Video Article

Irrelevant Stimuli and Action Control: Analyzing the Influence of Ignored Stimuli via the Distractor-Response Binding Paradigm

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Abstract

Selection tasks in which simple stimuli (*e.g.* letters) are presented and a target stimulus has to be selected against one or more distractor stimuli are frequently used in the research on human action control. One important question in these settings is how distractor stimuli, competing with the target stimulus for a response, influence actions. The distractor-response binding paradigm can be used to investigate this influence. It is particular useful to separately analyze response retrieval and distractor inhibition effects. Computer-based experiments are used to collect the data (reaction times and error rates). In a number of sequentially presented pairs of stimulus arrays (prime-probe design), participants respond to targets while ignoring distractor stimuli. Importantly, the factors response relation in the arrays of each pair (repetition vs. change) and distractor relation (repetition vs. change) are varied orthogonally. The repetition of the same distractor then has a different effect depending on response relation (repetition vs. change) between arrays. This result pattern can be explained by response retrieval due to distractor repetition. In addition, distractor inhibition effects are indicated by a general advantage due to distractor repetition. The described paradigm has proven useful to determine relevant parameters for response retrieval effects on human action.

Video Link

The video component of this article can be found at http://www.jove.com/video/51571/

Introduction

In order to maneuver our way through the endless stream of information to perceive, offering nearly infinite possibilities to behave in the world around us, our brain has to rely on a limited number of simple and efficient processes and mechanisms. One important mechanism is selective attention, that is, the ability to discriminate between relevant and irrelevant information. Once a stimulus is identified as being irrelevant, inhibition dampens the activation of the distractor representation[1] or blocks its access to the response system to reduce interference[2]. Distractor inhibition is one of the core concepts of cognitive control[3].

Another important characteristic of human behavior is that not each and every aspect of our actions can be intentionally controlled. Other mechanisms are necessary that translate intentional actions, resulting from a controlled and resource-demanding processing of information, into efficient behavioral routines. The retrieval of previous behavioral episodes might play an important role for such an automatization of behavior. According to recent instance based models, a specific stimulus can become integrated with a response that is executed in close temporal proximity to the occurrence of the stimulus. The compound of stimulus and response is then stored as an "instance"[4] or "event file"[5,6] in episodic memory. Re-encountering the stimulus of such an event file leads to a retrieval of the entire episode from memory, including the associated response[4-8]. This retrieval of previous actions operates fast and automatically, exerting efficient bottom up control of behavior by establishing stimulus driven behavioral routines. Recent evidence suggests that this mechanism can also be triggered by distractors, that is, distractor-based retrieval of previous episodes and responses has an impact on human action control as well[9].

The paradigm of distractor-response binding was developed to specifically investigate the influence distractors that compete with a target stimulus for the response, have on action control. In particular, this technique allows to disentangle the two mechanisms that have been discussed in the context of distractor processing, namely distractor inhibition and distractor based retrieval of responses.

The distractor-response binding paradigm originates from research using the negative priming paradigm (for a review see Fox[10]). In a negative priming paradigm, prime distractors that are repeated as targets on the probe lead to slower response times or more errors as compared to probe responses to targets that did not appear on the prime (*i.e.* the negative priming effect). One difficulty with this paradigm has been that at least two different mechanisms can account for the negative priming effect. On the one hand it has been proposed that a prime distractor is *inhibited* at prime presentation, in order to enable responding to the prime target. Residual inhibition of the former distractor stimulus results in a disadvantage if a response to this inhibited stimulus is required on the probe[1,11]. On the other hand, negative priming can be the result of

retrieval mechanisms[12,13]. For example, Neill assumed that the prime distractor is encoded together with a do-not-respond tag at the prime, which is then retrieved and in turn conflicts with responding to this stimulus if it is repeated as the probe target[14].

More recently, the Stimulus Response Retrieval theory (SRR[15]) assumed that distractors are integrated with and can trigger the retrieval of responses. This opens new possibilities to investigate retrieval effects due to distractor repetition separately. Based on the Theory of Event Coding[16], SRR proposes that target, distractor, and response features are encoded in one temporary episodic memory trace or *event file*. On the next encounter, any of these stimuli (*i.e.* also the distractor stimulus) can trigger the retrieval of the entire event file including the target response. These retrieval effects due to distractor repetition have been termed *distractor-response binding*. Distractor-response binding has been shown to influence performance in human reactions in the visual, the auditory, and the tactile modality[17-19]. It also modulates responses in location selection[20]. Various modulating factors of the effect evidence that distractor-response binding is not entirely automatic but influences behavior only under certain conditions[21-23].

