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Non-action effect binding: A critical re-assessment

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A R T I C L E I N F O

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A B S T R A C T

Humans typically act to cause effects in their environment, but at times they also voluntarily omit an action to cause a predictable effect. These effects may become bound to the causing non-actions, just as actions and their effects can become associated. In three experiments, we provide a critical re-assessment of previous reports of non-action effect binding. Following this work, participants completed an acquisition phase to associate actions and non-actions with particular effects. In a subsequent test phase, the former effects were presented as stimuli and participants were allowed to choose an action or non-action freely as a response. Binding should lead to more effect-consistent choices than predicted by chance. Previous studies, however, did not control for deliberate strategies of participants that might inflate the consistency bias and, also, did not address overall preferences for either acting or non-acting, which might introduce additional artifacts. We show that these confounds have a strong impact in common experimental designs and introduce ways to mitigate these effects. This improved assessment still corroborated evidence of binding between non-actions and their effects.

1. Introduction

Voluntarily influencing the world through own actions is an essential part of the human self. At first sight, such voluntary control seems to consist mainly of the ability to choose what to do in a given situation rather than being controlled by a reflex or an external stimulus. But intentional action not only comprises the idea that people can decide what to do, but also when to act and even whether to act at all (Brass & Haggard, 2008). That is to say, the omission of an action can lead to specific consequences and intentionally not acting can be chosen deliberately to bring these consequences about.

The voluntary omission of an action - i.e., intentional non-action - differs from voluntary actions for the simple reason that it does not involve any (distinctive) motor patterns but it is rather characterized by the absence of any visible change in motor activity. However, it has been proposed that actions and non-actions also share certain properties, especially a representation in terms of the sensory effects they produce (Kühn & Brass, 2010a, 2010b; Kühn, Elsner, Prinz, & Brass, 2009; Röttger & Haider, 2016). Empirical evidence for this claim has been gathered within the framework of ideomotor action control and we will therefore selectively review relevant studies from this domain in the following.

1.1. Non-actions in the context of ideomotor theory

Research on non-actions and their effects has been motivated by ideomotor theory, which proposes that voluntary actions are initiated by anticipating the consequences of these actions - or *action effects*. More precisely, it assumes that people acquire bidirectional associations between a movement and its effects. The movement can then be re-initiated by anticipating the corresponding action effects (see Shin, Proctor, & Capaldi, 2010, for a review). Numerous studies have accumulated evidence to support this idea (e.g., Elsner & Hommel, 2001; Hommel, 1993; Janczyk, Skirde, Weigelt, & Kunde, 2009; Kunde, Hoffmann, & Zellmann, 2002; Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Pfister, Kiesel, & Melcher, 2010; Wirth, Pfister, Brandes, & Kunde, 2016; Wolfensteller & Ruge, 2011).

Particularly relevant for the present purposes are studies that examined the assumed acquisition of bidirectional action-effect associations. Elsner and Hommel (2001) used an experimental setup with two phases to test this assumption. In an acquisition phase, participants performed left or right key presses which were consistently followed by specific, task-irrelevant tones. In the subsequent test phase, these tones were used as imperative stimuli and participants had to respond to the tones by choosing a left or right button press (Exp. 2–4). According to ideomotor theory, the tones should activate the associated response automatically, leading to an overall preference for effect-consistent responses over inconsistent responses (Elsner & Hommel, 2001; Greenwald, 1970). That is, participants should favor the action that had produced the tone in the acquisition phase and this very pattern was observed in the test phase (see also Eder, Rothermund, De Houwer, & Hommel, 2015; Hoffmann, Lenhard, Sebald, & Pfister, 2009;

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Maes, 2006; Pfister, Kiesel, & Hoffmann, 2011). The preference for consistent responses, of course, did not occur in an all-or-none fashion. That is, the consistent response was not chosen in 100% of the trials, but the former effect tone influenced response selection in a way that the consistent response was slightly favored over the inconsistent response.

Kühn et al. (2009) used a similar setup as Elsner and Hommel (2001) to investigate non-actions. In the acquisition phase, they provided their participants with three possible choices, a left key press, a right key press, or no key press, which were followed by specific sounds. In the test phase, participants were allowed to choose one of the three responses to react to the former effect sounds. Again, participants preferred the consistent action and, crucially, they also preferred not to act when the former non-action sound was presented. These findings suggest that non-actions and their effects indeed became associated with each other (see also Kühn & Brass, 2010b).

1.2. Methodological pitfalls

Even though the consistency effects in previous studies on non-action effect binding appear convincing at first, they might also be explained in terms of strategic response choices rather than reflecting actual effect-based priming. In the most simple case, participants might have remembered the (non-)action-effect mapping from the acquisition phase and decided to stick with this mapping as a default in the test phase. This decision does not necessarily have to involve ideomotor processes and might even be issued before presentation of the previous effect stimuli.

In contrast to studies on non-action effect binding, a possible role for such strategies has been acknowledged at least by a subset of previous studies on action effect binding. A first and straightforward way to address strategic factors is eliminating participants with implausible (i.e., near-perfect) consistency effects (Eder et al., 2015). Additionally, two variations of the test phase have been suggested to counter strategic factors by design. For one, a secondary task has been implemented in the free choice test phase to deplete the participants' cognitive resources: Under high cognitive demands participants should be less likely to apply deliberate response strategies, but the action effects should still activate the consistent response. Indeed, results show that the consistency effect persists under high cognitive demands (Elsner & Hommel, 2001, Exp. 4). For another, a forced choice task has been implemented in the test phase: Effects from the acquisition phase are presented as imperative stimuli and one half of the participants has to react with the consistent response to the former effects, while the mapping is reversed for the other half. Typically, responses are faster if the mapping is consistent rather than inconsistent (e.g., Dignath, Pfister, Eder, Kiesel, & Kunde, 2014; Elsner & Hommel, 2001; Hoffmann et al., 2009; Hommel, Alonso, & Fuentes, 2003; Wolfensteller & Ruge, 2011) and the small reaction time (RT) differences do not leave time for strategical decisions. This is particularly true when visual actions effects are additionally masked in the test phase to a degree that precludes any deliberate choice strategies (Kunde, 2004).

Forced choice test phases have also been used to corroborate evidence for non-action effect binding (Kühn et al., 2009, Exp. 2). But since RTs of non-actions (or the decision not to act) could not be measured, only RTs of actions were analyzed. Faster RTs were observed for the consistent mapping (acting when the former action effect is presented) compared to the inconsistent mapping (acting when the former non-action effect is presented). However, this RT difference can be explained by action effect binding alone: Presentation of an action effect activates the corresponding action and, thus, this action is retrieved more easily when the action effect is presented than when it is not presented. Non-action effect binding does not necessarily have to be involved. Röttger and Haider (2016, Exp. 3a), thus, expanded the experimental setup and introduced a neutral tone in the test phase. As expected, presentation of the compatible tone facilitated responding and participants reacted faster when the compatible tone was presented compared to the neutral tone. On the other hand, participants reacted slightly slower when the incompatible non-action tone was presented compared to the neutral tone, suggesting that the non-action effect hindered responding. Although these results are in line with the assumption that non-action effects can activate the corresponding non-action, these forced choice test phases only provide information about actions and, thus, the facilitation of non-actions via their effects cannot be analyzed. Studies on non-action effect binding using a free choice test phase, however, lack critical control conditions to weaken alternative explanations, such as strategy use, for the consistency effect. Thus, the present study was designed to scrutinize strategy use in a free choice test phase and to provide unambiguous evidence for non-action effect binding while controlling for strategy use.

