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Found in translation: The role of response mappings for observing binding effects in localization tasks

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ABSTRACT
According to action control theories, response and stimulus' features are integrated into event files. Repeating any of an event file's components retrieves the previously bound information, causing benefits for full repetition, but interference for partial repetition. Yet, such "binding effects" are absent in localization performance. By assuming sequential processing steps until response execution as assumed in visual search, we hypothesized that, for localization, participants can execute their response without the need to process target features. Hence, post-selective processing might be crucial for binding effects to emerge. Here, participants localized coloured targets appearing on one of four corners of a touchpad in two response conditions, namely, directly tapping on the target (direct response mapping), and tapping on the corner diagonal opposite to the target (translational response mapping). Only the translational response mapping yielded binding effects between localization response and colour. The direct response mapping instead showed an effect that is better explained by (non-spatial) Inhibition of Return or related change benefit effects. We conclude that an arbitrary response mapping – based on a translation of a spatial feature into a non-direct spatial response – can lead to binding effects even in localization tasks.

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Action control; attention; perception; stimulus-response binding; response mapping

Grabbing a cup of coffee or pressing a certain keyboard key can be described as an intentional movement, that is, a movement executed with a particular goal, and with anticipated perceptual effects in mind; this aspect, the intention, is an integral and defining part of what researchers call an "action" (e.g., Frings, Hommel, et al., 2020; Prinz, 1998). When a participant responds to a stimulus in a laboratory task, the stimulus, its accompanying features (even if task-irrelevant; Frings et al., 2007), and the response are integrated into a short episodic memory trace or *event file* (Frings, Hommel, et al., 2020; Hommel, 1998, 2004; Hommel et al., 2001). Upon repetition of any of its features, the previous event file is retrieved, causing benefits for full repetition, but interference for partial repetition. In contrast, full changes cause no interference, because nothing is retrieved (e.g., Frings, Hommel, et al., 2020). Such stimulus-response bindings are thought to underlie many actions (e.g., Frings, Koch, et al., 2020), and are active in a variety of experimental paradigms, for example, priming tasks that have a sequential character (see, e.g., Frings, Hommel, et al., 2020; Henson et al., 2014).

No effects for colour-location bindings?

However, the generality of binding effects for all action has been challenged recently. Schöpper, Hilchey, et al. (2020) asked participants to press a button upon detection of a coloured dot appearing at one of two locations, while systematically varying the target colour and location to fully repeat, partially repeat or fully change in a sequential design. According to action control theories, the detection of a stimulus by pressing a button is clearly an intentional movement and therefore constitutes an action (Frings, Hommel, et al., 2020; Prinz, 1998; Schöpper, Hilchey, et al., 2020). Indeed, a colour discrimination task (run as a control experiment) showed a reliable binding effect indicated by an interaction of response

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and location. The results for the detection task, however, showed no binding pattern but only a benefit for a location change, that is, inhibition of return (IOR; Klein, 2000).

This lack of interaction between colour and location as features, as well as non-spatial feature and response is a known finding in attentional-orienting research. Huffman et al. (2018) identified a set of 14 experiments investigating attentional orienting effects, which involved detecting or localizing targets in a sequence while repeating or non-repeating a task-irrelevant non-spatial target-feature (i.e., colour or shape).[1] In the reviewed experiments,[2] repeating or changing the non-spatial features did not interact with repeating or changing the location of the target; there was only an IOR-effect (Klein, 2000). Huffman et al. (2018) argued that when participants detect or localize a target, there is no need to process stimulus identity; in turn, binding effects should not occur. Although there have been rare cases of observed binding patterns for detection (Hilchey et al., 2020) and localization (Hilchey, Pratt, & Lamy, 2019) performance, IOR unmodulated by non-spatial feature repetitions or changes is the standard pattern observed in tasks that do not require target identity discrimination (see also Hilchey, Rajsic, et al., 2018).

One peculiarity in the localization experiments reviewed by Huffman et al. (2018) is noteworthy: Participants performed horizontal localization responses to horizontally appearing targets without any distractor stimuli (Pratt & Castel, 2001, which was conceptually replicated by Huffman et al., 2018; Tanaka & Shimojo, 1996, 2000; Taylor & Donnelly, 2002). Thus, participants could execute their response directly after localizing the object because, firstly, the perceived object is undoubtedly the target (i.e., there is no distractor or "decision noise", Pashler, 1987; see also Hilchey, Pratt, & Lamy, 2019), and, secondly, because there is no distractor-driven inhibition (e.g., Maljkovic & Nakayama, 1996) or negative priming (Neill & Mathis, 1998) by a previous distractor location (see also Hilchey, Antinucci, et al., 2019). Furthermore, it is unnecessary to process the target identity for forming a response (Huffman et al., 2018; Schöpper, Hilchey, et al., 2020), because a left/right target can be responded to with a spatially compatible, non-arbitrary left/right key press (see also Hilchey, Pratt, & Lamy, 2019; Huffman et al., 2018). Thus, there is no need to process the target's identity and translate it into an appropriate action because the action is directly specified by the target's location. As mentioned by Hilchey, Pratt, and Lamy (2019), the need of such response translation rules, or the lack thereof in localization tasks, is usually not addressed (but see, Tanaka & Shimojo, 2000). Yet, they appear likely to affect performance (e.g., Hilchey, Antinucci, et al., 2019).

Location in visual search

In visual search, a discrepancy between simply detecting a target and discriminating a non-spatial feature of said target is well known. When participants detect the presence of a pop-out target among several distractors (e.g., a blue bar among multiple red bars), repeating the dimension by which a target pops out (e.g., colour or orientation), results in faster reaction times (Found & Müller, 1996; Müller et al., 1995). However, discriminating an additional feature (e.g., vertical or horizontal stripes) of a pop-out target (so-called compound search tasks; e.g., Töllner et al., 2008; Zehetleitner et al., 2012) results in partial repetition costs when the dimension of the pop-out target and the subsequent discrimination response neither fully repeat nor fully change.

These differences in search tasks have been explained by a serial processing of stimuli and features (Müller & Krummenacher, 2006; Zehetleitner et al., 2012; see also Schöpper, Hilchey, et al., 2020). For example, according to Zehetleitner et al. (2012), in compound search tasks, the target stimulus is identified in a first, pre-attentive search stage, followed by a post-selective discrimination stage of the feature of interest, the latter leading to partial repetition costs when the response is initiated. Pashler (1991, 1998) proposed that when a participant responds to a stimulus, the execution of a response follows a first stage of perceptual analysis and a second stage involving a decision or response selection. In a similar vein, the guided search model (Wolfe, 1994; Wolfe et al., 1989) proposes a first stage in which basic visual features of a target are processed followed by a second stage involving cognitive processes that are performed on the target to execute a response. Thus, it can be argued, that for simply detecting or localizing the target, only the first stage of analysis is relevant.[3]