The effect is evidenced in sequential selection tasks by the influence distractor repetition has on performance depending on response repetition. If the same response has to be given on the prime and probe, distractor repetition leads to better performance as compared to distractor change because the distractor retrieves a compatible response. In contrast, if a change of response is required, repeating the distractor hampers responding as the distractor retrieves an incompatible response. Thus, distractor-based retrieval is indicated by the interaction effect of response repetition × distractor repetition.

One advantage over the negative priming paradigm is that the paradigm of distractor-response binding can differentiate between effects of distractor inhibition and response retrieval[24]. While retrieval effects are evidenced by an interaction of response repetition and distractor repetition, distractor inhibition is measured as the main effect of distractor repetition. That is, an inhibition account[1,25] would predict, that inhibiting the same stimulus two times in a row should always lead to benefits because after effects from distractor inhibition on the prime should facilitate distractor inhibition on the probe. This benefit effect of repeated distractors is, however, according to the inhibition theory independent of response repetition.

Further analyzing prerequisites and modulating factors of the distractor-response binding effect is important to get a better understanding of the way ignored objects in our everyday life influence human reaction. The present article gives a detailed description of the paradigm used to analyze the distractor-based retrieval and distractor inhibition.

Protocol

The protocol follows the ethical guidelines of the American Psychological Association and the World Medical Association (revised declaration of Helsinki, 1989).

1. General Experimental Setup

1. Collect data, concerning distractor-response binding effects, in reaction time experiments via computer.

2. Preparation of the Experiment

1. Use a standard experimental software to program the experiment. Most of the previous studies used E-Prime.
2. Decide on the stimulus material. Distractor-response binding has been shown with single letters, digits, colored dots, icons, and locations.
3. Create one stimulus set from which both targets and distractors will be drawn. For example, this set can include the eight letters S, D, F, G, H, J, K, and L.
    1. Separate the stimulus set into four groups and assign one response to each group. For example, assign S and D to a button press with the left middle finger, F and G to a button press with the left index Finger, H and J to a button press with the right index finger, and K and L to a button press with the right middle finger.
    2. Decide on a stimulus arrangement. Be sure to present target and distractor stimuli in a grouped fashion. Gestalt principles help to implement grouping of stimuli. For example, present letters in a horizontal rather than a vertical line.
    3. Decide on the criterion for target selection. This can remain unchanged throughout the experiment, but it can also be indicated before each display. For example, present targets and distractors in a horizontal line, and define certain locations to contain the target (*e.g.* "DKDKD", with K as the target and D as the distractor). Use the same stimulus arrangement for all displays throughout the experiment.
4. Prepare six different kinds of trial types (*i.e.* prime probe sequences), orthogonally varying response relation (response repetition with same target vs. response repetition with different targets *vs.* response change) and distractor relation (distractor repetition vs. distractor change). In each prime and each probe arrangement, be careful to combine distractors and targets that are mapped to different responses.
    1. For trial type RRi-DR, implement response repetition between the response to the prime target and the response to the probe target by presenting the same target stimulus identity on the prime and the probe display. Implement distractor repetition by presenting the same distractor stimulus on the prime and the probe display.
    2. For trial type RRi-DC, implement response repetition by presenting the same target stimulus identity on the prime and the probe display. Implement distractor change by presenting different distractor stimuli on the prime and the probe display.
    3. For trial type RR-DR, implement response repetition by presenting a target stimulus from the same response category on the prime and the probe display. Implement distractor repetition by presenting the same distractor stimulus on the prime and the probe display.
    4. For trial type RR-DC, implement response repetition by presenting a target stimulus from the same response category on the prime and the probe display. Implement distractor change by presenting different distractor stimuli on the prime and the probe display.
    5. For trial type RC-DR, implement response change by presenting a target stimulus from different response categories on the prime and the probe display. Implement distractor repetition by presenting the same distractor stimulus on the prime and the probe display.

6. For trial type RC-DC, implement response change by presenting a target stimulus from different response categories on the prime and the probe display. Implement distractor change by presenting different distractor stimuli on the prime and the probe display.

