



Uncovering effects of self-control and stimulus-driven action selection on the sense of agency



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ABSTRACT

The sense of agency refers to feelings of causing one's own action and resulting effect. Previous research indicates that voluntary action selection is an important factor in shaping the sense of agency. Whereas the volitional nature of the sense of agency is well documented, the present study examined whether agency is modulated when action selection shifts from self-control to a more automatic stimulus-driven process. Seventy-two participants performed an auditory Simon task including congruent and incongruent trials to generate automatic stimulus-driven vs. more self-control driven action, respectively. Responses in the Simon task produced a tone and agency was assessed with the intentional binding task – an implicit measure of agency. Results showed a Simon effect and temporal binding effect. However, temporal binding was independent of congruency. These findings suggest that temporal binding, a window to the sense of agency, emerges for both automatic stimulus-driven actions and self-controlled actions.

1. Introduction

The sense of agency – the feeling that one causes one's own actions and their subsequent outcomes – is a pervasive and socially well-shared experience that is fundamental to human self-perception and social functioning (Frith, 2014; Wegner, 2002). The sense of agency has been mainly conceptualized and studied as a product of volitional action (Haggard, 2017). Specifically, goal-directed action simultaneously triggers a predictive signal of sensory action-outcomes and a sense of agency emerges when the prediction is consistent with the actual sensory feedback (Haggard, 2008; Haggard & Clark, 2003). The voluntary nature of agency has been nicely demonstrated in the temporal binding task. This implicit measure of the sense of agency hinges on pre-reflective, sensorimotor processes (Haggard, Clark, & Kalogeras, 2002; Stenzel, Schneider, & Engel, 2011), and reveals that intentional action selection produces a temporal contraction in perception between action and outcome compared to when the same action is externally generated. Accordingly, the sense of agency is suggested to originate in self-controlled action selection, and hence represents the voluntary nature of human behavior.

Whereas the voluntary nature of the sense of agency has received much theoretical and empirical attention in research on the temporal binding between action and effect (see Hughes, Desantis, & Waszak, 2012), research on the role of externally controlled action selection in temporal binding has been relatively limited. Building on the notion that behavior is a function of the will and habit (Ach, 1910/2006; James, 1890), the present study aimed to investigate the differential effects of self-control driven versus automatic stimulus driven actions on the sense of agency. Specifically, we examined whether the temporal binding of action and effect is modulated when action selection shifts from processes that rely on volition towards more externally driven processes. Understanding this shift is important, as it provides insight into the question of whether the sense of agency decreases when

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individuals move from willful to habitual behavior, and hence volition has a special status for human social functioning (Bayne & Pacherie, 2015).

1.1. *Intentional binding – a window to the sense of agency*

The sense of agency over actions is primarily rooted in motor-prediction processes described in models of goal-directed motor control (Crapse & Sommer, 2008; Frith, Blakemore, & Wolpert, 2000; Pynn & DeSouza, 2013; Wolpert & Flanagan, 2001). The voluntary selection of a goal-directed action is accompanied by the prediction of sensory action-outcomes based on internal copies of movement-predicting signals (i.e., efference copies) generated by the sensorimotor system. This prediction is supposed to be absent in cases where action selection is involuntary or externally controlled and behavior is fully automatic and unintentional. The efference copy pertains to signals sent out from brain areas involved in motor control to the sensory (e.g., auditory) cortex and allow for a comparison with the actual sensory feedback of action (e.g., when pushing a key predicts the occurrence of a high frequency tone). These internal motor predictions are generally considered to be short-lived but very reliable, and sensory outcomes are readily perceived as self-produced unless the prediction does neither correspond with the actual outcomes nor occur in the first place.

The notion that self-produced effects are perceived differently from externally caused effects allows for a systematic measurement of self-causation. According to a pre-activation account of the sense of agency, predicting a sensory outcome increases the baseline activation of the representation of the outcome in the sensory cortex. When the predicted outcome actually occurs, the increased activation causes the outcome to be perceived sooner, as the increased baseline gives the perception of the outcome a head start in reaching the threshold of consciousness (Waszak, Cardoso-Leite, & Hughes, 2012). Thus, a match between the predicted and actual outcome causes one to implicitly perceive (see, hear, or feel) the sensory outcome-information that comes in from the environment earlier and faster, compared to situations in which the baseline activation is not increased or the predicted and actual sensory outcome do not match.

