Blasl, to visualize the experimental setup. R = response. See the online article for the color version of this figure.

(second prime) stimulus appeared on top of this obstacle. Responding again triggered a location change of the animal to the next obstacle to the right, and after 500 ms the first probe stimulus appeared on top of this obstacle. After responding the animal appeared in front of the last obstacle to the right and 500 ms later, the second probe stimulus was presented on top of this obstacle. Responding to this stimulus led to the animal being presented for 500 ms to the right of the last obstacle, at the location that was occupied by the coin during the entire rest of the trial, while the coin was not visible anymore. For this brief presentation, the animal changed form, now facing the participant. This gave the impression of the animal having accomplished the collection of the coin. Then the entire scene changed either from woods to under water or vice versa and the other animal was presented in front of the obstacle at the very left of the scene and the first prime stimulus of this next trial appeared on top of this obstacle. In case of an incorrect response, an error message was presented in the center of the screen (before the background of the scenery) for 1,500 ms immediately following the erroneous response. In a second block,

participants experienced the same sequence of events. However, here the last response in one scenario and the first response in the next scenario were treated as to-be-integrated responses (prime R1 and prime R2) for our analysis and the second and third responses were used to measure this binding effect (probe R1 and probe R2; see Figure 3). That is, participants always executed four responses in one scenario, likely perceiving these as a unit, before the scenario changed to the next. With the different blocks (treating different responses within/across the scenarios as prime R1 and prime R2), we were able to measure binding between responses given during the same scenario and between responses given during different scenarios, respectively. In each block, participants were prompted twice to take a short break after which they resumed the task in their own time.

Each instance of binding and each (directly following) instance of retrieval included two consecutive responses, R1 and R2. The two factors relation of response R1 between the time of binding and the time of retrieval (repetition vs. change) and relation of response R2

**Figure 3***Results of Experiment 1 and Experiment 2*

*Note.* Response–response binding effects in the two experiments as a function of whether to-be bound (prime) responses were given within or across event boundaries (Experiment 1), or of whether retrieving response and the response to-be-affected by retrieval (probe responses) were given within or across event boundaries (Experiment 2). Binding effects are calculated as the advantage of probe R1 repetition over probe R1 change in probe R2 repetition trials minus the advantage of probe R1 repetition over probe R1 change in probe R2 change trials:  $(R1cR2r - R1rR2r) - (R1cR2c - R1rR2c)$ . The snippets from comics for this figure were created by Stephanie Blas, to visualize the experimental setup. R = response; R1c = R1 change trials; R1r = R1 repetition trials; R2r = R2 repetition trials; R2c = R2 change trials; RR = response–response. See the online article for the color version of this figure.

\*  $p < .05$ .

(repetition vs. change) were varied orthogonally, while stimuli did not repeat between prime and probe. In R1 repetition trials (R1r), the presented stimuli required the same response as prime response R1 and probe response R1. In R1 change trials (R1c), the presented stimuli required different responses as prime response R1 and probe response R1. In R2 repetition trials (R2r), the presented stimuli required identical responses as prime response R2 and probe response R2. In R2 change trials (R2c), the presented stimuli required different responses as prime response R2 and probe response R2. For example, the sequence of the Stimuli A, 3, 1, C required the responses left middle finger, right index finger, left middle finger, right index finger, which is an example for a R1r (specifically left middle finger → left middle finger) R2r (specifically right index finger → right index finger) trial. The factor event boundary (before first to-be-integrated response vs. between to-be-integrated responses) was varied blockwise as described above. The order of blocks was counterbalanced across participants. Each experimental block included 128 trials (32 of each of the four conditions R1rR2r, R1rR2c, R1cR2r, R1cR2c). The practice phase included eight trials (subsample of trials in the first experimental block).