Merging ideas: Action control, attentional orienting, and visual search

Applying such a serial processing logic of visual search to a non-spatial discrimination task would mean that a non-spatial discrimination response is the result of a first perceptual analysis in which the target is located, followed by the discrimination of the non-spatial feature to determine the correct response; the latter is achieved by an arbitrary stimulus-response (S-R) mapping (e.g., Henson et al., 2014). Thus, to execute the response, a cognitive operation has to be performed after the selection stage in order to discriminate features that are not defined by location (see also, e.g., Hilchey, Leber, & Pratt, 2018; Huffman et al., 2018). We will call this a *post-selection* operation. In this view, the initial perceptual stage may be common for detection, localization, and non-spatial discrimination performance (e.g., Treisman & Gelade, 1980). However, when participants merely have to *detect* or *localize* a target, they do not need to involve the post-selection discrimination stage (i.e., no S-R mapping is needed to translate the stimulus feature into a response): The response is directly specified by the selection. Although there is always an S-R mapping when participants detect or localize a target, as long as a response is given to a stimulus (i.e., there is some sort of mapping to identify, for example, the right key on a keyboard as the response field for targets appearing in the right half of a screen), we argue that an S-R mapping for detection and localization responses is executed without any post-selection processing, because it is based on direct (visuomotor) mechanisms (see, e.g., Fournier et al., 2010, 2015; Wiediger & Fournier, 2008), is fully compatible (see, e.g., Kornblum et al., 1990), non-arbitrary, and highly overlearned (see, e.g., Kiesel et al., 2010). Referring to the translational model (for Stroop interference) by Virzi and Egeth (1985), in localization performance a spatial stimulus is processed (by some sort of spatial system) to give a spatially congruent response, whereas a non-spatial stimulus (processed by some sort of non-spatial system) demands a translational mechanism to give a spatial response. Similar translational sequences have been argued for differentiating detection and localization performance from discrimination and compound search performance in visual search (cf. Müller et al., 2003, pp. 1032–1033): For example, Töllner et al. (2012) argued that response selection in localization and detection tasks relies on rather automatic processes ("feedforward processing"); in contrast, response selection in discrimination and compound tasks involves recurrent extraction of stimulus identity information ("recurrent processing"). In other words, a translation from feature space to response space is necessary for non-spatial discrimination tasks. Simply put, binding effects might be found (only) in translation.

The present study

We hypothesized that a binding effect would manifest in a localization task if the location itself has to be processed in a post-selection stage to be translated into a response. To test this prediction, we asked participants to localize red or blue target dots that appeared in the four corners of a touch screen. In one response condition, participants had to directly tap on the appearing target. In the second response condition participants had to tap the corner diagonally opposite to the target. We hypothesized that the arbitrarily assigned but constant S-R mapping that had to be processed after selection in the second response condition should produce a binding effect (i.e., it is found in translation of the S-R rule): Participants should be faster when response-relevant location[4] and response-irrelevant colour both repeat, but interference should occur if colour changes. In contrast, response-relevant location changes should be beneficial if colour changes compared to repeats (i.e., we expect partial repetition costs due to response repetitions and changes, congruent with S-R binding; Hommel, 1998, 2004). This effect should be absent for the direct response mapping, in which participants could directly respond to the location without the need to process a stimulus feature post-selection.

Experiment 1

Participants

In the current study, a binding pattern between localization response and colour is computed as the interaction of location relation x colour relation. Such a pattern is typically absent in localization performance (e.g., Huffman et al., 2018; Schöpper & Frings, submitted). However, binding effects between response and location, colour, or form, etc., in discrimination performance are usually strong and stable with a medium to high effect size (e.g., Frings et al., 2007; Schöpper, Hilchey, et al., 2020; Schöpper, Singh, & Frings, 2020). Thus, we set out to achieve a power of at least $1-\beta = .90$, and expected medium effect size of $d = 0.5$ resulting in a minimum sample of $N = 36$ participants (G*Power, Version 3.1.9.2; Faul et al., 2007). Accordingly, forty students of the University of Trier participated for course credit and gave written informed consent. The experiment complied with ethical standards for conducting behavioural experiments at the University of Trier. One participant did not comply with the instructions and often failed to tap onto the target; this participant's data were excluded from analysis. This resulted in a sample of 39 participants (29 women, 10 men, $M_{age} = 22.54$, $SD_{age} = 3.33$, age range: 18–33 years) with sufficient power for detecting a medium sized effect of $1-\beta = .92$ (error probability: $\alpha = 0.05$, one-tailed).

Apparatus and materials

The experiment was run in E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA). Stimuli were displayed on a 7″ touch monitor (Faytech Ldt., Henzen, China) secured on a mount with an approximate average viewing distance of 45 cm in front of the participant. Instructions for the experiment appeared on a larger monitor behind the touch monitor prior to testing. The touch monitor spanned a field of 19.42° × 10.92° of visual angle, on which a screen resolution of 1680 × 1050 px was projected. Because the aspect ratio of the physical screen size and screen resolution did not fully match, the presented stimuli appeared minimally stretched (i.e., round target dots were minimally elliptical); additionally, some pixels on each edge disappeared behind the physical frame of the touch monitor. In front of a black background (0.32 cd/m^2), a white fixation cross (158.43 cd/m^2) spanning a field of approximately 0.89° × 0.76° (length × height) of visual angle was presented at the centre of the screen. Each corner contained a grey circle (R/G/B-coordinates: 127/127/127; luminance: 21.63 cd/m^2) spanning a field of approximately 1.38° × 1.23° of visual angle with an approximate line width of 0.1° (horizontal plane)/ 0.06° (vertical plane) of visual angle. These circles were empty (i.e., black) and served as key-equivalents or placeholders (see below). A red (R/G/B-coordinates: 237/28/36; luminance: 28.23 cd/m^2) or blue (R/G/B-coordinates: 63/72/204; luminance: 14.7 cd/m^2) target dot could appear in any of the four grey circles. Accordingly, these coloured fillings were approximately 1.17° × 1.06° of visual angle. The four possible target locations were horizontally approximately 15.56° of visual angle and vertically approximately 7.12° of visual angle apart (centre-to-centre). The diagonal distance between the fixation cross and target locations was approximately 8.64° of visual angle (centre-to-centre). A touch response in the lower field of the screen, spanning up to 225 pixel (approx. 2.42° of visual angle) above the centre of the lower target dots, or a touch response in the upper field of the screen, spanning up to 225 pixel (approx. 2.42° of visual angle) below the centre of the upper target dots was counted as a response by the programme. All responses to the lower/upper left half of the screen were counted as a lower/upper left response, and all responses to the lower/upper right half of the screen were counted as a lower/upper right response.

Design

The experiment used a 2 (response condition: direct response vs. translational response) x 2 (location relation: repetition vs. changed) x 2 (colour relation: repetition vs. changed) design. All variables were varied within-subjects. A binding effect is derived from the interaction of location relation and colour relation, its modulation by task type is derived from the three-way interaction.

Procedure

Participants either responded by directly tapping on the target (direct response condition) or by tapping on the grey circle on the opposite diagonal corner of the appearing target (translational response condition). Participants performed both response conditions; their order was balanced across participants. Except for the response mapping, the procedure of both versions was the same. The experiment took place in a dimly lit room, with the experimenter sitting in a directly adjacent room. The experiment started with the instructions appearing on the larger monitor behind the touch monitor, including a photograph of how to grab the touch monitor (cf. Figure 1 (a), the "neutral" position of the non-responding thumb in-between circles). In the instructions, participants were encouraged to ask the experimenter if any questions persisted; if not, participants worked through the whole experiment without supervision. After the first response condition was completed, the instructions for the second condition appeared on the screen. Participants started the experiment by pressing the space bar. During testing, the screen of the larger monitor was black and the experiment took place on the touch screen. A trial consisted of a prime display and response followed by a probe display and response. The probe display either repeated or changed the target's location and/or colour of the prime display. During a whole prime-probe-sequence, there was a grey circle placeholder in every corner of the touch screen (which only disappeared during error messages or a break). A trial