An important implicit way to measure this shift in time perception as a window to the sense of agency is the intentional binding task (Haggard et al., 2002). In an adaption of the Libet, Gleason, Wright, and Pearl (1983), participants perform an action (e.g., a key press) directly followed (e.g., 250 ms) by an outcome (e.g., the occurrence of a tone), and judge the timing of their own action and the outcome with the help of a concurrently rotating clock hand on a computer screen. When selecting actions voluntarily, participants commonly perceive the occurrence of the action and effects as closer in time, hence, the term intentional binding. Crucially, when the action is induced involuntarily by means of transcranial magnetic stimulation (TMS) over the primary motor cortex, and thus does not issue an efference copy to predict the outcome, the binding effect vanishes or even reverses. This latter finding has been taken as evidence that binding of action and effect in terms of perceived time is indeed a result of volition, and hence, represents an implicit measure of the sense of agency.

Building on this work, several studies have examined qualifiers of the motor-prediction process in yielding the sense of agency, such as manipulating the predictability of the action-effect, the time delay between action and effect, externally induced action movement, and motivational boosting of action-effect anticipation by reward signals (e.g., Aarts et al., 2012; Dogge, Schaap, Custers, Wegner, & Aarts, 2012; Haggard et al., 2002). In short, this research indicates that intentional binding occurs when action follows from a voluntary generated movement, and the prediction signal accompanying the preparation of action is strong and reliable enough to render a comparison with the actual sensory feedback of the action possible.

1.2. *Stimulus-driven processes versus self-controlled processes*

So far, research suggests that the intentional binding effect is closely associated with the sense of agency, especially when agency emerges from self-control processes that involve voluntary action selection and the prediction of resulting sensory effects (Brass & Haggard, 2007; Renes & Aarts, in press). Taking away voluntary action selection decreases intentional binding, as involuntary or externally triggered actions do not (or to a lesser extent) produce a prediction signal of the sensory outcomes. The specificity of the temporal binding effect to voluntary movement implies the involvement of sensorimotor control mechanisms that may play a key role in generating the sense of agency.

The difference between voluntary vs. involuntary action selection addressed above speaks to the degree to which human behavior is directed by the will or habit (Ach, 1910; James, 1890), that is, how much of the behavior is under the control of volition or external stimuli (Aarts & Custers, 2009; Aarts, Verplanken, & Knippenberg, 1998; Berberian, Sarrazin, Le Blaye, & Haggard, 2012; Waszak et al., 2005). Habits are proposed to represent stimulus-driven actions in which goal-relevant cues can initiate actions automatically, thus rendering volitional control more or less redundant in selecting that very same action. However, apart from this functionality aspect, stimulus-driven actions can also be dysfunctional, such as when the stimulus-driven response opposes the selection of an instructed action to produce an effect, and volitional control is required to overcome the pre-potent response. In other words, goal-directed actions (that is, selecting an action to cause a subsequent effect) can follow from a high or low degree of volition, depending on whether action selection relies on self-control or a more automatized process. Assuming that volition, rather than automatism, is the key to the sense of agency, proper selection of an action that competes with a stimulus-driven response may be associated with a stronger sense of agency than an automatic stimulus-driven response, because selecting the action to cause an effect is more effortful and the result of an act of self-control (Danner, Aarts, & Vries, 2008; Demanet, Muhle-Karbe, Lynn, Blotenberg, & Brass, 2013; Wegner, 2002).

Most research on the role of external control in agency has relied on methods (such as TMS or a finger pull device) that fully remove action selection processes (Haggard & Clark, 2003; Haggard et al., 2002; Kühn, Brass, & Haggard, 2013; Moore, Teufel,

Subramaniam, Davis, & Fletcher, 2013). Less research attention has been given to the relation between stimulus-driven action vs. self-controlled action and the sense of agency. Recent research has started to examine the modulating role of stimuli-driven effects on the sense of agency. One study (Wenke, Waszak, & Haggard, 2009) examined how temporal binding between action and effect changes as a function of volitional or externally induced selection of action alternatives and timing (the *what* and *when* component of volition). Participants had to press a left or right key, either self-chosen or in response to a specific cue. Furthermore, the time of each keypress was either self-chosen or it was cued to occur in one of two designated time intervals. Temporal binding was found to be equal for (freely) self-chosen and for stimulus-based actions. However, binding was more pronounced when the action alternatives and action timing were selected in the same way (i.e. when action and timing were both self-chosen or both stimulus-driven) in comparison to when the two selections were made in different ways (i.e. when action was self-chosen and timing was stimulus-driven, and vice versa). This suggests that individuals establish a more coherent experience of behavior when actions result from a single mode of selection, thereby increasing binding between action and effect.