A related finding of previous studies on non-action effect binding was that, generally, participants seemed to prefer acting over not acting - even if they were instructed to aim at an equal distribution of actions and non-actions (Kühn & Brass, 2010b). An unequal distribution of actions and non-actions, however, distorts the typical comparison of the observed frequency of consistent responses to chance (e.g., 50% for a two choice task of action vs. not acting, 33% for a choice between pressing a left key, pressing a right key, or not pressing any key). The relevance of this potential pitfall becomes evident when assessing previous findings that indicated overall choice frequencies to amount to 57% for acting and to 43% for not acting (computed as the mean percentage of action/non-action choices from the information provided in Kühn & Brass, 2010b, about absolute response frequencies in the acquisition and test phases). This statistical effect likely biases the assessment of non-action effect binding and should therefore be taken into account when analyzing consistency effects for actions and non-actions.

1.3. The present experiments

The present study comprises three experiments to critically re-assess if non-actions, like actions, can become associated with their effects. Following previous methods, participants completed an acquisition phase to associate actions and non-actions with specific effects (visual effects in Experiment 1; auditory effects in Experiment 2–3). In the subsequent test phase, participants reacted to the former effects and were free to choose between effect-consistent or effect-inconsistent (non-)actions.

In Experiment 1 and 2, we used an experimental setup that closely resembles the setup of Kühn et al. (2009) and we examined if participants used deliberate response strategies in this setup. As a first indicator of deliberate strategies, we identified participants who showed an implausibly large consistency effect. According to ideomotor theory, (non-)action effects should prime the consistent response but other response tendencies can influence response selection as well (e.g., tendencies toward repetition or alternation; Elsner & Hommel, 2001) so that the amount of consistent choices should be substantially lower than 100%. This assumption is supported by previous studies on action effect binding, which showed mean consistency effects of only up to 64% for two-choice test phases (Elsner & Hommel, 2001; Hoffmann et al., 2009; Pfister et al., 2011). We, therefore, excluded participants who chose the consistent response in more than 75% (given the fact that participants could choose between three rather than two potential responses in the present setup, 75% largely exceeds the mean consistency effect of up to 64% of previous studies).

Since choosing the consistent response is not the only possible response strategy, we decided to examine our data further to detect other potential strategies. Two additional strategies suggested themselves. First, participants could also deliberately choose an inconsistent mapping, which would reduce the possibility to find evidence for non-action effect binding. Data from such participants would also distort the assessment of (non-)action effect binding and we therefore also identified participants who chose an inconsistent response in more than 75% of the cases. Second, we supposed that allowing participants to freely choose between acting (left and right key presses) and not acting might encourage some participants to switch between an action mode (a sequence of trials where participants respond to the color effect with left or right key presses) and a non-action mode (a sequence of trials where participants can lean back and relax without pressing a key). Such a strategy would minimize the time during which participants have to stay alert, while at the same time participants comply with the instructions to use all responses and such a strategy is not punished in the experiments. However, such a strategy is easily revealed by the resulting data, as participants should show long trial sequences with only actions (left and right key presses) or non-actions and can thus be excluded. To assess the impact of strategies, we analyzed the data of each experiment twice: once using the data of all participants and once using only the data of participants who were not identified as using strategies. We expected a preference for effect-consistent response choices in both groups.

In Experiment 3, we introduced a secondary task to prevent the use of response strategies while also controlling for strategies as in Experiment 1 and 2. Participants now had to complete a mouse-tracking task while listening and reacting to the effect sounds from the acquisition phase. Even under dual-task conditions, the sound should activate the associated response, leading to an overall preference for consistent responses (Elsner & Hommel, 2001).

2. Experiment 1

The experiment was set up to replicate the consistency effect for actions and non-actions, while examining if participants used response strategies. In an acquisition phase, participants were allowed to choose a left key press, a right key press or no key press. Each response was consistently followed by a colored effect on the computer screen. In the test phase, participants' task was to react spontaneously to the former color effects with one of the three responses.

In order to take unequal overall preferences for actions and non-actions into account, we baseline-corrected the frequency of consistent choices. To that end, we calculated the frequency of consistent choices for each response effect (e.g., the number of left key presses divided by the number of trials with the left action effect) and the global frequency of each response (e.g., the number of left key presses divided by the total number of (correct) trials in the test phase). Then, we subtracted the global frequency from the frequency of consistent choices for each response and participant. If participants preferred the consistent response, this difference should be substantially higher than zero. This approach takes into account that participants might prefer left and right actions over not acting (Kühn & Brass, 2010b; see section 1.2). Following the idea that actions and non-actions are similarly represented in terms of their effects (Kühn et al., 2009), a systematic preference for consistent choices should be visible in the baseline-corrected frequencies of both actions and non-actions.

We examined the data of each participant to check if participants had used a specific response strategy. We used two different approaches to check for response strategies. For one, we examined if participants' data indicated that they had used a specific color-response mapping (e.g., if they had always pressed the left key when they saw the former left color-effect). As a cut-off, participants were excluded when they chose to respond to a specific color with the same (either consistent or inconsistent) response in more than 75% of the trials. For another, we examined if participants showed extraordinarily long sequences of trials with only actions (left or right key presses) or only non-actions and excluded participants if the longest or even more extreme sequences were highly unlikely ($p < .0001$).

Data analyses were performed twice, once using the entire set of participants and once using the subset of participants who were not identified as using response strategies. A preference for consistent responses should be visible in both groups, the whole data set (comparable to the results of Kühn et al., 2009) and, if non-actions and effect can indeed become associated with each other, also in the subset when controlling for strategy use.

2.1. Methods

2.1.1. Participants

Thirty-three participants were recruited (mean age: 27.8 SD: 7.5, 8 male, 3 left-handed). All participants gave informed consent and received either course credit or monetary compensation for participation. An a priori power analysis based on the results of Kühn et al. (2009, Exp. 1) suggested that a sample size of n = 9 ensured a power of 0.8 to detect non-action effect binding (with $d = \frac{t}{\sqrt{n}} = \frac{3.98}{\sqrt{12}} = 1.15$), and a sample size of n = 20 for action effect binding (with $d = \frac{2.35}{\sqrt{12}} = 0.68$). In order to have sufficient power to show both action effect and non-action effect binding, we decided to collect data of at least twenty participants who did not use any strategies.

2.1.2. Stimuli and experimental setup

Participants were seated in front of a 17″ computer monitor at a viewing distance of approximately 60 cm. They operated the *v* key of standard German QWERTZ keyboard with their left index finger and the *n* key with their right index finger. Colored rectangles (red, blue and yellow) of 3 × 4 cm were used as action effects and appeared in the center of the screen on a black background.