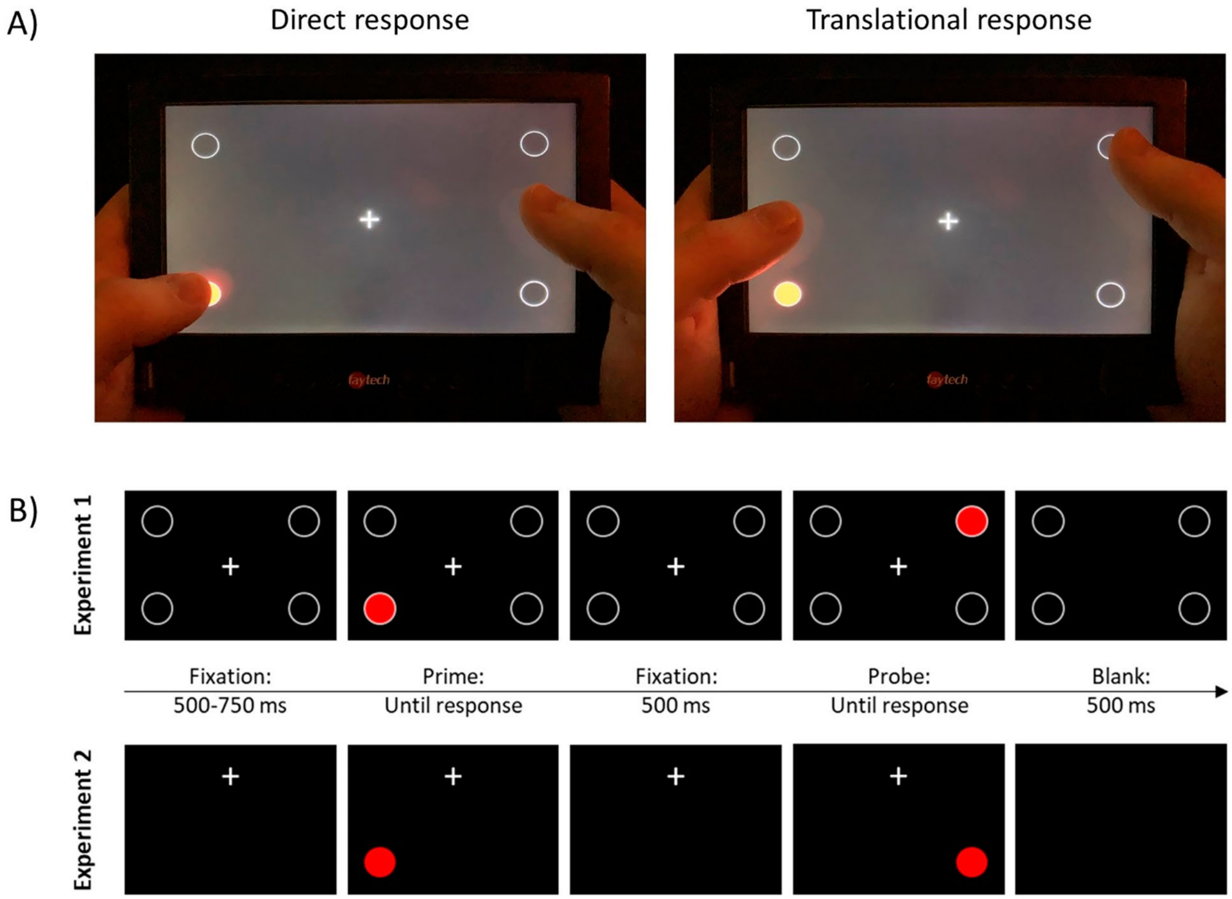

Figure 1. (a) The display for both response mapping conditions in Experiment 1 was the same (colour, and luminance, the latter causing some blurriness in the photograph, are not adequately captured by the camera due to dimmed light; see *materials*-section for colour and luminance); the versions only differed in the instructions given for responding. The example depicts a display, in which a coloured dot appears in the lower left corner. In the direct response condition, participants would have to directly tap on it. In the translational response condition, participants would have to tap the corner diagonally opposite to the target dot, that is, they would have to tap the grey circle in the upper right corner. Note that the red or blue dot could appear in any of the four corners. (b) Experimental sequence (not drawn to scale) of an example trial for Experiment 1 (upper row) and Experiment 2 (lower row). In Experiment 1, a red or blue target dot could appear at all four corners on screen and participants were instructed to either directly tap on it or to tap on the grey circle in the diagonally opposing corner, depending on the response mapping condition (see main text). Note the grey circles in Experiment 1, which were shown throughout a whole prime-probe sequence and served as key-equivalents/ placeholders. In Experiment 2, a red or blue target dot could appear at either of the two lower positions on the screen and participants were instructed to directly tap on it. Both sequences depict a trial, in which the location changes, but the colour repeats (LCCR).

started by a fixation interval of 500–750 ms, in which a white fixation cross was visible on screen. Afterwards, for the prime display the fixation cross was accompanied by a red or blue target dot appearing in one of the grey circles of the touch monitor. Participants responded according to the instructions given for the respective response conditions (see Figure 1 (a)). Responses on the left side of the screen had to be executed with the left thumb, responses on the right side of the screen had to be executed with the right thumb. The prime target stayed on screen until a response was given without a time limit. After the prime response, only the fixation cross and the grey circles were shown for 500 ms, followed by the probe display. The probe display and task were the same as for the prime display. After a probe response was given, the screen turned blank (i.e., only grey circles on black background) for 500 ms, ending a prime-probe sequence. After an incorrect response, an error message appeared on the touchscreen for 1500 ms.

From prime to probe, the colour and position of the target dot could repeat or change, resulting in four prime-probe conditions. In trials with location repetition and colour repetition (LRCR), the same colour repeated from prime to probe at the same position. In trials with location repetition and colour change (LRCC), the colour switched from prime to probe but appeared at the same position. In trials with location change and colour repetition (LCCR), the colour of the target dot repeated while the position changed. Finally, in trials with location change and colour change (LCCC), both the colour and position of the target dot changed from prime to probe. Because there were four possible locations, location changes could occur horizontally, diagonally, or vertically. Although we were interested in the overall location change effect, the three response change possibilities were equally balanced across change conditions. Each response condition consisted of sixteen practice trials followed by 288 experimental trials. The latter comprised 72 trials for each prime-probe condition. Participants started with one response condition, followed by the other response condition, with the order being switched with every new participant. In each response condition, colour, location, and location changes were pseudo-randomly balanced across all participants. An example trial is presented in Figure 1(b), upper row. After the 96th and 192nd trial in each response condition, the participant could take a self-paced break.

Results

Reaction times

Reaction times were operationalized as the time of probe response execution after probe target onset. Only reaction times above 100 ms or below 1.5 interquartile ranges above the third quartile of a participant's distribution (Tukey, 1977) were included for analysis. Additionally, only trials in which the prime and probe response was correct[5] were included. This resulted in 8.12% of probe trials being discarded.

We performed a 2 (response condition: direct response vs. translational response) x 2 (location relation: repeated vs. changed) x 2 (colour relation: repeated vs. changed) repeated measures ANOVA on reaction times. There was a main effect of response condition, $F(1, 38) = 233.20$, $p < .001$, $\eta_p^2 = .86$, with participants responding faster in the direct response condition (472 ms) than in the translational response condition (557 ms). There was a main effect of location relation, $F(1, 38) = 202.93$, $p < .001$, $\eta_p^2 = .84$, with participants responding faster, when location repeated (464 ms) compared to when it changed (564 ms). The main effect of colour relation was not significant, $F(1, 38) = 1.36$, $p = .252$, $\eta_p^2 = .03$. There was an interaction of response condition and location relation, $F(1, 38) = 76.18$, $p < .001$, $\eta_p^2 = .67$: Changing (622 ms) the location was slower than repeating the location (491 ms) in the translational response condition. This pattern was also found when responding directly, but not as pronounced (location repetition: 437 ms; location change: 506 ms). There was also an interaction of response condition and colour relation, $F(1, 38) = 8.83$, $p = .005$, $\eta_p^2 = .19$: Changing (560 ms) the colour yielded slower responses than repeating the colour (554 ms) in the translational response condition. This pattern was absent when responding directly (colour repetition: 473 ms; colour change: 471 ms). The interaction of location relation and colour relation was not significant, $F(1, 38) = 0.02$, $p = .887$, $\eta_p^2 < .01$ (LRCR: 463 ms; LRCC: 465 ms; LCCR: 563 ms; LCCC: 565 ms). Crucially, the three-way interaction of response condition, location relation and colour relation was significant, $F(1, 38) = 9.28$, $p = .004$, $\eta_p^2 = .20$.