5. Under the restrictions defined by the respective trial type, randomly assign stimuli from the stimulus set to the roles of prime target, prime distractor, probe target and probe distractor. Remember to be careful in each prime and each probe arrangement to use distractors that are mapped to a different than the target response. Do the assignments for each trial type and repeat this 30x, resulting in 180 trials.
6. Randomize the order of the 180 trials.
7. Use a random sample of 60 trials for a practice block.

3. Experimental Procedure

1. Welcome participant(s) and assign computers. Testing in groups is possible. Testing participants in individual sound proof chambers is preferable.
2. Collect additional data like age, gender and defective vision first.
3. Give written instructions that include a description of the task (always press the button assigned to the target stimulus while ignoring the distractor stimulus) and the reminder to respond as fast as possible without making errors. Instructions can be given via the computer screen.
4. Present the following displays in each trial (see **Figure 1**). The single letters should have a horizontal and vertical visual angle between 0.5° and 1°. Present target and distractor stimuli in each prime and each probe display adjacent to each other (maximizing grouping of the stimuli).
    1. Present a cue (*e.g.* an asterisk) that indicates to the participants that the next trial can be started by pressing the space bar. Breaks can be taken at this point between trials, before pressing the space bar. (Alternatively, use an intertrial interval of 1,500 msec).
    2. Present a fixation marker (*e.g.* a plus sign) at the center of the screen for 500 msec.
    3. Present the prime display at the center of the screen until the participant responds by pressing one of the response buttons.
    4. Log the prime response time (prime onset until response) and accuracy of the prime response.
    5. In case of an inaccurate response, present a warning for 1,500 msec that reminds the participant to react as fast but also as correct as possible.
    6. Present a fixation marker (*e.g.* a plus sign) at the center of the screen for 500 msec. Be careful to keep this time between prime response and probe onset shorter than 1,000 msec.
    7. Present the probe display at the center of the screen until the participant responds by pressing one of the response buttons.
    8. Log the probe response time (probe onset until response) and accuracy of the probe response.
    9. In case of an inaccurate response, present a warning for 1,500 msec that reminds the participant to react as fast as possible but without making errors.

5. Omit response repetition trials with target identity repetition (*i.e.* RRi trials) to exclude influences of target identity repetition effects.
6. For the analyses of probe response times, only consider trials with correct responses to the prime and the probe and exclude anticipatory (below 200 msec) and outlier response times (*e.g.* Tukey[26]).
7. Enter probe response times into a 2 (Response Relation: repetition vs. change) × 2 (Distractor Relation: repetition vs. change) ANOVA. The same ANOVA can be used to analyze probe error rates.

Representative Results

In a 2 (Response Relation: repetition vs. change) × 2 (Distractor Relation: repetition vs. change) ANOVA on probe response times, a significant interaction of response relation and distractor relation indicates the effect of distractor-response binding. The advantage of distractor repetition is larger in response repetition than in response change trials. That is, the difference in mean response times between RR-DC and RR-DR trials is significantly larger than the difference in mean response times between RC-DC and RC-DR trials. A significant main effect of distractor repetition indicates an additional distractor inhibition effect. If only the effect of distractor-response binding influences the pattern, distractor repetition effects are expected as depicted in **Figure 2A**. Repeated distractors lead to an *advantage* in response repetition but to a *disadvantage* in response change trials. If distractor inhibition also influences response times, a pattern as depicted in **Figure 2B** is expected. A general additional advantage of distractor repetition leads to an even larger effect of distractor repetition in response repetition trials and cancels out the disadvantage due to distractor repetition in response change trials. Note that the difference in distractor repetition effects between response repetition and response change remains the same, still evidencing distractor-response binding. **Figure 3** is an example for data collected by Frings, Rothermund and Wentura (2007). **Figure 4** summarizes the distractor-response binding effects of 33 experiments in different modalities[9,18-24,27-30]. The effects become larger with more difficult tasks and thus with longer response times. This can be understood as a consequence of the retrieval process working in parallel to the algorithm that calculates the currently required reaction. With longer lags between triggering response retrieval and execution of the response, the retrieval process is more likely to be completed before response execution[22]. Hence, the distractor-response binding effect becomes more pronounced. Note that this modulation can be represented by the same function for all modalities. It can be assumed that auditory and tactile tasks were more demanding and therefore led to generally slow response times[31]. Yet the influence of these response times on the distractor-response binding effect was the same as in visual experiments.

The same 2 (Response Relation: repetition *vs.* change) × 2 (Distractor Relation: repetition *vs.* change) ANOVA can be conducted on error rates. Depending on the response criterion, participants use, the same result pattern is sometimes found here. Yet, oftentimes, participants make very few errors and no significant effects are found in the error rates.