## Results

Performance in probe R2 was the dependent variable of interest. If the two prime responses R1 and R2 were integrated, repeating prime

response R1 as probe R1 may trigger retrieval of prime R2, which would then influence probe R2 performance. Only trials with correct responses both in prime and probe were considered for the analysis of probe R2 response times (RTs). The rate for at least one error in the prime responses was 10.1%. Probe error rates were 4.9% for R1, and 4.8% for R2 (only including trials without errors in the previous responses). RTs that were more than 1.5 interquartile ranges above the third quartile of the participant's RT distribution (Tukey, 1977) and RTs, below 200 ms were excluded from the analyses. Due to these constraints, 22.1% of the trials were excluded from the RT analyses. See Table 1 for mean RTs and error rates.

In a 2 (R1 relation: repetition vs. change)  $\times$  2 (R2 relation: repetition vs. change)  $\times$  2 (event boundary: before to-be-integrated responses vs. between to-be-integrated responses) multivariate analysis of variance on probe response R2 RTs with Pillai's trace as the criterion, the main effects of R1 relation,  $F(1, 38) = 16.56$ ,  $p < .001$ ,  $\eta_p^2 = .30$ , and R2 relation,  $F(1, 38) = 13.67$ ,  $p < .001$ ,  $\eta_p^2 = .27$ , were significant. Participants responded faster, if R1 repeated ( $M = 596$  ms,  $SD = 58$  ms) than if R1 changed from prime to probe ( $M = 602$  ms,  $SD = 60$  ms), and if R2 changed ( $M = 592$  ms,  $SD = 61$  ms) than if R2 repeated from prime to probe ( $M = 606$  ms,  $SD = 58$  ms). The interaction of R1 relation with R2 relation was significant,  $F(1, 38) = 16.19$ ,  $p < .001$ ,  $\eta_p^2 = .30$ , indicating binding between the responses. Importantly, this binding effect was modulated by event boundary,  $F(1, 38) = 12.93$ ,  $p < .001$ ,  $\eta_p^2 = .25$ . Separate analyses

**Table 1**  
*Response Times and Error Rates in Experiment 1*

R1 relation	To-be-bound responses within event				To-be-bound responses across event			
	R2 repetition		R2 change		R2 repetition		R2 change	
	RT	ER	RT	ER	RT	ER	RT	ER
R1 change	618	5.6	581	4.5	613	6.1	600	4.0
R1 repetition	590	4.1	597	5.0	604	5.2	593	3.8
Priming effect	28	1.5	-16	-0.5	9	0.9	7	0.2

*Note.* Mean response times (RT, in ms) and mean error rates (ER, in percent) for probe responses R2 in Experiment 1, as a function of probe R1 relation from prime to probe, probe R2 relation, and event boundary (before prime responses vs. between prime responses). R = response.

revealed that repeating prime R1 as probe R1 retrieved prime R2 only, if both prime responses were executed within the same background scenario,  $F(1, 38) = 22.05$ ,  $p < .001$ ,  $\eta_p^2 = .37$ , but not if the background scenario switched between prime R1 and prime R2,  $F(1, 38) < 1$ ,  $p = .731$ ,  $\eta_p^2 = .01$  (see Figure 3, left hand side). For the sake of completeness, the main effect of event boundary was close to significance,  $F(1, 38) = 3.32$ ,  $p = .076$ ,  $\eta_p^2 = .08$ , with numerically faster responses, if the event boundary was before prime responses ( $M = 596$  ms,  $SD = 56$  ms) than between prime responses ( $M = 602$  ms,  $SD = 64$  ms). None of the other effects reached significance; all  $F < 1$ ,  $p > .49$ ,  $\eta_p^2 < .02$ .

In the same analysis on probe R2, error rates the numerical pattern was similar. Yet, only the main effect of R1 relation,  $F(1, 38) = 3.40$ ,  $p = .073$ ,  $\eta_p^2 = .08$ , was close to significance. All other  $F < 2.7$ ,  $p > .1$ ,  $\eta_p^2 < .07$ .