Because the response condition modulated the interaction of location relation x colour relation – that is, task type presumably modulated the occurrence of binding effects – we calculated the 2 (location relation: repeated vs. changed) x 2 (colour relation: repeated vs. changed) ANOVA separate for both tasks for better comparability. In the direct response condition, the main effect of location relation was significant, $F(1, 38) = 61.36$, $p < .001$, $\eta_p^2 = .62$ (location repetition: 437 ms; location change: 506 ms), whereas the main effect of colour relation was not, $F(1, 38) = 0.80$, $p = .376$, $\eta_p^2 = .02$. The interaction of location relation and colour relation (see Figure 2(a)) was significant, $F(1, 38) = 5.57$, $p = .024$, $\eta_p^2 = .13$. However, this pattern was opposite to what binding approaches in action control would predict: Repeating a location was slower when the colour repeated (441 ms) compared to when it changed (434 ms); however, this partial repetition *benefit* did not reach significance, $t(38) = 2.01$, $p = .052$, $d = .32$. Location changes[6] descriptively yielded mild benefits for colour repetitions (505 ms) compared to colour changes (508 ms), which, however, was not significant, $t(38) = 1.40$, $p = .171$, $d = 0.22$. In the translational response condition, the main effect of location relation, $F(1, 38) = 370.47$, $p < .001$, $\eta_p^2 = .91$ (location repetition: 491 ms; location change: 622 ms), and the main effect of colour relation, $F(1, 38) = 6.13$, $p = .018$, $\eta_p^2 = .14$ (colour repetition: 554 ms; colour change: 560 ms), were significant. The interaction of location relation and colour relation (see Figure 2(b)) was significant, $F(1, 38) = 4.85$, $p = .034$, $\eta_p^2 = .11$, and congruent with assumptions about binding effects: Repeating a location was faster when the colour also repeated (486 ms) compared to when it changed (496 ms); this partial repetition *cost* was significant, $t(38) = 3.19$, $p = .003$, $d = 0.51$. Location changes were not significantly affected by repeating (622 ms) or changing (623 ms) the colour, $t(38) = 0.41$, $p = .682$, $d = 0.07$.

The interactions showed a pattern that was congruent with a binding effect between localization response and colour for the translational response condition, but not for the direct response condition. For sake of completeness and comparability with previous studies, we analyzed the overall binding effects (see, e.g., Frings, 2011; Schöpper, Singh, & Frings, 2020; Singh et al., 2016). We calculated a differential value of (LRCC-LRCR)-(LCCC-LCCR) for each response condition. This differential value resembles the interaction of location relation and colour relation of each condition and sums up the benefit of full over partial repetition for localization response repetitions and the benefit of full over partial change for localization response changes. A (significant) positive value is interpreted as a binding pattern, a value not significant from 0 indicates no effect, and a (significant) negative value is interpreted as a pattern resulting from other processes than binding (i.e., a pattern incongruent with binding assumptions). Each value was submitted to a one-sample t-test (two-sided). The value for the direct response was −10 ms and significantly smaller from zero, $t(38) = 2.36$, $p = .024$, d

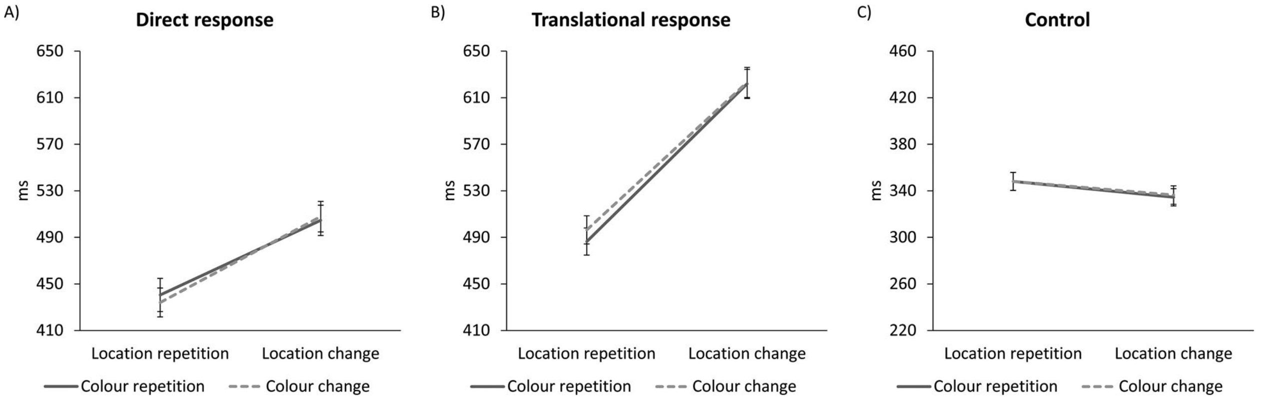

Figure 2. Line graphs depicting the interactions of location relation and colour relation, separate for the (a) direct and (b) translational response conditions of Experiment 1, as well as (c) the control condition of Experiment 2. Error bars represent the standard errors of each mean.

= 0.38. It resulted mostly from the (non-significant) 7 ms benefit for colour change when location repeated (see above). The value for the translational response was 9 ms, significantly larger than zero, *t* (38) = 2.20, *p* = .034, *d* = 0.35, and thus showing a binding effect. This effect was driven by the 10 ms benefit for colour repetition when location repeated (see above). As indicated by the three-way interaction above, the two calculated effects (see Figure 3(a)) were different from each other when submitted to a paired sample t-test, *t*(38) = 3.05, *p* = .004, *d* = 0.49.