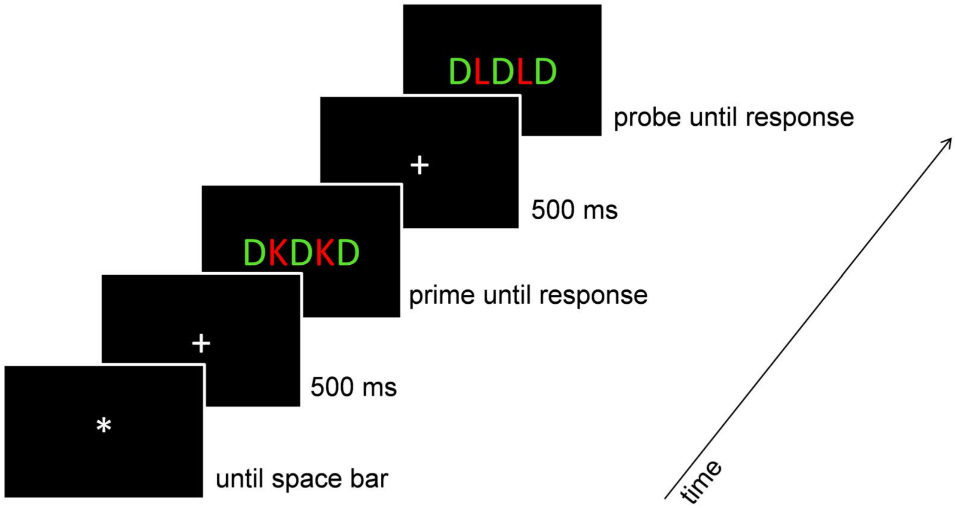

Figure 1. Sequence of events in one trial. Participants respond to the red letters and ignore the green. This is an example of a trial with response repetition (target change) and distractor repetition. Stimulus-response mapping: S, D: left middle finger; F, G: left index finger; H, J: right index finger; K, L: right middle finger. Note that stimuli are not drawn to scale.

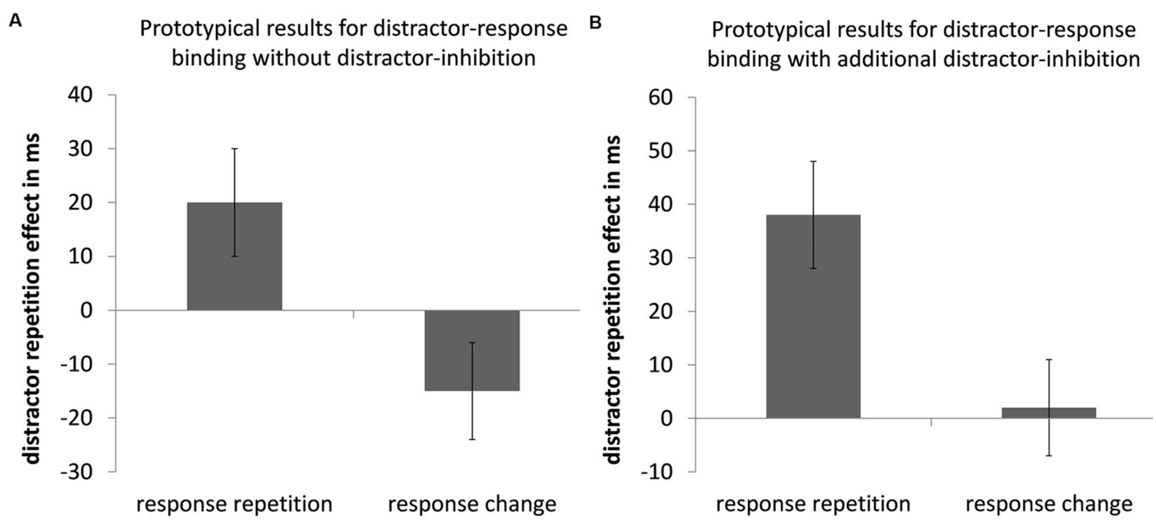

Figure 2. A) Prototypical distractor repetition effects without an additional effect of distractor inhibition. The effect of distractor-response binding is evidenced by a significant difference between distractor repetition effects in response repetition and response change trials (*i.e.*, the difference between the depicted columns). Error bars depict the standard error of the means. Distractor repetition effects are calculated as the mean response time in distractor change trials minus the mean response time in distractor repetition trials. **B)** Prototypical distractor repetition effects with an additional effect of distractor inhibition. The effect of distractor-response binding is evidenced by a significant difference between distractor repetition effects in response repetition and response change trials (*i.e.* the difference between the depicted columns). A distractor inhibition effect is evidenced if the mean of the distractor repetition effects in response repetition and response change trials is significantly larger than zero. Error bars depict the standard error of the means. Distractor repetition effects are calculated as the mean response time in distractor change trials minus the mean response time in distractor repetition trials.