## Discussion

Our findings from Experiment 1 provide evidence of response-response binding in a slightly more complex environment compared to previous studies. We observed significant binding effects when sequential responses—for that we measured binding—occurred within the boundaries between underwater and woods scenarios. However, when responses were separated by an event boundary (i.e., a transition from one scenario to the other), there was no discernible evidence of binding effects. Even more, the magnitude of binding effects differed significantly depending on the timing of the event boundary. That is, it appears that one mechanism, by which we translate the structure of our environment into action control involves the modulation of the binding process. According to the BRAC framework (Frings et al., 2020), both binding and retrieval processes can be modulated individually via top down influences. The current evidence suggests that our understanding of the structure in our environment is one important example for such an influence.

We need to mention that even though the switch from one event to the next occurred between to-be-bound responses, still both binding and retrieval processes would be necessary for the observation of binding effects. Therefore, we cannot exclude the possibility that our manipulation in Experiment 1 also affected the retrieval process (e.g., because retrieval might be sensitive to the context stored during binding). Yet, it is safe to say that a boundary occurring

between two to-be-bound responses affected the binding effect (resulting from binding and retrieval processes) regarding these responses. In practical terms, we can expect that the binding between a response given before an event boundary and the following response after the boundary is less likely to influence following actions during this event than the binding between similar responses that were executed within the same event. With the next experiment, we aimed to test whether the binding effect can also be modulated via segmentation at the time of the retrieval process.

## Experiment 2

In Experiment 1, we obtained clear evidence that our perception of environmental structure influences a fundamental process in action control. Notably, our focus was on the binding process, which—due to the sequence of events—may be more readily impacted by the presence of an event boundary. *Binding* of two responses occurs at the time of Response 2 execution, that is, *after* perception of a boundary between prime Response 1 and prime Response 2. That is, if the boundary signals closure to any further integration, it might be unsurprising that following binding is not initiated.

The case of retrieval differs slightly. In sequential actions, the execution of one response can initiate the retrieval process, which subsequently influences performance in the following response. That is, to examine the retrieval mechanism in action sequences, we need to once again, consider two sequential responses. The intriguing question now is whether a boundary between these responses can also impact retrieval. However, while binding occurs at the time of the second of the to-be-bound responses, retrieval is initiated by the first response, affecting the second response. Consequently, an event boundary between the response initiating retrieval and the response affected by this retrieval would be perceived *after* the retrieval process has already commenced. In Experiment 2, we investigate whether such a boundary can still impact the ongoing action control process.

## Method

### Participants

We expected larger binding effects if probe responses are executed during the same event than if the response to be influenced by retrieval (i.e., probe R2) is separated by an event boundary from the response, starting retrieval (i.e., probe R1). We also assumed that this effect of modulation via event boundary might be somewhat smaller than in Experiment 1: We have to assume that the repetition of Response 1 in the probe starts retrieval of the other bound response. It is then an ongoing activation of the retrieved response that would have to be aborted at the perception of a boundary (compared to an omission to initiate binding in Experiment 1). If the abortion of retrieval is sometimes unsuccessful, the effect of event boundary would turn out to be smaller than in Experiment 1. We therefore roughly doubled the sample size to 77 participants. A power analysis with the program G\*Power revealed that this sample size was sufficient to find an effect of  $d = 0.34$  with  $\alpha = .05$  (one-tailed) and a power of  $1 - \beta = .90$  (Faul et al., 2007). Fifty-nine female and 18 male participants from Trier University took part in the experiment. The median age was 22 years (19–31). Three additional participants had to be excluded from the analyses. One did not follow instructions and two were far outs in prime error rates



(more than 40% errors). All participants received partial course credit for their participation. The experiment was in accordance with ethical standards at Trier University.

### Design

The design included three within-subjects factors: Response R1 relation from prime to probe (response repetition vs. response change), Response R2 relation from prime to probe (response repetition vs. response change), and event boundary (after retrieval affected response vs. before retrieval affected response).