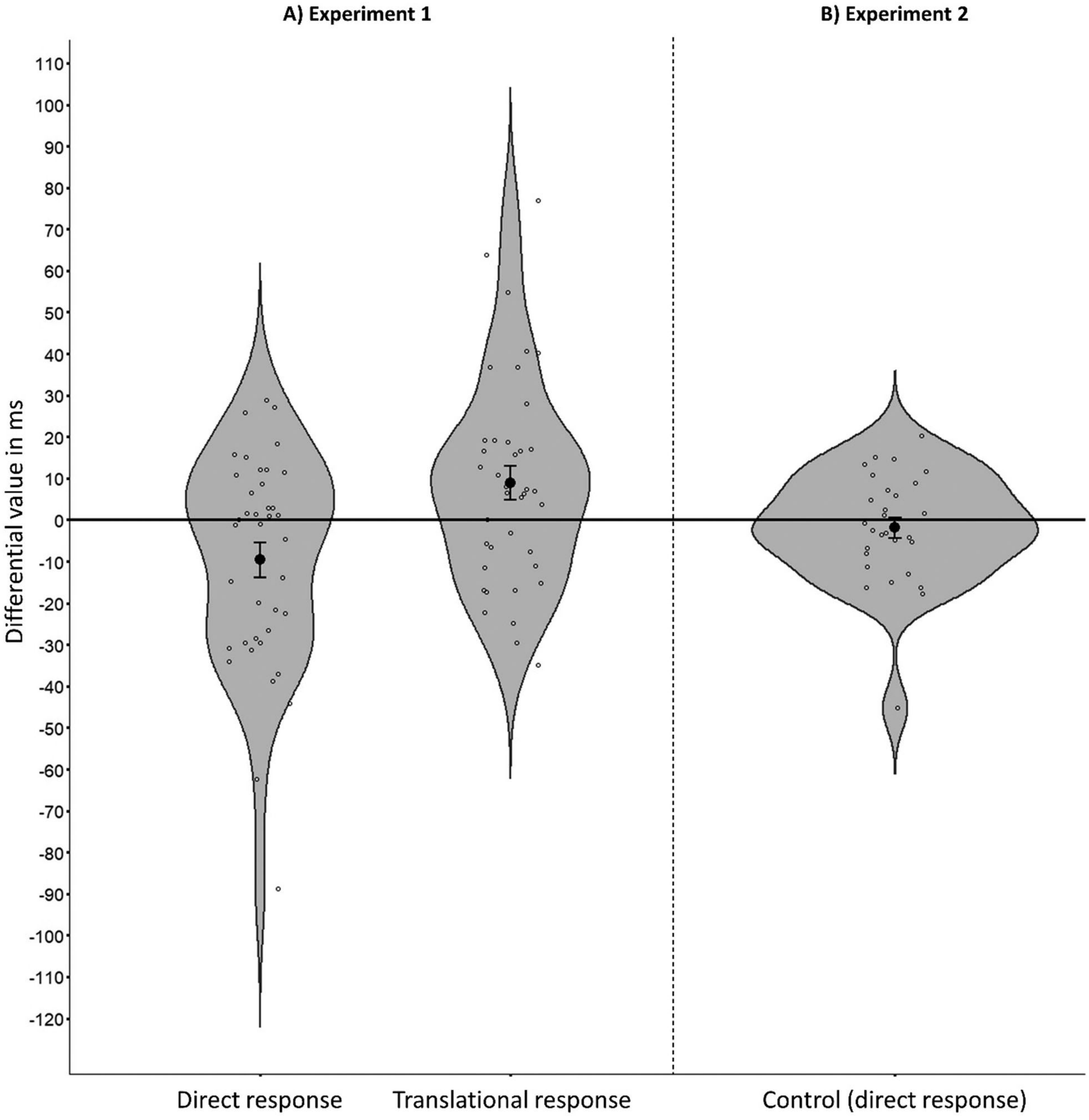

Figure 3. Violin plots of calculated interactions of location relation and colour relation, separate for (a) direct and translational response conditions of Experiment 1, and (b) the control condition of Experiment 2. Every black unfilled dot represents a calculated value for a participant in the respective response condition. Black filled dots are means, and error bars depict the standard error of each mean. Note that in Experiment 1, participants performed both response conditions, but that a different sample participated in Experiment 2. (a) The translational response shows a binding effect of 9 ms. The direct response shows no binding but an effect driven by a colour change benefit in location repetitions due to IOR-like inhibitory processes (Hu et al., 2011). (b) The control experiment shows no binding effect.

Reaction time distribution analyses

The translational responses were on average 85 ms slower than the direct responses. This fits well with the idea that spatially compatible responses are usually fast (e.g., Fitts & Deininger, 1954; Fitts & Seeger, 1953; Kornblum & Lee, 1995; Schaffer, 1965), but is also consistent with the view that translation involves a serial, post-selection, processing stage, which takes time to complete. In a different view (see Schöpper, Hilchey, et al., 2020), one might argue that retrieval and response generation race in parallel towards action and that the direct localization response is executed so fast that retrieval processes have no chance to alter it ("horserace account", Frings & Moeller, 2012; Neill, 1997). If so, a binding pattern in direct responses would manifest in late reaction times. To test for this, we calculated cumulative reaction time distribution functions (e.g., Taylor & Ivanoff, 2005; see also Schöpper et al., 2022; Schöpper & Frings, 2022).

After applying the cut-off criteria mentioned above, we took the 10th, 25th, 50th, 75th, and 90th percentile of each condition of each participant, separate for direct and translated responses (see Table A1 in Appendix). From that, we calculated the differential value of (LRCC-LRCR)-(LCCC-LCCR), that is, the binding effect, separate for each percentile for each response condition. We then submitted the calculated binding effects of direct and translated responses to separate ANOVAs (with Greenhouse-Geisser correction due to violations of sphericity) with percentile (10th vs. 25th vs. 50th vs. 75th vs. 90th) as the only factor. For direct responses, the main effect of percentile was significant, $F(1.397, 53.097) = 5.72$, $p = .012$, $\eta_p^2 = .13$, in that the calculated differential value became increasingly negative with increasing percentile (10th: 2 ms; 25th: 6 ms; 50th: −7 ms; 75th: −22 ms; 90th: −34 ms; see Figure 4). For translated responses, the main effect of percentile was not significant, $F(1.888, 71.743) = 0.31$, $p = .725$, $\eta_p^2 = .01$, in that the calculated differential value remained stable across percentiles (10th: 6 ms; 25th: 8 ms; 50th: 14 ms; 75th: 13 ms; 90th: 9 ms; see Figure 4).

Discussion

In Experiment 1, participants performed the same localization task in two different response conditions. When participants had to translate their response prior to execution, and thus had to process the S-R mapping after stimulus selection (similar to a response selection stage in visual search; e.g., Pashler, 1991; Zehetleitner et al., 2012), colour was bound to the localization response and caused retrieval upon repetition. Intriguingly, a binding effect that is normally not observed in location tasks was found. As expected, no binding effect, but even a pattern completely contrary to what action control theories would predict, was observed when participants directly tapped onto the appearing target (i.e., without the need to process anything after localization).

The binding effect in the translational response condition was purely driven by a colour repetition benefit at localization response repetitions – in other words we only observed partial repetition costs when the response repeated. Usually, one could also expect partial repetition costs for response changes, that is, whenever an event file's components partially repeat (e.g., Hommel, 2004; Schöpper, Hilchey, et al., 2020). Because partial repetition costs only manifested in localization response repetitions, the overall binding effect was smaller in size compared to what has been observed in other studies (e.g., Singh et al., 2016; Schöpper, Singh, & Frings, 2020). In turn, one might argue that the results are better explained via other effects, like stimulus-response repetition heuristics: If all information repeats, responses are faster, compared to a response repetition with partial repetition of information (e.g., Pashler & Baylis, 1991), with no specific predictions for response changes. However, we think this might relate to our mapping of four responses on two fingers: Response repetitions were likely the easiest or least laborious responses because the corresponding thumb was already at the correct location after the prior response. Location changes – and with that response changes – might have been "contaminated" by motor selection biases towards response repetitions. This interpretation of a bias for location repetitions due to our experimental design is also supported by a 69 ms benefit for location repetitions in the direct response condition. At first glance, this location repetition benefit is in stark contrast with a location repetition cost, that is, IOR, which would be expected in a localization task in which the target resembles the response (e.g., Huffman et al.,