2.1.3. Experimental procedure

Participants received written instructions at the beginning of the experiment. The acquisition and test phase were introduced one after another and participants were allowed to practice each phase. The phases were named *phase A* and *phase B* in the instructions.

Fig. 1 depicts the experimental setup. The experiment consisted of thirteen blocks in total, seven acquisition blocks (A) and six test blocks (B). The block order for all participants was AAAAABBABBABB. Participants were allowed to take a break between blocks.

For the acquisition phase, participants were informed that in each trial they should produce one of three responses, either a key press with their left index finger (key *v*), a key press with their right index finger

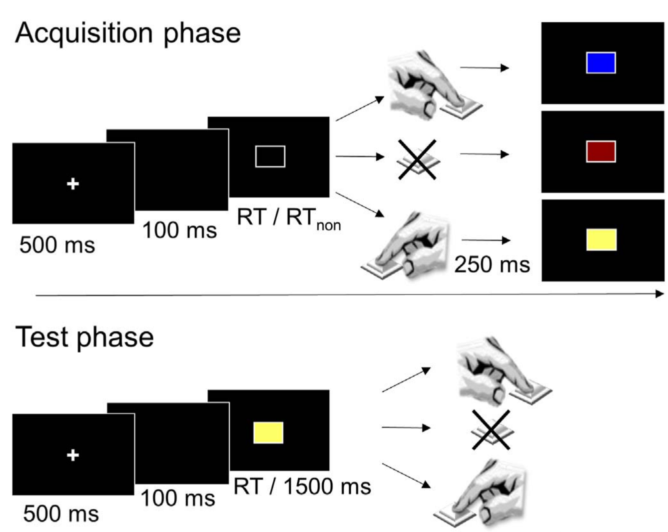

Fig. 1. Setup of Experiment 1. In the acquisition phase, participants could choose between a left key press, a right key press and no key press. Each response triggered a contingent color effect. In the test phase, the former color effects were presented as stimuli and participants could freely choose one of the three responses upon presentation of these effects.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(key *n*) or no key press. Participants were encouraged to produce each response equally often within one block and received feedback about the frequency of each response after every block. Each acquisition blocks consisted of 45 trials.

Acquisition trials started with a white cross against a black background, which was displayed for 500 ms, followed by a blank screen for 100 ms. Then, a white-framed rectangle with a black filling appeared, signaling participants to choose one of the three responses. The participants' responses filled the rectangle with a response-specific color. For each participant, the response-color mapping remained constant throughout the experiment, but the mapping was randomized across all participants. If participants chose a left or right key press, the color changed 250 ms after the key press. The RT history of the participants' left and right key presses was used to determine when to present the non-action color. Therefore, the participant's RTs of key presses within the current block were saved and the interval between onset of the white rectangle and the non-action color was calculated as (mean RT + mean RT + last RT)/3 + 300 ms (cf. Kühn & Brass, 2010b). If no RT history was available (e.g., in the first trial of each block) the non-action interval was set to 1500 ms. If no key press occurred in this interval, the non-action effect color was displayed. In follow-up questionnaires participants reported that they had indeed had the impression of causing the non-action effect. The next trial started after an intertrial interval of 1000 ms. If participants pressed a key before presentation of the white rectangle, as well as during or after presentation of the color effect, an error message occurred immediately and a new trial started. All trials containing such errors were excluded from analysis.

Test blocks consisted of 45 trials each. Trials started with a white cross, which was displayed for 500 ms, followed by a blank screen for 100 ms. Then, one of the three colored rectangles of the acquisition phase appeared within a white frame, signaling participants to choose one of the responses. Participants were instructed to respond spontaneously to the color without using any specific strategy. After 500 ms the color disappeared but the white-framed rectangle (now filled black) remained on the screen for another 1000 ms. If participants had not pressed a key within these 1500 ms after color onset, a non-action was registered. To discourage participants from deciding for and pre-planning a response before the color onset, an error message was displayed whenever participants responded before or within 200 ms after color onset. If participants pressed a key after the white rectangle had disappeared (i.e., 1500 ms after color onset), an error message appeared, informing participants that they had responded too late and encouraging them to respond faster in the next trial. The next trial started after an intertrial interval of 1000 ms.

2.1.4. Statistical analysis

To ensure that participants had the opportunity to establish links between action, non-action and the associated effects, we assessed the number of valid trials per response-effect pairing in the acquisition phase. Participants were excluded if the number of valid trials was below 75 for at least one response-effect pair (this applied to one participant).

We then computed the baseline-corrected frequency of consistent choices. To that end, we calculated the global frequency of each response in the test phase for every participant (e.g., the number of left key presses divided by the total number of correct test trials) and the frequency of consistent choices for each response and participant (e.g., the number of left key presses divided by the number of trials with the left action effect). Then, we subtracted the former from the latter. These baseline-corrected frequencies of consistent choices were tested against zero using two-tailed, one-sample *t*-tests in order to test if participants chose the consistent response significantly more often than chance would suggest. Effect sizes were calculated as $d = \frac{t}{\sqrt{n}}$.

A repeated measures analysis of variance (ANOVAs) with the within-subject factor Response (left key press, right key press, no key press) was used to test whether global response frequencies differed between responses. If the assumption of sphericity was violated, Greenhouse-Geisser corrections were applied and corrected *p*-values along with original degrees of freedom are reported. To analyze if the baseline-corrected frequencies of consistent choices differed between actions and non-actions, the data of both action effects (left and right key press effects) were averaged and a two-tailed, paired *t*-test was computed. In case of a non-significant test, we computed the Bayes factor according to the BayesFactor package of the R software environment to further analyze the data (BF > 3 were considered evidence for one hypothesis over the other; Rouder, Speckman, Sun, Morey, & Iverson, 2009).

RTs of actions (left and right key presses) were also analyzed using a repeated-measures ANOVA with the within-subjects factor Tone Relation. The factor Tone Relation comprised the levels compatible (i.e., a left action effect responded to by a left key press and right action effect responded to by a right key press), incompatible (right action effect ► left key press; left action effect ► right key press) and non-action (non-action effect ► left key press; non-action effect ► right key press). For the RT analysis, all trials with errors, as well as all trials following errors and all trials deviating more than 2.5 standard deviations from the cell mean were excluded.

All statistical analyses of the test phase were performed twice, once on the whole data set, and once on a subset of participants who were not identified as using deliberate response strategies. In order to decrease the effect of response strategies we applied the following criteria to determine which participants entered the subset:

1. Participants were classified as using strategies if they used a predefined stimulus-response mapping. To determine that we computed the relative frequency of each stimulus-response pair for each participant and the data of participants with any of these frequencies exceeding 75% were discarded. This criterion identified seven participants, who were not included in the subset analysis. Five of these participants predominantly chose a consistent mapping.
2. Participants were classified as using strategies if they showed implausibly long sequences of trials with only actions or only non-actions. To identify those participants, we inspected the participants' data of the test phase and chose the longest sequence of successive trials with only actions (left and right key presses) and only non-actions. Assuming a Bernoulli process under the assumption of no strategy use, we calculated the probability of a trial sequence - P(action) for action sequences and P(non-action) for non-action sequences - with at least this length according to the binomial distribution (as described in the formulas below). The participant's overall frequency of actions or non-actions in the test phase served as an estimate for the probabilities p_{action} and $p_{non\text{-}action}$, respectively, and k represents the length of the trial sequence:

$P(\text{action}) = p_{action}{}^{k}$.
$P(\text{non-action}) = p_{non\text{-}action}{}^{k}$.