### Materials and Procedure

Materials and procedure were identical to Experiment 1 with the exception of the time of the boundary in one of the blocks. As in Experiment 1, in one of the blocks, the switch from one scenario to the other occurred before the first-to-be-integrated response and after the response, affected by retrieval. This block was used to measure binding effects if both retrieving response and response affected by the retrieval were perceived as elements of the same scenario. In the other block, participants experienced the same sequence of events. Yet, we analyzed whether binding between the second and third responses in one scenario could be measured via retrieval, triggered by the fourth response that affected the first response of the following scenario (see Figure 3, right hand side).

### Results

As in Experiment 1, performance in probe R2 was the dependent variable of interest. Only trials with correct responses both in prime and probe were considered for the analysis of probe R2 RTs. The rate for at least one error in the prime responses was 10.7%. Probe error rates were 5.4% for R1, and 5.4% for R2 (only including trials without errors in the previous responses). RTs that were more than 1.5 interquartile ranges above the third quartile of the participant's RT distribution (Tukey, 1977) and RTs, below 200 ms were excluded from the analyses. Due to these constraints, 21.1% of the trials were excluded from the RT analyses. See Table 2 for mean RTs and error rates.

In a 2 (R1 relation: repetition vs. change)  $\times$  2 (R2 relation: repetition vs. change)  $\times$  2 (event boundary: after retrieval affected response vs. before retrieval affected response) multivariate analysis

of variance on probe response R2 RTs with Pillai's trace as the criterion, the main effects for event boundary,  $F(1, 76) = 384.79$ ,  $p < .001$ ,  $\eta_p^2 = .84$ , and for R2 relation,  $F(1, 76) = 5.44$ ,  $p = .022$ ,  $\eta_p^2 = .07$ , were significant. Participants responded faster if the event boundary was after retrieval ( $M = 610$  ms,  $SD = 64$  ms) than within retrieval ( $M = 755$  ms,  $SD = 97$  ms), and if R2 changed ( $M = 675$  ms,  $SD = 73$  ms) than if R2 repeated from prime to probe ( $M = 682$  ms,  $SD = 73$  ms). The interaction of R1 relation with R2 relation was significant,  $F(1, 76) = 34.28$ ,  $p < .001$ ,  $\eta_p^2 = .31$ , indicating binding between the responses. Importantly, this binding effect was modulated by event boundary,  $F(1, 76) = 10.45$ ,  $p = .002$ ,  $\eta_p^2 = .12$ . Separate analyses revealed that repeating prime R1 as probe R1 affected probe R2 responding only, if both probe responses were executed within the same background scenario,  $F(1, 76) = 43.92$ ,  $p < .001$ ,  $\eta_p^2 = .37$ , but not if the background scenario switched between probe R1 and probe R2,  $F(1, 76) = 2.98$ ,  $p = .088$ ,  $\eta_p^2 = .04$  (see Figure 3, right hand side). For the sake of completeness, the interaction of event boundary and response R2 relation was significant as well,  $F(1, 76) = 15.47$ ,  $p < .001$ ,  $\eta_p^2 = .17$ . None of the other effects reached significance;  $F_s < 1$ ,  $p_s > .47$ ,  $\eta_p^2 < .01$ .

In the same analysis on probe R2 error rates the interaction of R1 relation and R2 relation was significant,  $F(1, 76) = 7.49$ ,  $p = .008$ ,  $\eta_p^2 = .09$ , indicating binding effects. This interaction was again modulated by event boundary,  $F(1, 76) = 5.01$ ,  $p = .028$ ,  $\eta_p^2 = .06$ . Binding effects were only significant if retrieving and affected response were part of the same event,  $F(1, 76) = 12.00$ ,  $p < .001$ ,  $\eta_p^2 = .14$ , but not if they were separated by an event boundary,  $F(1, 76) < 1$ ,  $p = .711$ ,  $\eta_p^2 < .01$ . In addition, the interaction of Event Boundary  $\times$  R2 relation was significant as well,  $F(1, 76) = 5.54$ ,  $p = .021$ ,  $\eta_p^2 = .07$ . All other  $F < 2.3$ ,  $p > .13$ ,  $\eta_p^2 < .03$ .