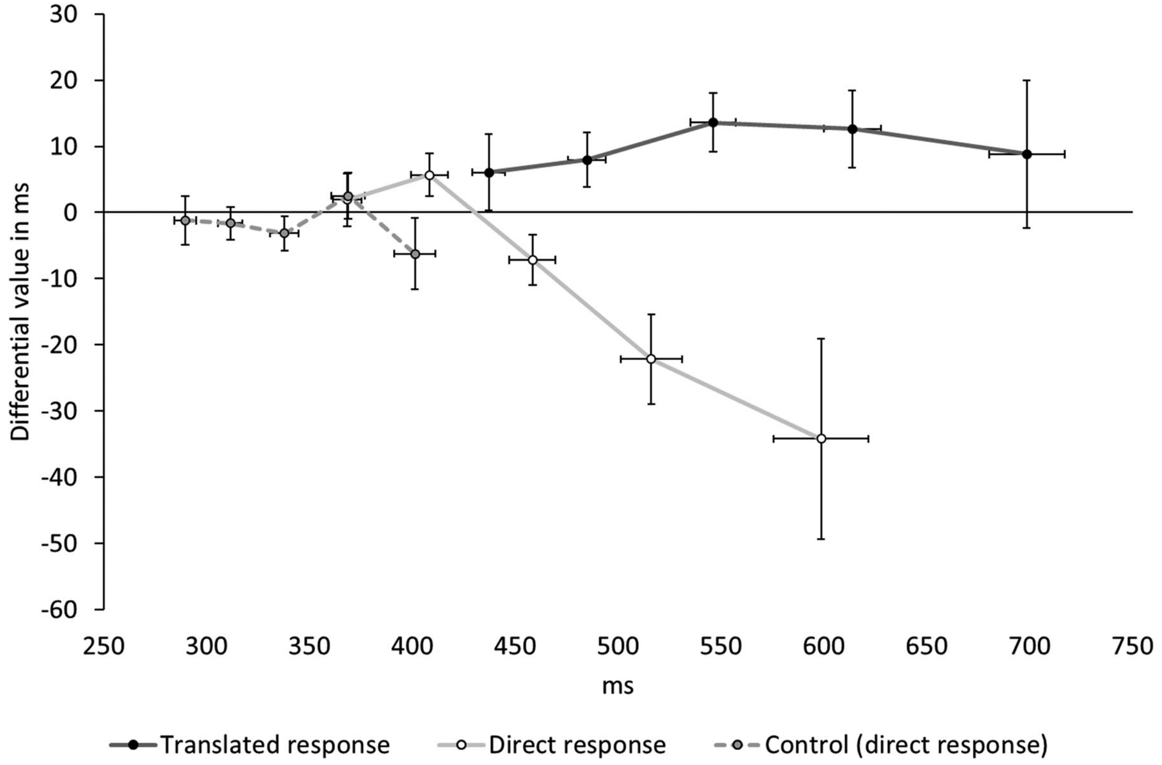

Figure 4. The calculated interaction of location relation and colour relation on the y-axis and reaction times on the x-axis as a function of percentile (cf. delta plots; see De Jong et al., 1994; Ridderinkhof, 2002) and response conditions of Experiment 1 (translated and direct response) and Experiment 2 (control: direct response). The black (translated response), white (direct response), and grey (control: direct response) dots represent the 10th, 25th, 50th, 75th, and 90th percentile for each function. See the main text for explanations. Error bars represent the standard error of each mean of each averaged percentile for the differential value (y-axis) and overall reaction times (x-axis).

2018); however, other studies investigating IOR involving more than one response option for a hand movement had participants move their hand to a neutral position in-between responses (e.g., joystick-studies; Avery et al., 2015; Cowper-Smith & Westwood, 2013). Although this would have avoided motor contamination in the current study as well, this would also come with the cost of longer intervals between responses. We refrained from introducing a neutral position between responses, because more time between prime and probe weakens binding effects (e.g., Frings, 2011; Hommel & Frings, 2020; Schöpper et al., 2022). In conclusion, mapping *one* finger on *two* responses, each of which mapped to *one* location (i.e., a 1:2:1 mapping), in both of our localization tasks, is more complex compared to mapping *one* finger on *one* response for *one* (i.e., a 1:1:1 mapping; e.g., Tanaka & Shimojo, 2000) or *multiple* (e.g., a 1:1:2 mapping in Hilchey, Pratt, & Lamy, 2019) target locations. Accordingly, we suggest interpreting the absence of partial repetition costs in location/response changes of Experiment 1 with some caution.

Reaction time distribution analyses revealed that no binding pattern emerged in late direct responses. In contrast, the "negative binding effect" in the direct response condition, which was also observed in the mean reaction time analysis, was increasingly pronounced with increasing percentile (see General Discussion). The binding effects calculated for the translated response condition did not significantly differ between percentiles.

Experiment 2 (IOR control)

As expected, the direct response condition in Experiment 1, in which participants had no need to process any stimulus feature after localization, did not show a binding pattern. However, neither did it show a benefit for location changes, likely because of a (motor) bias for response repetitions. There was a mild, non-significant colour change benefit when location repeated. On the one hand, this fits with other experimental paradigms in which so-called *negative repetition effects* emerge, that can occur independent of event file retrieval (e.g., Cochrane & Milliken, 2020; cf. Spadaro et al., 2012). On the other hand, such feature-change benefits for non-spatial features – in the literature debated as resembling non-spatial IOR (e.g., Hu et al., 2011, 2013; Law et al., 1995) or repetition blindness (Fox & de Fockert, 2001; Taylor & Klein, 1998) – can arise in complex detection tasks specifically at location repetitions (Hu et al., 2011, 2013). For example, Lupiáñez (2010) argues that (in cue-target designs, in which one responds only to the second of two stimuli) a whole object (file) is generated at a location and causes IOR if the location repeats, because the cognitive system assumes the object to resemble the previous one (i.e., "detection-cost theory"). Crucially, if non-spatial information is part of the object file, non-spatial feature repetition slows down responding, because it is thought to be "absorbed" by the previous object file – whereas a feature change is beneficial as the cognitive system assumes the detection of something new (for a discussion, see Hu et al., 2011).

To test that direct localization responses are affected by "typical" IOR,[7] we conducted Experiment 2. In this simplified version of the direct response condition of Experiment 1, participant localized coloured dots appearing at only two locations. By this, *one* finger was mapped to *one* response for *one* location (i.e., a 1:1:1 mapping as in, e.g., Tanaka & Shimojo, 2000), which should yield a typical IOR-pattern as observed in previous localization tasks (e.g., Huffman et al., 2018).

Methods

Participants

Thirty students of the University of Trier participated for either course credit or a monetary reward (4 €), and gave written informed consent. Experiment 2 complied with ethical standards for conducting behavioural experiments at the University of Trier. One participant did not directly tap on targets and was excluded from analysis. This resulted in a sample size of 29 participants (22 women, 7 men, $M_{age} = 23.24$, $SD_{age} = 4.05$, age range: 18–37 years). Experiment 2 was done to replicate the standard IOR-effect which is reliably observed with much smaller sample sizes (e.g., Tanaka & Shimojo, 1996). Accordingly, a sample size of 29 participants yields a power of $1-\beta = .96$ for detecting a medium to large effect (e.g., Huffman et al., 2018; Schöpper & Frings, submitted) of $d = 0.65$ (error probability: $\alpha = 0.05$, one-tailed).

Apparatus and materials

Experiment 2 used the same apparatus as Experiment 1. The visual display of Experiment 2 was a modification of that used in Experiment 1. The white fixation cross (0.89° x 0.76° of visual angle) was presented in the upper half of the screen. Red or blue target dots (1.17° x 1.06° of visual angle) could appear at the left or right side in the lower half of the screen. There were no grey circle placeholders. The two possible target locations were approximately 15.69° of visual angle apart and the diagonal distance between the fixation cross and target locations was approximately 9.4° of visual angle (all centre-to-centre). Participants were instructed to directly tap on the appearing target; a touch response in the lower field of the screen, spanning up to 200 pixels (approx. 2.16° of visual angle) above the centre of the target dot, was counted as a response by the programme. All responses to the left half of the screen were counted as a left response and all responses to the right half of the screen were counted as a right response.

Design

The experiment used a 2 (location relation: repetition vs. change) x 2 (colour relation: repetition vs. change) design. All variables were varied within-subjects.

Procedure

The trial sequence (see Figure 1(b), lower row) was identical to Experiment 1, except for the following. In the prime or probe display, a red or blue target dot appeared in the lower left or lower right of the touch monitor. Participants were instructed to tap their left or right thumb directly on targets appearing on the left or right side, respectively. The experiment consisted of sixteen practice trials followed by 240 experimental trials, the latter comprising 60 trials for each prime-probe condition. Colour and location were pseudo-randomly balanced across all conditions and participants. After the 80th and 160th trials the participant could take a self-paced break.

Results

Reaction times

The same inclusion and cut-off criteria as reported for Experiment 1 were used,[8] resulting in 7.16% of probe trials being discarded.

A 2 (location relation: repeated vs. changed) x 2 (colour relation: repeated vs. changed) repeated measures ANOVA revealed a main effect of location relation, $F(1, 28) = 7.23$, $p = .012$, $\eta_p^2 = .21$, indicating IOR: Participants responded faster when location changed (335 ms) compared to when it repeated (348 ms). The main effect of colour relation was not significant, $F(1, 28) = 0.55$, $p = .463$, $\eta_p^2 = .02$. The interaction of location relation and colour relation (see Figure 2(c)) was not significant, $F(1, 28) = 0.60$, $p = .446$, $\eta_p^2 = .02$. Repeating (348 ms) or changing (348 ms) the colour did not affect localization response repetitions, $t(28) = 0.01$, $p = .993$, $d < 0.01$. Neither did repeating (334 ms) or changing (336 ms) the colour significantly affect localization response changes, $t(28) = -1.23$, $p = .230$, $d = -0.23$. For the sake of completeness, we calculated the differential value of the interaction as in Experiment 1. The differential value (see Figure 3(b)) for this interaction was −2 ms and as expected not significant, $t(28) = -0{,}77$, $p = .446$, $d = -0.14$.