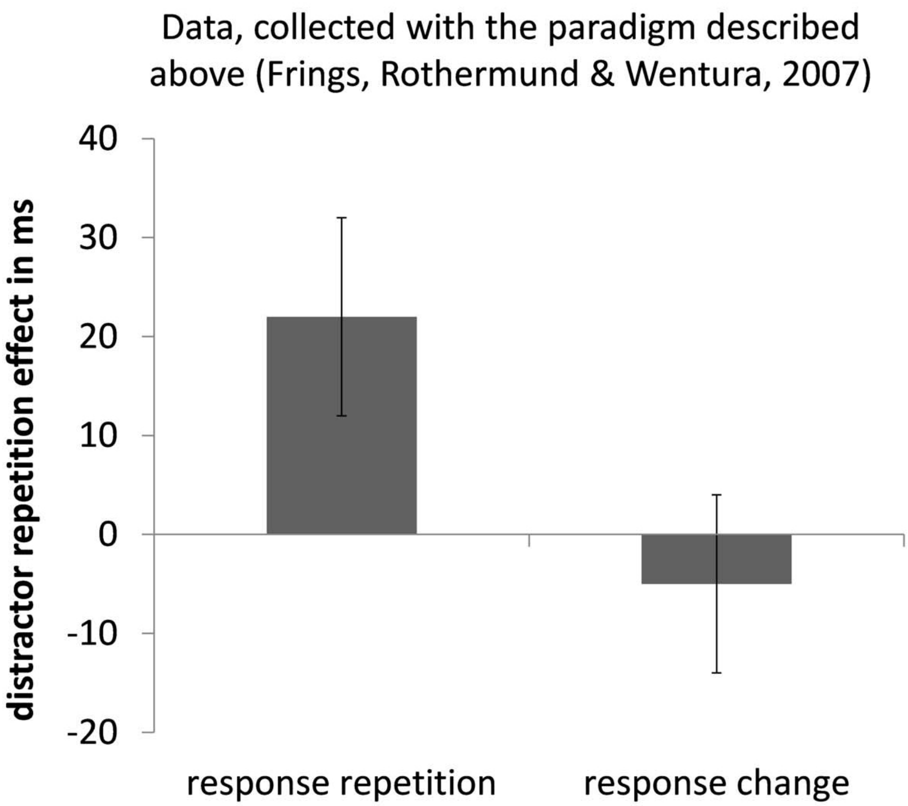

Figure 3. Distractor repetition effects as reported by Frings *et al.* (2007). Error bars depict the standard error of the means. Distractor repetition effects are calculated as the mean response time in distractor change trials minus the mean response time in distractor repetition trials.