### Discussion

In Experiment 2, we replicated the finding from Experiment 1 that sequential responses are bound and retrieve each other also in slightly more complex scenarios than previously shown. Response–response binding effects were significant if the response starting retrieval and the one being affected by retrieval were part of the same event. Notably, following responses were not affected by retrieval if the two responses involved in retrieval were separated by a boundary and importantly, this difference in binding effects for retrieval within compared to across event boundaries was significant. This result pattern offers insight into how flexibly retrieval is used in action control. Apparently, even an ongoing retrieval process can be modulated, depending on the situation. Moreover, the perceived structure of the environment can be used for this modulation, indicating a second possibility how our perception of this structure may be translated into our actions.

It may also be noted that, as in Experiment 1, we found a general R2 change benefit. This is a typical effect found in the response–response binding paradigm and likely the case because stimuli never repeat during one trial: Participants have to execute the same response even though the stimulus changes, which leads to performance costs (see e.g., Kleinsorge, 1999).

### General Discussion

Literature on event segmentation indicates that we structure our perceptions into more or less fine-grained events. Yet, to date it is

**Table 2**  
*Response Times and Error Rates in Experiment 2*

R1 relation	Retrieval effect within event				Retrieval effect across event			
	R2 repetition		R2 change		R2 repetition		R2 change	
	RT	ER	RT	ER	RT	ER	RT	ER
R1 change	627	6.3	592	3.6	755	5.0	753	5.6
R1 repetition	608	4.9	614	5.8	751	5.7	761	6.6
Priming effect	19	1.4	−22	−2.2	4	−0.7	−8	−1.0

*Note.* Mean response times (RT, in ms) and mean error rates (ER, in percent) for probe responses R2 in Experiment 2, as a function of probe R1 relation from prime to probe, probe R2 relation, and event boundary (After probe response vs. between probe response). R = response.

not entirely clear, how this structure in perception translates to ongoing action. With the present results, we were able to demonstrate that one way to shape our behavior according to an event structure functions via modulation of two very basic processes in action control: binding and retrieval. In prior research, the focus was typically on examining either the perception of event boundaries or the binding and retrieval processes within limited environments. Our study, however, introduced distinct event boundaries and revealed their influence on both binding and retrieval processes (see Figure 1).

It is also noteworthy that we found clear evidence of binding effects between individual responses in a somewhat more complex task. While previous studies regarding response–response binding effects, presented very simple stimuli (e.g., letters and digits) centrally on an otherwise completely black or gray background, the present experiments used a more naturalistic setting with two different characters moving through different sceneries in order to collect a coin. The task was almost identical to previous studies. However, the instructions stressed that participants would help the main characters in their progress by clearing the digits and letters out of the way, thus relating responses to the events (i.e., the characters' progress in the sceneries). In addition, each response resulted in the character moving further across the screen. It is possible that this relation between responses and event structure was necessary for the observed result pattern.

While the present findings are in line with a study by Qiu et al. (2023) who found that an auditory stimulus and a response that was executed toward this stimulus were integrated to a larger extent if they shared the same contextual sound in the background than if the contextual sound changed between stimulus presentation and response execution, we take several steps further. With the present experiments we transferred the observation to somewhat more natural event like situations and analyzed effects on performance in action sequences. Possibly most importantly, with the present study, we investigated the influence of event boundaries on binding and retrieval mechanisms separately (according to BRAC, Frings et al., 2020), showing that both were affected. The current experiments together with the mentioned study suggest that binding and retrieval mechanisms and their modulations function similar, regardless of the scale of a given event.