Reaction time distribution analyses

After applying the cut-off criteria mentioned above, we took the 10th, 25th, 50th, 75th, and 90th percentile of each condition (see Table A2 in Appendix) of each participant and calculated the differential value of the interaction as reported for Experiment 1. The ANOVA (with Greenhouse-Geisser correction) revealed no main effect of percentile, $F(1.927, 53.954) = 1.26$, $p = .291$, $\eta_p^2 = .04$ (10th: −1 ms; 25th: −2 ms; 50th: −3 ms; 75th: 3 ms; 90th: −6 ms; see Figure 4).

Discussion

In Experiment 2, participants localized coloured target dots appearing at two locations by directly tapping on them. The results replicated the classic IOR-effect typically found in localization tasks (Huffman et al., 2018) without any evidence of a binding pattern. Thus, we conclude that the pattern for direct responses in Experiment 1 was likely due to IOR-like processes.

General discussion

Stimulus-response binding effects typically occur when participants have to discriminate non-spatial features but not when their action only involves the localization of targets (see Huffman et al., 2018). We asked whether this distinction relies on the need of a translational S-R mapping in the former situation that is not needed in the latter. In Experiment 1, participants either tapped on a coloured dot (direct response condition), or tapped in the diagonal opposite corner (translational response condition). The translational response yielded a binding effect of localization response and colour, whereas the direct response did not.

Our experiment referred to a proposed serial processing architecture in visual search (e.g., Pashler, 1998; Töllner et al., 2012; Wolfe, 1994; Zehetleitner et al., 2012) by instructing participants in the translational case to process a target after identification, that is, post selection: To execute the (spatial) response, participants had to perform a cognitive operation based on the location of the target (a spatial feature, see also Hilchey et al., 2020) – the non-spatial feature (colour) was completely task-irrelevant. Thus, binding effects are not necessarily absent in all kinds of simple localization performance. When the response requires minimal spatial feature processing through a direct spatial mapping (i.e., highly compatible and overlearned; c.f., Kiesel et al., 2010; Kornblum et al., 1990), no binding effects are observed (e.g., Huffman et al., 2018). However, the translational case, which required spatial information as well but demanded expanded processing, showed binding and retrieval of responses and non-spatial feature (colour). We thus conclude that a more general post-selection stage that processes spatial and non-spatial features leads to partial repetition costs (e.g., Hilchey, Rajsic, et al., 2018; Schöpper, Hilchey, et al., 2020; Zehetleitner et al., 2012).

This is not the first study that compared localization performance with spatially congruent and incongruent responses. Several researchers investigated if such response mappings have an effect on IOR in cue-target designs in which a response is given only to the second of two targets. For example, Wascher et al. (2015) showed that IOR in a cue-target design was not modulated by compatible or incompatible (e.g., left key for right target) manual key presses (see also Eng et al., 2017). Given the current results, this could be traced back to not giving a response to the cue – in contrast, our design involved a response to the first stimulus, that is, the prime target, spurring on the integration of information into an event file which could be subsequently retrieved (e.g., Frings, Hommel, et al., 2020). However, Khatoon et al. (2002) found that indirect eye and manual pointing movements (e.g., Experiment 3: Executing a saccade or pointing response, respectively, to the position opposite to the target position), leads to IOR being observed at later stimulus-onset-asynchronies (SOAs) between cue and target compared to an earlier onset for direct eye and manual pointing movements. Among others, the authors discuss this in the context of indirect responses being potentially influenced by prolonged facilitation of the position of the cue (Khatoon et al., 2002, pp. 2702–2703). This would be congruent with our view that the translated-response condition in the current study benefited from information from the previous trial, that is, retrieval of the prime event file. Lastly, Eng et al. (2017) found that in saccadic responses, spatially incompatible eye movements (e.g., a saccade to the left as a response for a target appearing to the right) diminishes or even reverses IOR into a benefit for location repetitions (see also Khatoon et al., 2002). Given the current results, this could be attributed to a spatially incompatible response spurring on retrieval of previous stimulus information due to post-selective target processing. This then masks IOR (cf. Hilchey, Rajsic, et al., 2018; Schöpper et al., 2022). However, as in Wascher et al. (2015), Eng et al. (2017) did not observe this effect for manual keypresses. Why this effector difference in cue-target designs arises is unclear from an action control perspective (as both eye and manual movements are affected by integration and retrieval, Schöpper et al., 2022), but might be attributed to saccadic IOR being influenced by specific oculomotor processes (e.g., Klein & Hilchey, 2011; Wang et al., 2012; for a discussion, see Schöpper et al., 2022).

In previous studies, location and colour usually did not bind together (Hilchey et al., 2017; Hommel, 1998, 2007; Huffman et al., 2018, 2020; but see Hilchey, Pratt, & Lamy, 2019). Hommel (2007) argues that location becomes bound only when it is task relevant (e.g., by task demands or a spatially defined response set). Hilchey et al. (2020) recently reported partial repetition costs for location in detection performance when participants had to detect or localize coloured dots depending on if they appeared on the vertical or horizontal axis. They attributed this to the need for spatial information processing prior to responding. This is consistent with our proposal that binding occurs when target features (e.g., location or colour) have to be processed after selection to produce a translational response.

There is a longstanding debate in attention research, whether location is processed in the same way as other features like colour or shape (e.g., Bundesen, 1991), or whether it is special (e.g., Sagi & Julesz, 1985; Van der Heijden, 1993). Furthermore, it is debated if non-spatial feature processing is contingent on location processing (Tsal & Lavie, 1988). Fituousi (2016) showed that the contingency of colour processing following location processing can be dependent on the ease of discriminability of the location feature (relative to the discriminability of a non-spatial feature): Following Fituousi (2016), making the location feature harder to discriminate spurs on processing as for non-spatial features. In contrast, in typical localization tasks (see Introduction) the location feature is usually easily discriminable. This was also the case in the current study: One localizable (coloured) dot on screen demanded a response. Future research needs to determine whether our proposed sequential stages – target identification followed by post-selective processing (which then leads to response execution) – can be further modulated. Starting points could be, for example, that binding between non-spatial features occurs irrespective of location repetitions or changes (Fitousi, 2018; Hommel, 1998), or that different types of feature-binding emerge depending on whether location varies or is kept constant (Singh & Frings, 2020).

Following the horserace-account (Frings & Moeller, 2012; Neill, 1997), it could be argued that detection and localization responses are executed so fast that retrieval has no chance to affect them (Schöpper, Hilchey, et al., 2020; see also Chao & Hsiao, 2021). However, first, reliable binding effects in colour discrimination tasks have been found in the time-range of the direct responses[9] of Experiment 1 (e.g., Schöpper, Hilchey, et al., 2020) as well as in even faster auditory detection responses (Mondor & Leboe, 2008; Schöpper & Frings, 2022). Second, we looked at the differential value of the calculated interaction – in the action control literature referred to as the binding effect (e.g., Schöpper, Singh, & Frings, 2020; Singh et al., 2016) – depending on reaction time percentiles (see also Schöpper & Frings, 2022, submitted). Although feature repetitions and changes affected especially late responses in the direct response condition, this effect was diametral to what action control theories would predict: A partial repetition *benefit* (in reaction time means driven by a feature change benefit at location repetitions; see also Hu et al., 2011, 2013) spurring on a negative differential value that was increasingly pronounced with increasing percentile. This suggests some type of retrieval operation affecting especially late responses in IOR effects and alike (see also Chao et al., 2020). Hu et al. (2011) argued that non-spatial IOR specifically emerges in complex displays. In a follow-up study, Hu et al. (2013) showed that this type of non-spatial feature change benefit declines with decreasing display complexity – interestingly, response times also became faster with decreasing display complexity. Given Chao et al. (2020) and the current results it could be argued that it is not display complexity per-se, but rather increasing response times that come with increasingly complex displays spurring on non-spatial IOR effects and alike. However, it still remains unclear why retrieval affects localization (current study) and detection (Chao et al., 2020) performance differently than it affects tasks in which partial repetition *costs* are found. Additionally, it would be interesting to see if both effects similarly decline with increasing intervals between prime and probe displays, as event files quickly decay over time (Frings, 2011; Hommel & Frings, 2020; Schöpper et al., 2022; see however, stable effects for longer SOAs in Hu et al., 2011). To summarize, time is not necessarily the crucial limitation for binding patterns in classical localization experiments: More general, the context of an action (Hommel et al., 2000; Memelink & Hommel, 2007), accompanying distractors (Campana & Casco, 2009; Hilchey, Pratt, & Lamy, 2019), response rules and response mappings (e.g., Hommel & Schneider, 2002; Hilchey, Leber, & Pratt, 2018; Hilchey, Pratt, & Lamy, 2019), and, with that, specific task demands (e.g., Hilchey et al., 2020) seem to play an important role. Lastly, the question emerges, if the translated localization response as used in our study is still a localization response or already a discrimination response based on location, thus, sharing more similarities with colour or shape discrimination procedures than with localization procedures. Future studies could investigate, if the transition from "pure" localization to location discrimination to non-spatial feature discrimination is continuous or organized in discrete steps.