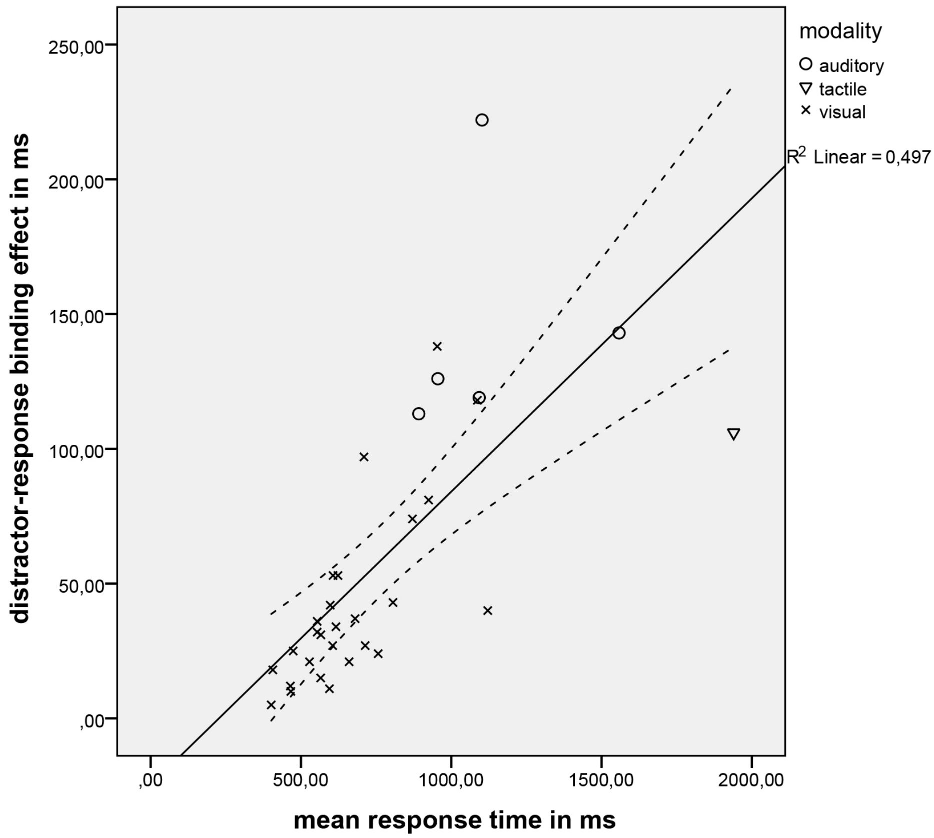

Figure 4. Distractor-response binding effects in msec that were found in 33 experiments (27 using visual, five using auditory, and one using tactile stimuli) as a function of mean response times in the experiments. Each data point represents the interaction of response relation and distractor relation in one experiment. The continuous line indicates the function explaining 50% of the variance between the effects in the different experiments. The confidence interval is indicated by broken lines.

Discussion

The paradigm of distractor-response binding is useful to investigate influences of distractors that compete with the target stimulus for a response execution. In particular, it can differentiate certain mechanisms that have been proposed to influence performance in selection tasks. Namely, both retrieval and inhibition effects concerning distractor stimuli can be analyzed separately. In addition, it is possible to manipulate the different aspects of distractor-response binding separately in this paradigm. If the effect a certain factor (*e.g.* attention, distractor target onset asynchrony, an additional alerting signal, etc.) has on response *integration* with the distractor is of interest, this factor can be varied on the prime, while it is held constant on the probe. For an analysis of an influence on response retrieval, the factor can be manipulated on the probe while being kept constant on the prime[22,23].

Since the paradigm is not restricted to certain stimuli, retrieval and inhibition effects can be analyzed in various modalities. So far evidence for distractor-response binding has been found in the visual, auditory, and tactile modality[18,19,32]. Although mean response times modulate the effect, this modulation seems to be the same in previous visual, tactile, and auditory experiments (see **Figure 4**). These results also suggest that the effect evidences a rather central mechanism of action control.

Some variations of the procedure have been introduced that did not prevent distractor-response binding effects. For example, primes and probes do not need to be presented until participants respond. Several experiments revealed the same pattern with stimulus presentation of 300 msec[19,32]. A response window of 800 msec does also not alter the result pattern[29], and a variable period of 150 to 350 msec between prime response and probe onset has been used successfully, as well[28]. On the other hand, it is crucial that the time between prime response and probe stimulus onset is sufficiently short. No effect of distractor-response binding was found with an onset asynchrony of 1,500 msec[30]. Another prerequisite seems to be the presentation of target and distractor in a grouped fashion[19,21]. Yet, more research is necessary to define further modulating factors of the effect. In addition it should be mentioned that the same pattern of distractor-response binding has been found with one-to-one stimulus-response mappings[9]. However, to exclude an influence of bindings between target and distractor stimuli, it is important to analyze response repetition trials that do not include target repetitions. Yet, to prevent strategic responding by participants, it can be useful to include trials with target repetition in the procedure.

Unpublished data of participants with autism spectrum disorder give a first indication that the effect of distractor-response binding can be found with similar trial numbers in a clinical sample. However, no other clinical samples have been examined yet. Therefore, it cannot be ruled out that higher numbers of trials are required for the investigation of inter-individual differences in the effect of distractor-response binding.

Taken together, using the paradigm of distractor-response binding, gives insight into the influence, distractor stimuli have on human action. Two different mechanisms (distractor based response retrieval and distractor inhibition) can be analyzed separately. Finally, the paradigm is relatively flexible and therefore particularly useful to analyze effects that distractors of various modalities have on action control.

Disclosures

The authors have nothing to disclose.

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