A trial sequence was considered implausible if the probability was less than 10^{-4}. This criterion identified five participants who were not included in the subset analysis.

2.2. Results

In the acquisition phase, participants produced all required responses with a substantial frequency (on average 34.2% left key presses, 33.9% right key presses, 31.9% non-actions), but the frequencies of responses differed significantly, $F(2,62) = 7.43$, $p = .003$, $\eta_p{}^2 = .19$ ($\varepsilon = 0.82$). In the test phase, participants responded too early on 3.9% of the trials (i.e., they pressed a key before or within 200 ms after color onset) and too late on 0.5% of the trials. These trials were excluded from further analyses. Fig. 2 shows response frequencies for

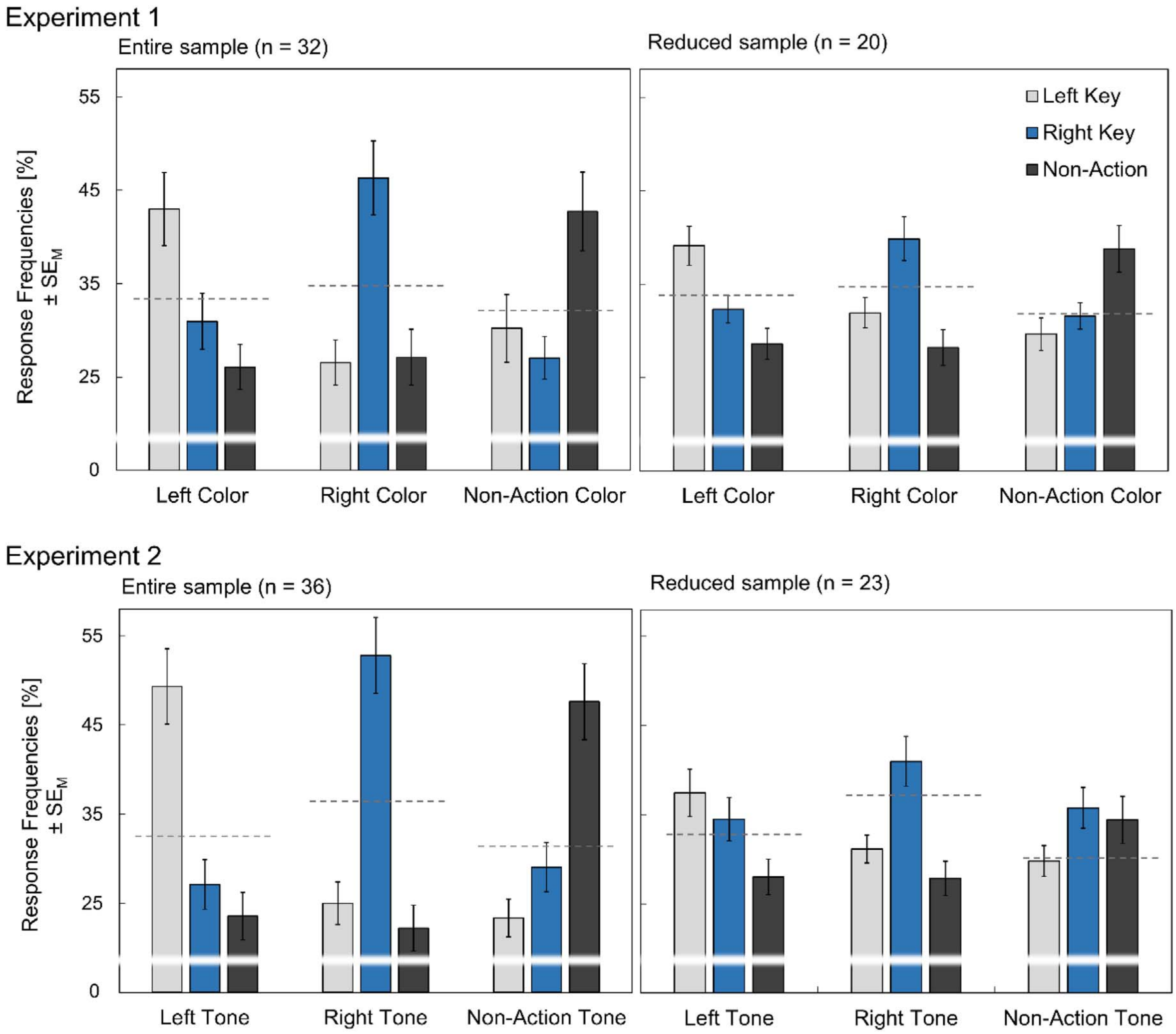

Fig. 2. Mean response frequencies in the test phase for left actions, right actions and non-actions in response to the effects of the acquisition phase. Panels on the left show the data of the entire sample, whereas panels on the right show the data of the reduced sample without participants who showed signs of strategy use. Participants preferred the consistent response (e.g., a non-action in response to the non-action effect) in both experiments. Dashed gray lines indicate mean global frequencies for left key presses, right key presses and non-actions in the entire test phase against which the consistency effects were tested. Error bars represent standard errors of the mean.

Table 1
Mean global response frequencies of actions and non-actions in the test phase, and mean frequencies of consistent choices of actions and non-actions for Experiment 1–3.

	Left Key		Right Key		Non-Action	
Experiment 1	Global	Consistent	Global	Consistent	Global	Consistent
Entire sample (n = 32)	33.2%	43.0%	34.8%	46.3%	32.0%	42.7%
Reduced sample (n = 20)	33.5%	39.1%	34.6%	39.9%	31.9%	38.8%
Experiment 2						
Entire sample (n = 36)	32.5%	49.3%	36.4%	52.8%	31.1%	47.6%
Reduced sample (n = 23)	32.8%	37.5%	37.1%	41.0%	30.1%	34.4%
Experiment 3						
Entire sample (n = 28)	51.2%	55.5%	–	–	48.8%	53.2%
Reduced sample (n = 23)	50.8%	53.7%	–	–	49.2%	52.2%

left key presses, right key presses and non-actions as a function of the presented color effect, both for the whole set of participants and the reduced subset of participants, who were not identified as using response strategies. Global response frequencies and frequencies of consistent choices are also listed in Table 1.