Lastly, we argue that the translation of spatial feature space into non-direct response space is what causes the emergence of binding effects in localization performance. However, both response conditions not only differ in their S-R mapping but also, for example, in the time needed to execute a response and the amount of colour visible due to the (non-)obstruction of the stimulus colour by the thumb when executing the response. The latter might be tackled by using response fields or keys spatially congruent but not directly overlapping with the appearing targets, like keys on a keyboard spatially congruent with the hemisphere the targets appear in on a screen (e.g., Huffman et al., 2018). Additionally, one might muse that in the translation response condition, the cognitive system has to inhibit a spatially congruent localization response, as the latter might be initiated initially (cf. Kiesel et al., 2010; Kornblum et al., 1990). However, note that all these come as a consequence of applying the translational response mapping to the task. Future studies could investigate which processes and effects (additionally) cause the occurrence of binding effects in such a translation mechanism.

Taken together, our results show that stimulus-response bindings occur in localization tasks if participants have to translate the location feature of the stimulus into a spatially non-compatible response – which was typically not the case in previous studies using localization tasks.

Notes

1. Although the paradigm is different, the sequential design involving the systematic variation of repeating or non-repeating spatial and non-spatial features of a target stimulus is similar to the prime-probe sequences used in action control research (see Huffman et al., 2018; Schöpper, Hilchey, et al., 2020).
2. One study (Pratt & Castel, 2001) showed partial repetition costs in a localization task; this study was replicated by Huffman et al. (2018) with more power, with the results being in line with their overall interpretation.
3. Wolfe (1994, p. 232) discusses that detection responses can be based on the pre-attentive stage, potentially resulting from parallel search, but also mentions that such detection performance can be influenced by previous information (e.g., Bundesen, 1991; see also Found & Müller, 1996). Moreover, regarding location, detection performance in visual search tasks ("pop-out tasks"; e.g., Müller et al., 1995) produces a different outcome than detection performance in attentional orienting tasks (see, e.g., Hilchey, Pratt, & Lamy, 2019), namely, a benefit for a target repeating its location (e.g., Krummenacher et al., 2009) compared to changing its location (Huffman et al., 2018). We refer to such models, because they offer a serial processing architecture that can be transferred to the experiments at hand; however, we do not equate the (processes that lead to the) effects which we are investigating with effects that result from complex visual search displays.
4. Of note, in this design, location and response are fully confounded (c.f., localization tasks reviewed by Huffman et al., 2018; see also Hilchey, Antinucci, et al., 2019), so that location repetitions and changes equal response repetitions and changes. In turn, any observed binding pattern could be due to binding between location and colour, response and colour, or both. Of importance, binding between response and colour typically does not occur in simple localization performance (e.g., Schöpper & Frings, submitted). To avoid confusion, we will refer to the binding effect as being caused by binding between localization response and colour.
5. Error rates were close to ceiling; we therefore did not analyze the error rates in a manner comparable to reaction times. Overall error rates (i.e., the percentage of all incorrect probe responses given after all correct prime responses irrespective of condition) were higher in the translational response condition (1,00%) compared to the direct response condition (0,39%), $t(38) = 4.38$, $p < .001$, $d = 0.70$ (paired sample t-test, two-sided).
6. Location changes could be executed with the same (vertical changes) or the other thumb (diagonal and horizontal changes). Although event file retrieval can survive effector switches (Moeller et al., 2015), one might muse that using the same versus a different thumb could have had an impact on responding. We collapsed the horizontal and diagonal changes and conducted a 2 (response change type: same thumb vs. different thumb) x 2 (color relation: repeated vs. changed) ANOVA on probe reaction times of location changes separate for the direct and translated mapping. For the direct mapping, the main effect of change type was significant, $F(1, 38) = 106.73$, $p < .001$, $\eta_p^2 = .74$: Response changes were faster when executed with a different (492 ms) compared to the same thumb (535 ms). However, neither the main effect of colour relation, $F(1, 38) = 2.65$, $p = .112$, $\eta_p^2 = .07$, nor its modulation by response change type, $F(1, 38) = 0.86$, $p = .361$, $\eta_p^2 = .02$, were significant. For the translated mapping, a main effect of response change type emerged, $F(1, 38) = 103.67$, $p < .001$, $\eta_p^2 = .73$, also depicting a response change benefit when executed with a different (612 ms) compared to the same thumb (645 ms). Neither the main effect of colour relation, $F(1, 38) < 0.01$, $p = .965$, $\eta_p^2 = .00$, nor its modulation by response change type, $F(1, 38) = 2.07$, $p = .158$, $\eta_p^2 = .05$, were significant. To conclude, using the same thumb hindered overall responding, however, this did not have an impact on the effects of interest.
7. One could also expect IOR-processes in the translational response condition, as binding and IOR can work in parallel (Hommel, 2004), with binding effects potentially masking IOR (Hilchey, Rajsic, et al., 2018; Schöpper et al., 2022). However, we were interested in whether a translational response condition for localization performance yields a binding pattern and not whether such a response is (additively) affected by IOR-processes.
8. As with Experiment 1, error rates were close to ceiling (e.g., nine of 29 participants did not make errors at all after a correct prime). In total (i.e., error rate collapsed across conditions), participants gave 0.87% incorrect probe responses after a correct prime response.
9. Note that the color discrimination tasks in Schöpper, Hilchey, et al. (2020; Experiment 1: 412 ms, Experiment 2: 395 ms) were in fact even faster than the direct response condition in Experiment 1 of the current study (472 ms). However, we interpret this strong reaction time difference with some caution, as both studies used different response mappings and materials: Schöpper, Hilchey, et al. (2020) used two fingers mapped on two keys on a keyboard compared to our current use of two fingers mapped on four “keys” on a touch-monitor.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data of both experiments is available at http://dx.doi.org/10.23668/psycharchives.8271. Code for analysis of both experiments is available at http://dx.doi.org/10.23668/psycharchives.8270.

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Appendix

Table A1. Averaged percentiles in ms of probe responses separate for conditions and response condition in Experiment 1.

		Percentiles				
Condition	Response	10th	25th	50th	75th	90th
LRCR	Direct	341	371	419	488	576
	Translated	373	412	466	538	643
LRCC	Direct	342	375	418	470	557
	Translated	382	424	482	548	642
LCCR	Direct	396	444	495	552	623
	Translated	495	549	617	686	760
LCCC	Direct	395	442	502	556	639
	Translated	498	554	620	684	750

Table A2. Averaged percentiles in ms of probe responses separate for conditions in Experiment 2.

		Percentiles				
Condition	Response	10th	25th	50th	75th	90th
LRCR	Direct	294	317	344	375	410
LRCC	Direct	295	317	344	377	408
LCCR	Direct	284	306	331	362	391
LCCC	Direct	286	307	334	362	395