According to event segmentation theory (Zacks et al., 2007), an important cue for updating the working model for a current event (i.e., perceive an event boundary) is the occurrence of a prediction error. Yet, such updating can also rest on the perception of a large amount of change from the recent past to the current situation, even if the change is expected (Richmond & Zacks, 2017). The sequences of events were indeed highly predictable in the present study, not only within events, but also across event boundaries. For example, after the fish moved across the screen to the right hand side, it would collect the coin and the next moment would feature the monkey in its woods environment, positioned at the left hand side of the screen. Event boundaries were therefore not signaled by prediction errors but by changes in color schemes, character and character position, and their interpretation. This set of changes was sufficient to diminish both integration and retrieval mechanisms regarding sequential responses.

Note that with the complete changes of characters and backgrounds in the present study, one could make the case that our “event boundaries” would be better described as context changes. Yet, it

should also be noted that the consistency and variation of context can play a role in identifying distinct episodic events within continuous experiences (Clewett & Davachi, 2017). Hence, any perceived context changes in the present study likely contributed to event segmentation, as recently shown by other event segmentation experiments and neurophysiological data (Ghorbani et al., 2024; Prochnow, Zhou, Ghorbani, Roessner, et al., 2024; Prochnow, Zhou, Ghorbani, Wendiggensen, et al., 2024). While we present the first evidence that event boundaries (possibly induced by context changes) affect how we represent and execute our ongoing stream of actions, it will be interesting to also investigate whether other cues, signaling event boundaries (e.g., change in motion or prediction error) have an identical effect on these basic processes in action control.

While good event segmentation generally increases memory for observed events (Flores et al., 2017), recall of specific sequential order is disrupted by boundaries between contexts (e.g., Clewett & Davachi, 2017; DuBrow & Davachi, 2013). This disruption of binding in memory due to event boundaries is complemented by the current findings that already binding and retrieval of the currently executed actions is similarly impaired by switches between events. Hence, it is possible that the modulation of these processes in action control contribute to memory formation within and across events. More specifically, it has been proposed that bindings are a first step toward learning (Frings et al., 2023; Moeller & Pfister, 2022) in this case, of an action sequence. The current results may indicate that even at this early stage, the continuous sequence of actions is grouped into sensible units, facilitating association of individual responses to more complex actions, especially when those responses share common attributes, such as their relevance to the same event. Hence, it can be speculated that the interpretation of the current situation affects learning of action sequences via this early stage.

Previous studies have shown that large visual changes between the time of binding and the point in time at which retrieval starts, diminishes binding effects (e.g., Selimi et al., 2022). That is, one might have expected that retrieval would not start, if the current scenario (probe Response 1) does not match the binding scenario (prime Response 2). Note that this was not the case in the present study. Instead, the event boundary in Experiment 2 occurred only *after* completion of the response that started retrieval. Hence, this is the first evidence that an ongoing retrieval process can still be shaped according to the structure of the surroundings. Because changes in the scenarios were always predictable in the present study, another possible interpretation is that knowledge of an upcoming event boundary reduces retrieval from the beginning. Either way, the process of retrieval seems to be highly flexible and not strictly determined by the information present at the time it is triggered.

### Constraints on Generality

Binding and retrieval processes have been assumed to be universal cognitive functions (e.g., Frings et al., 2020; Hommel, 2004), while event segmentation can be affected by age and clinical disorders (e.g., Bailey et al., 2013; Zacks et al., 2006). Here we collected a convenience sample of only young healthy adults. Therefore, we can expect similar effects in other healthy young adults. Whether the same pattern can be found in older adults, children, or clinical samples, needs to be investigated in separate projects.

## Conclusion

We combined the views of two different fields in cognitive psychology that typically analyze event representation on very different grain sizes. Results indicate that larger scale changes in scenery that imply an event boundary, modulate very basic processes in action control. The extent to which sequential responses were bound or affected each other via retrieval depended on whether or not responses were executed within or across event boundaries. This is a first indication that a modulation of the basic mechanisms binding and retrieval can help to translate the structure we perceive in our surroundings into the way we perform our actions.

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