2.2.1. Analysis of the entire sample (n = 32)

In the test phase, participants chose the left key press in 33.2% of the trials, the right key press in 34.8% of the trials and no key press in 32.0% of the trials and these global response frequencies did not differ significantly from each other, $F(2,62) = 2.24$, $p = .131$, $\eta_p^2 = .07$ ($\varepsilon = 0.74$). Participants preferred the consistent response when the action effects of the left keypress, $t(31) = 2.45$, $p = .020$ $d = 0.43$, and the right keypress were presented, $t(31) = 2.94$, $p = .006$, $d = 0.52$. Importantly, a consistency effect also emerged when the non-action effect was presented, $t(31) = 2.68$, $p = .012$, $d = 0.47$. The baseline-corrected frequency of consistent choices did not differ between action effects and the non-action effect, $t(31) = 0.05$, $p = .960$, $d = 0.01$ and a Bayes factor of $B_{01} = 7.29$ indicated evidence in favor of the null hypothesis of equally strong consistency effects.

For RT analysis, one participant had to be excluded because of missing values in one cell. RTs for actions following a compatible action effect ($M = 458$ ms), an incompatible action effect ($M = 448$ ms) or the non-action effect ($M = 447$ ms) did not differ from each other, $F < 1$.

2.2.2. Analysis without response strategies (n = 20)

In the subset of participants without detected response strategy, the left key press was chosen in 33.5%, the right press in 34.6% and the non-action in 31.9% of the trials in the test phase and these global response frequencies did not differ from each other, $F < 1$. As in the whole data set, the percentage of consistent choices was significantly greater than chance for the left action effect, $t(19) = 2.77$, $p = .012$, $d = 0.62$, right action effect, $t(19) = 2.62$, $p = .017$, $d = 0.59$, as well as for the non-action effect, $t(19) = 3.70$, $p = .002$, $d = 0.83$. The baseline-corrected frequency of consistent choices did not differ between action effects and the non-action effect, $t(19) = 1.36$, $p = .189$, $d = 0.30$ and the calculated Bayes factor of $B_{01} = 2.50$ provided ambiguous support for the null hypothesis (with numerically stronger consistency effects for the non-action effect).

RTs for actions following a compatible action effect ($M = 415$ ms), an incompatible action effect ($M = 400$ ms) or the non-action effect ($M = 414$ ms) differed from each other, $F(2,38) = 3.67$, $p = .035$, $\eta_p^2 = .162$. Two-tailed, paired *t*-tests showed that participants reacted faster following an incompatible action effect compared to a compatible action effect, $t(19) = 2.39$, $p = .027$, $d = 0.53$, and compared to the non-action effect, $t(19) = 2.79$, $p = .012$, $d = 0.62$. RTs did not differ following a compatible effect and the non-action effect, $t(19) = 0.26$, $p = .795$, $d = 0.06$.

2.3. Discussion

The purpose of Experiment 1 was to investigate whether typical measures of non-action effect binding might be affected by deliberate response strategies and, if this was the case, to assess non-action effect binding when these strategies are controlled for. About one third of the participants did indeed show clear signs of strategy use, suggesting that the nature of the free choice task does prompt participants to rely on response strategies rather than spontaneous response selection. This indicates that evidence for (non-)action effect binding in common experimental designs is confounded with participants' use of such deliberate strategies. Still, in the present experiment a consistency effect was found not only in the entire set of participants, but also when analyzing only the subset of participants who were not identified as using response strategies. Furthermore, Bayes factors indicated that the frequency of consistent choices was not smaller for non-actions than for actions. The results are in line with the assumption that participants acquired non-action effect associations in the acquisition phase and that presentation of the non-action effect activated the non-action in the test phase.

The results of the response strategy analysis indicate that in common experimental studies on (non-)action effect binding, a substantial number of participants does not answer spontaneously, as instructed, but according to a deliberate response strategy. However, the high number of participants using strategies in the current experiment could also be due to the visual effects used in Experiment 1, because such effects come with low saliency and may therefore invite participants to focus their attention on other aspects of the task (such as deliberate strategies). Auditory stimuli (as used by e.g., Elsner & Hommel, 2001; Kühn et al., 2009) draw attention more automatically than visual stimuli (Posner & Nissen, 1976) and might create a more engaging situation in which participants do not rely as strongly on using explicit strategies. To test this assumption, we used auditory stimuli in Experiment 2.

Finally, RTs following compatible, incompatible and non-action effects did not differ in the analysis of the entire sample. That is in line with previous studies using the free choice test phase (Elsner & Hommel, 2001; Hoffmann et al., 2009; Pfister et al., 2011). In the subset, however, participants reacted faster to incompatible action effects compared to both compatible action effects and the non-action effect. This result is unexpected in the light of ideomotor theory and it is at odds with studies using compatible and incompatible effects as imperative stimuli (e.g., Dignath et al., 2014; Elsner & Hommel, 2001; Hoffmann et al., 2009; Wolfensteller & Ruge, 2011). However, because this result did not replicate in the following Experiment 2, we are cautious to draw any conclusions from this effect.

3. Experiment 2

In Experiment 2, we attempted to replicate Experiment 1 with auditory action and non-action effects. At the same time, we assumed that auditory action effects would reduce the number of participants who use response strategies.

3.1. Method

3.1.1. Participants, stimuli, and experimental setup

Forty participants were recruited (mean age: 27.4 SD: 6.7, 14 male, 1 left-handed). Considering a dropout rate of about one third due to strategy use (as in Experiment 1), a sample size of 40 ensured that at least 20 participants should remain in the group of participants without response strategy use (the necessary sample size to detect action and non-action effect binding based on the results of Kühn et al., 2009; see also Experiment 1). All participants gave informed consent and received either course credit or monetary compensation for participation.

The experimental setup and trial procedure were identical to Experiment 1 except for the following changes. Participant now wore headphones to listen to the sound effects, which were delivered binaurally and consisted of three different animal sounds (a dog barking, a cat meowing, and a bird chirping) with durations between 522 and 862 ms. In the acquisition phase, after participant's response the corresponding sound effect was played instead of the colored action effect of Experiment 1. In the test phase, participants heard one of the former effect tones and simultaneously the white-framed rectangle appeared, signaling participants to choose one of the response alternatives. The white-framed rectangle remained on the screen for 2000 ms in total. If participant had not pressed a key within 1500 ms after tone onset, a non-action was registered[1].

3.1.2. Statistical analysis

Statistical analysis was identical to Experiment 1 (see Section 2.1.4 for details). In total, 13 participants were identified as using deliberate response strategies. Three participants showed an implausibly long sequence of non-action trials and ten additional participants used a predefined stimulus-response mapping (nine of these participants predominantly chose the consistent response).

3.2. Results

Four participants were excluded from all analyses because the number of valid trials in the acquisition phase was below 75 for at least one response-effect pair. All other participants produced the required responses about equally often (on average 33.5% left key presses, 33.5% right key presses, 33.0% non-actions) in the acquisition phase. The response frequencies did not differ, $F < 1$. In the test phase, participants responded too early on 1.5% and too late on 0.4% of the trials. These trials were excluded from further analyses. Response frequencies for left key presses, right key presses and non-actions as a function of the presented effects are shown in Fig. 2, both for the whole set of participants and the reduced subset of participants, who were not identified as using response strategies. Global response frequencies and frequencies of consistent choices for both analyses are also listed in

[1] Due to a programming error, the white rectangle remained on the display for another 500 ms after the participant's response was counted as a non-action. This was different from Experiment 1, where the white rectangle disappeared after 1500 ms, informing participants that a non-action had been registered.

Table 1.

3.2.1. Analysis of the entire sample (n = 36)

In the test phase, participants chose a left key press in 32.5% of the trials, a right key press in 36.4% of the trials, and no key press in 31.1% of the trials. These differences between global frequencies were marginally significant, $F(2,70) = 2.87$, $p = .080$, $\eta_p^2 = .08$ ($\varepsilon = 0.74$). Participants preferred the consistent response when the left action effect was presented, $t(35) = 4.17$, $p < .001$ $d = 0.70$, when the right action effect was presented, $t(35) = 4.07$, $p < .001$ $d = 0.68$, and when the non-action effect was presented, $t(35) = 4.12$, $p < .001$ $d = 0.69$. The baseline-corrected frequency of consistent choices did not differ between action effects and the non-action effect, $t(35) = 0.08$, $p = .934$, $d = 0.01$, and a Bayes factor of $B_{01} = 7.69$ indicated evidence in favor of the null hypothesis of equally strong consistency effects.

For RT analysis, one participant had to be excluded because of missing values in one cell. RTs for actions following a compatible action effect ($M = 683$ ms), an incompatible action effect ($M = 683$ ms) or the non-action effect ($M = 650$ ms) did not differ from each other, $F(2,68) = 1.94$, $p = .164$, $\eta_p^2 = .054$ ($\varepsilon = 0.76$).

3.2.2. Analysis without response strategies (n = 23)

The subset of participants who were not identified as using response strategies chose a left key press in 32.8%, a right key press in 37.1%, and no key press in 30.1% and these global frequencies differed significantly, $F(2,44) = 3.60$, $p = .036$, $\eta_p^2 = .14$. Furthermore, participants preferred the non-action when the non-action effect was presented, $t(22) = 2.12$, $p = .046$ $d = 0.44$. The preference of consistent choices for actions was only marginally significant, $t(22) = 2.05$, $p = .053$, $d = 0.43$ and $t(22) = 1.80$, $p = .085$, $d = 0.38$, for the left and right action effect respectively. However, the baseline-corrected frequencies of consistent choices did not differ between action effects and the non-action effect, $t(22) = 0.03$, $p = .976$, $d = 0.01$, and a Bayes factor of $B_{01} = 6.25$ indicated evidence for the null hypothesis of equally strong consistency effects. RTs for actions following a compatible action effect ($M = 674$ ms), an incompatible action effect ($M = 659$ ms) or the non-action effect ($M = 662$ ms) did not differ from each other, $F < 1$.

3.3. Discussion

In Experiment 2 participants preferred not to act when the former non-action effect was presented. As in Experiment 1, this was true in both analyses, indicating that non-actions and their effects became associated with each other. However, the number of participants that were classified as using response strategies was not reduced compared to Experiment 1, indicating that strategy use introduces a strong confound in common experimental designs of (non-)action effect binding.

When analyzing only those participants who did not use strategies, the consistency effect for actions (left and right key presses) was only marginally significant, although Bayes factors indicated that the relative frequency of consistent choices was equally high for actions and non-actions. As previous studies have found convincing evidence for action effect binding (e.g., Dignath et al., 2014; Elsner & Hommel, 2001; Hoffmann et al., 2009; Hommel et al., 2003; Pfister et al., 2011; Wolfensteller & Ruge, 2011), the present results appear to stem from a Type II error. However, they also suggest that response strategies do indeed inflate consistency effects in typical free-choice designs and should be carefully controlled for also in studies on action effect binding.

The rather high amount of participants using response strategies in Experiment 1 and 2 also indicates that simply measuring response strategies is not a particularly economic approach. As outlined in the introduction, however, a complementary method to control for response strategies can be implemented by changing the design of the test phase. High cognitive demand can reduce the participants' ability to use deliberate response strategies. However, as the influence of action and non-action effects on response selection should be automatic, the consistency effect should persist even under higher cognitive demands (Elsner & Hommel, 2001). We therefore implemented an additional task in the test phase of Experiment 3.

4. Experiment 3

In Experiment 3 we used a secondary task in the test phase to prevent the use of response strategies by design. The acquisition phase was similar to Experiment 1 and 2, but participants could only choose between two responses, a key press with their left hand or no key press, which were consistently followed by specific tones. In the test phase, the former effect tones were presented as stimuli and again, participants were allowed to respond either with a key press or by not pressing the key. Simultaneously, participants performed a mouse-tracking task with their right hand. As the mouse-tracking task should induce a distraction from the free choice task, less or no participants should use explicit response strategies in the present test phase. Still, we expected a reliable consistency effect for actions and non-actions alike.

4.1. Method

4.1.1. Participants

Twenty-eight participants (mean age = 21.2, SD = 5.3, 4 male, 3 left-handed) were recruited for the experiment. Based on the mean effect size computed from all four effect size estimates for non-action effect binding determined in Experiment 1 and 2 a sample size of 28 ensure a power above $1\text{-}\beta = 0.8$ to detect non-action effect binding. All participants gave informed consent prior to the experiment and received either course credit or monetary compensation for participation.

4.1.2. Stimuli and experimental setup

Participants sat in front of a 22″ flat screen monitor at a viewing distance of approximately 60 cm and operated the *c* key of standard German QWERTZ keyboard with their left index finger and the mouse with their right hand (one left-handed participant used the mouse with the left hand and operated the c key with the right index finger). Stimuli appeared in the center of the screen on a black background. A high-pitched and a low-pitched MIDI tone (dulcimer timbre) of 500 ms duration served as sound effects and were delivered binaurally through headphones to the participants.

4.1.3. Experimental procedure

The acquisition phase and test phase were introduced separately by written instructions at the beginning of the experiment. The phases were named *phase A* and *phase B* in the instructions and participants were allowed to practice each phase separately at the beginning of the experiment and pose questions. The experimental setup is depicted in Fig. 3. Acquisition blocks (A) comprised 50 trials per block and test blocks (B) comprised 30 trials per block. The block order for all participants was AAAABBBABBB.

In the acquisition phase, participants were requested to choose between two responses, a key press or no key press. Key presses were performed with the index finger of that hand which participants normally do not use to operate the mouse (i.e., in most cases the left hand). The experimental procedure of the acquisition phase was identical to Experiment 1 and 2, with the exception that no blank screen was presented between the fixation cross and the white rectangle.

In the test phase, participants had to complete two tasks, a mouse-tracking task and a free choice task and the instructions encouraged participants to prioritize the mouse-tracking task. For the mouse-tracking task, a small circle (radius: 50 pixels, corresponding to 2.5 cm) with blue circumference was displayed on the screen and moved randomly to the left or to the right with a constant horizontal velocity

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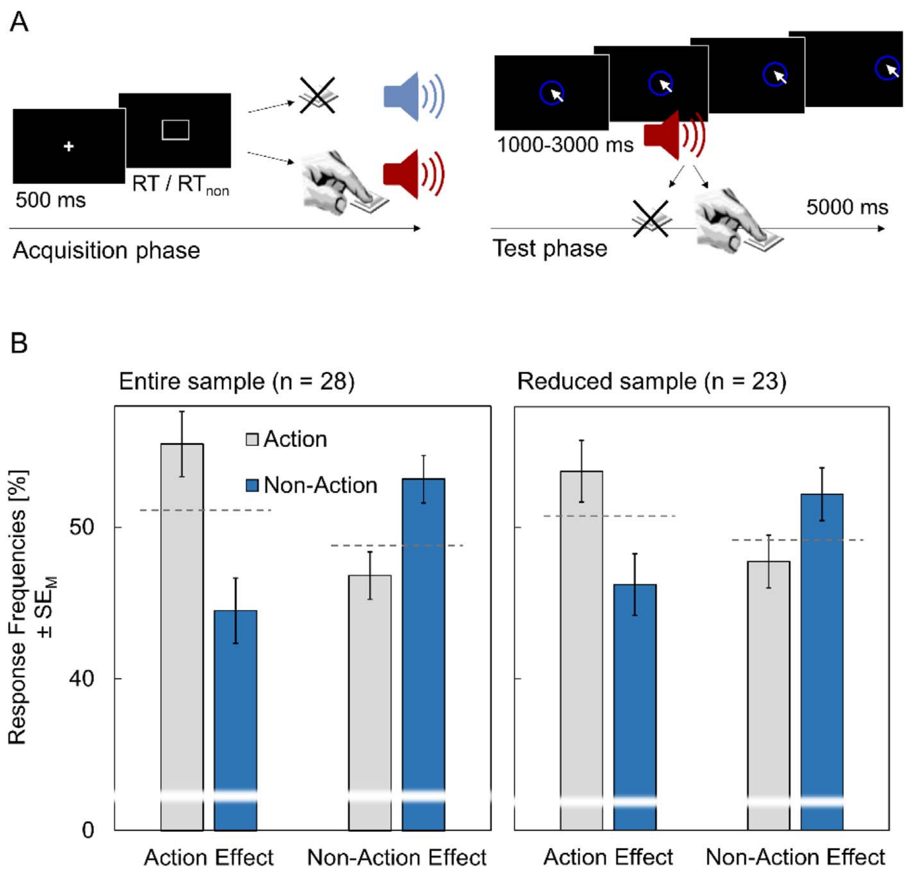

Fig. 3. Setup and results of Experiment 3. (A) In the acquisition phase, participants could choose between pressing or not pressing a key when a white rectangle was presented. Each response triggered a contingent sound effect. In the test phase, participants completed a mouse-tracking task. Each trial lasted five seconds. During the tracking task, one of the former sound effects was presented and participants reacted to the sound by choosing a key press or no key press. (B) Mean response frequencies of action and non-action choices in the test phase in response to the previous sound effects. The left panel shows data of the entire sample, whereas the right panel shows data of the reduced subset of participants who did not show any signs of strategy use. Participants preferred the consistent response (e.g., a non-action in response to the non-action effect) in both analyses. Dashed gray lines indicate the mean global frequency of actions and non-actions in the entire test phase. Error bars represent standard errors of the mean.

(176 px/s). Participants' task was to track the circle with the mouse in a way that the mouse cursor remained within the circumference. For the free choice task, one of the effect tones of the acquisition phase was presented as a stimulus. Participants had to respond to this tone with one freely chosen response, either a key press or no key press. Participants were told to use both responses about equally often and not to use any specific strategies to choose between key press and no key press, but to choose spontaneously. Both tasks had to be handled simultaneously. This is, each trial started with a display of the circle and the mouse cursor in the center of the screen for 500 ms. Then, the circle began to move and participants had to track the circle. After a randomly chosen delay of 1000 to 3000 ms, one of the former effect tones was presented, prompting participants to choose a response. The mouse-tracking task lasted five seconds in total. Between trials, a black screen was shown for 1000 ms. If participants pressed a key before tone presentation, an error message was displayed and a new trial started. Additionally, participants received warning messages if they produced unequal amounts of actions or non-actions (> 75% of the trials with only one type of response). After the experiment, participants completed an additional questionnaire about whether they had used specific strategies to choose between key press and no key press in the acquisition and the test phase.

4.1.4. Statistical analysis

Statistical analysis was similar to Experiment 1 and 2 (see section 2.1.4). To analyze if participants preferred the consistent response, for each participant the global frequency of each response in the entire test phase was subtracted from the frequency of consistent choices for this response. Two-tailed, one-sample *t*-tests were used to evaluate if these baseline-corrected frequencies of consistent choices were greater than zero. Two-tailed, paired-sample *t*-tests were furthermore used to test whether participants preferred one of the responses in the acquisition and the test phase and whether the baseline-corrected frequencies of consistent choices differed between response alternatives.

RTs of key presses were also analyzed using a two-tailed, paired *t*-test, comparing the RTs of key presses following the (compatible) action effect and of key presses following the non-action effect. For the RT analysis, all trials with errors, as well as all trials following errors and all trials deviating more than 2.5 standard deviations from the cell mean were excluded.

Statistical analyses were again performed twice, once on the entire data set, and once on the subset of participants who were not identified as using response strategies. In the post-experimental questionnaire, four participants reported that they had used strategies throughout the test phase. Using the strategy criteria from Experiment 1 and 2, two participants were identified as using deliberate response strategies. One of these participants chose a consistent response in more than 75% of the trials and also indicated so in the questionnaire. The other participant also chose consistent response in more than 75% of the trials and additionally showed an unnatural long sequence of non-actions. However, that participant did not indicate strategy use in the post-experimental questionnaire. Nevertheless, all five participants were excluded from the subset analysis[2].

4.2. Results

In the acquisition phase, key presses (51.2%) were performed more often than non-actions (48.8%), $t(27) = 2.17$, $p = .039$, $d = 0.41$. In the test phase, participants responded too early on 1.5% of the trials. These trials were excluded from further analyses. Global response frequencies and frequencies of consistent choices in the test phase are

[2] One participant indicated that he or she had not used strategies in the entire test phase, but only occasionally. Further exclusion of this participant from the subset showed that participants still preferred the consistent response for the action effect, $p_{\text{one-tailed}} = .043$, and the non-action effect, $p_{\text{one-tailed}} = .044$.

listed in Table 1.

4.2.1. Analysis of the entire sample ($n = 28$)

Participants chose to press a key in 51.2% of the valid trials, non-actions in 48.8% and these global frequencies did not differ, $t(27) = 1.06$, $p = .297$, $d = 0.20$. Participants preferred the consistent response for both, the action effect, $t(27) = 2.84$, $p = .008$, $d = 0.54$, and the non-action effect, $t(27) = 2.83$, $p = .009$, $d = 0.53$. The baseline-corrected frequencies of consistent choices did not differ between response alternatives, $t(27) = 0.75$, $p = .457$, $d = 0.14$ and a Bayes factor of $B_{01} = 5.21$ indicated evidence for the null hypothesis of equally strong consistency effects. RTs for key presses following the action effect ($M = 709$ ms) did not differ from RTs following the non-action effect ($M = 714$ ms), $t(27) = 0.38$, $p = .710$, $d = 0.07$.

4.2.2. Analysis without response strategies ($n = 23$)

Key presses were performed in 50.8% of the valid trials, non-actions in 49.2% and these global frequencies did not differ, $t(22) = 0.64$, $p = .528$, $d = 0.13$. Participants preferred the consistent response for both, the action effect, $t(22) = 2.10$, $p = .047$, $d = 0.44$, and the non-action effect, $t(22) = 2.10$, $p = .048$, $d = 0.44$. The baseline-corrected frequencies of consistent choices did not differ between response alternatives, $t(22) = 0.63$, $p = .533$, $d = 0.13$ and a Bayes factor of $B_{01} = 5.16$ indicated evidence for the null hypothesis of equally strong consistency effects. RTs for key presses following the action effect ($M = 700$ ms) did not differ from RTs following the non-action effect ($M = 708$ ms), $t(22) = 0.45$, $p = .659$, $d = 0.09$.

4.2.3. Mouse data

The mean deviation of the mouse cursor to the circle center was 11.9 pixel (*SE*: 0.2), which was smaller than the width of the circle radius (50 pixel). Participants' individual mean deviations were also below 50 pixels with a range from 6.7 to 28.6 pixels.

4.3. Discussion

Experiment 3 set out to corroborate evidence for non-action effect binding by preventing the use of response strategies with a dual-task setting in the test phase. Participants now performed a mouse-tracking task in the free choice test phase, which should induce higher cognitive demands so that participants are not able to use response strategies or to keep track of the strategies. Despite the additional task, participants clearly favored the consistent response for both action and non-action. This indicates that non-actions and their effects became associated in the acquisition phase and that presentation of a non-action effect in turn activated the non-action in the test phase.

The additional task also successfully reduced strategy use. In the post experimental questionnaires only four participants indicated that they had used response strategies throughout the test phase and using the criteria of Experiment 1 and 2, only two participants were identified as using strategies. Introducing a secondary task thus proves to be a helpful tool to reduce strategy use in common free choice designs[3].

5. General discussion

The present experiments re-assessed the hypothesis that non-actions, i.e., intentional decisions not to act, can become bound to the effects they produce. The experiments were divided into two phases. In the acquisition phase, participants could freely decide between pressing a key or not. Actions and non-actions were both consistently followed by specific and contingent effects. In the test phase, these effects were presented as imperative stimuli and participants were again allowed to choose between acting and not acting. If actions and non-actions can become associated with their respective effects in the acquisition phase, this should lead to a preference for consistent action and non-action choices in the test phase. The critical question was whether such a preference is driven by automatic influences of action and non-action effects (as could be derived from ideomotor theory) or by explicit strategical considerations.

In Experiment 1 and 2 we showed that common free choice test phases are prone to strategy use and that evidence for (non-)action effect binding as provided by these free choice tasks is at least partly driven by strategy use. However, the present experiments also showed reliable consistency effects when strategy use was controlled for by excluding participants, as in Experiment 1 and 2, or by introducing a secondary task, as in Experiment 3. Our results therefore confirm that non-actions can become bound to the sensory effects they produce.

As final methodological concern, however, preferences for not acting when the non-action effect is presented could still be explained without the necessity to assume non-action effect binding. More precisely, a preference not to act when the non-action effect is presented could also stem from the fact that participants prefer not to act unless a stimulus (i.e., a former action effect) activates an action. Even though the overall choice preferences of the participants might be taken as first evidence against this alternative explanation, it is also possible to directly assess its validity using data from the current experiments: The frequency of non-actions in the acquisition phases provides an estimation for participant's default selection of non-actions. Pooling the data of all three experiments showed that the frequency of consistent non-action choices in the test phase was considerably higher than the frequency of non-action choices in the acquisition phase both, for the entire group of participants, $t(95) = 4.59$, $p < .001$, $d = 0.47$, and for the group of participants that was not identified as using response strategies, $t(65) = 2.60$, $p = .012$, $d = 0.32$. This indicates that a preference for non-actions in response to non-action effects does not stem from a default preference for not acting but does indeed reflect non-action effect binding.

Our experiments further showed that the frequency of consistent choices was equally high for non-actions and actions, indicating that associations between non-actions and their effects might be as strong as associations between actions and their effects. This is in line with the idea that non-actions and actions are represented in the same way, namely, via the sensory effects they produce (Kühn et al., 2009). The present state of the field, however, can only be seen as a first sign for an effect-based representation of non-actions. Future research needs to address the question whether the anticipation of non-action effects can influence not acting, as it has been shown for actions (e.g., Ansorge, 2002; Keller & Koch, 2006; Kunde, 2001; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014; Pfister & Kunde, 2013; Yamaguchi & Proctor, 2011; Zwosta, Ruge, & Wolfensteller, 2013).

Furthermore, the question remains what part of a non-action is bound to the effects and what exactly is activated by the presentation of the non-action effects, as non-actions are not simply characterized by a unique motor pattern. It has been proposed that a non-action representation contains information about the specific action that is omitted by the non-action (Kühn & Brass, 2010b). This proposal seems to be particularly relevant for response inhibition. Assuming response inhibition is controlled in an effect-based manner (Ridderinkhof, van den Wildenberg, & Brass, 2014), an already started action (e.g., a key press with the left index finger) might be stopped by anticipating the distinct sensory consequences of the stopping which in turn results in a specific deactivation or reversal of the movement patterns involved in the action (i.e., a stopping of the left finger movement). The non-action

[3] We collected data for an additional experiment which was identical to Experiment 3 but included a novel tone (in addition to the action tone and the non-action tone) in the test phase which had not been associated with action or non-action before. In this experiment, we found no consistency effect for acting and not-acting at all. The complete absence of binding effects in this experiment is difficult to explain convincingly in light of the preceding three experiments. Still, the data of this experiment helps to paint a clearer picture of the replicability of this effect. Data of this additional experiment can be retrieved from the Open Science Framework: https://osf.io/q8tgk.

representation would then activate rather specific muscles. However, in a situation where response selection has not yet been completed and choosing not to act is one option among other action possibilities (as might be assumed for the test phases of the current experiments), the representations might be more general and non-actions might suppress all kinds of movements. These considerations need to be investigated more thoroughly in future research. A first step might be to expand the contexts and settings under which non-actions are examined.

6. Conclusion

In the present experiments, action effects and non-action effects alike triggered their corresponding responses, even when controlling for potential confounding factors, such as overall action tendencies and the use of deliberate choice strategies. This indicates that non-actions, just like actions, can become bound to their subsequent effects and provides further support for the assumption that non-actions are represented in terms of sensory consequences they produce.

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Author contributions

LW developed the study concept in cooperation with RP and WK. LW designed the experiment, collected the data and analyzed the data. LW drafted the manuscript, RP and WK provided critical revisions. All authors approved the final version of the manuscript for submission.

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