The previous findings offer a first exploration of the relation between stimulus-driven action vs. self-controlled action and the sense of agency. It should be noted, however, that action selection was not stimulus-driven per se, in the sense of an automatically evoked response to stimuli, as quite some time was passed between the external cue and selection of action. That is, the stimulus-based movements (external choice, external timing) clearly require volitional premotor preparation and initiation of action to produce a specific effect. In line with a more automatic stimulus-driven perspective, other studies examined the effects of “ease” of action selection on subjective ratings of perceived control in a reaction-time task. Participants had to rapidly select one of two alternative actions followed by a visual effect. Action selection was preceded by subliminal response primes that facilitated or interfered with the selected actions (Chambon & Haggard, 2012; Wenke, Fleming, & Haggard, 2010). Subjective ratings of perceived control turned out to be lower when primed responses interfered with the selected action. In another study (Siderus & Haggard, 2016; Siderus, Vuorre, Metcalfe, & Haggard, 2017), participants performed a Eriksen flanker task to manipulate the difficulty of action selection (that is, flanker stimuli automatically distracted participants to properly select the desired action). Actions were followed by a visual outcome. Findings show that difficult decisions to select actions were associated with lower ratings of control. The general gist of these findings, then, suggests that the intention to act appears to be disrupted during action selection when conflict emerges, which triggers an experience-based feeling of disfluency that alters the sense of agency.

Whereas the findings alluded to above offer a metacognitive account for the sense of agency, it should be noted that the sense of agency was assessed with subjective judgments of control. Whereas such explicit judgments provide an explicit (introspective) measure of agency attributions, rather than an implicit (pre-reflective) measure of the sense of agency (such as intentional binding), these judgments might represent sense of agency, but also some other type of subjective feelings associated with agency relevant task features, such as perceived difficulty or ability (Bandura, 1977; Malmberg & Little, 2007; Sebanz & Lackner, 2007; Vallacher & Wegner, 1989). Accordingly, whether temporal binding of action and effect is modulated when action selection shifts from a self-control process to a more environmentally driven process remains an open question. The present research was designed to further explore this issue.

1.3. The present study

We combined an auditory version of the Simon task and the intentional binding task. That is, participants had to produce a tone by selecting an action in response to a stimulus, and temporal binding between action and effect was measured by using the *Libet clock setup* (1983). In a typical auditory Simon task (Simon & Rudell, 1967), stimuli consist a high-pitched sound and a low-pitched sound that require the selection of two alternative actions. There are two dimensions of the stimuli, the identity (the pitch relevant for the specific selection of an action, e.g., low push left, high push right) and the position of the sound (left or right ear). It is generally assumed that presentation of the stimulus activates two parallel response-activation routes. The conditional route activates a response according to the task-relevant stimulus dimension as indicated by the S-R pairings specified by the instructions. The unconditional route activates a response on the basis of the location of the stimulus so that the response that spatially corresponds to stimulus location is automatically primed irrespective of task instructions (De Jong, Liang, & Lauber, 1994; Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990). While the conditional route is assumed to be slow and under intentional control, the unconditional one is considered fast and automatic. Importantly, the time-course of both routes converges at response selection stage. When the conditional and the unconditional routes activate different responses (incongruent trials), a conflict arises at response selection stage that must be solved by an act of volition or self-control before the correct response can be executed. This process takes times, increasing RTs and error rates. However, when the two routes activate the same response (congruent trials), the initiation of the movement is relatively more influenced by the external cues and the process is faster and more automatic compared to the incongruent trials. Thus, the Simon task offers a tool to induce automatic (congruent trials) as well as more self-controlled (incongruent trials) actions.

Based on previous research, two hypotheses can be formulated. If participants feel less in control when action selection is disturbed and difficult, then a weaker intentional binding should show up for (incongruent) primed actions that hamper proper action selection. Alternatively, in the congruent condition, participants may rely on volition and mobilize more effort to overcome the “urge” to perform the interfering (incongruent) primed action. This act of self-control and the accompanying enhanced effort to overcome the obstacles may increase the sense of agency (Damen, Dijksterhuis, & Baaren, 2014; Demanet, De Baene, Arrington, & Brass, 2013) leading to stronger intentional binding under conditions of conflict. We report two experiments to test these two competing hypotheses.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-two university students ($M_{\text{age}} = 21.80$ years, $SD = 2.78$; 24 females) participated in the present study. Based on previous research (Dogge et al., 2012; Ruys & Aarts, 2010), this sample size should suffice to find reliable Simon effects as well as Intentional binding effect. All participants were right-handed and reported having no hearing problems. Informed consent was obtained from all individual participants included in the study. Two participants were excluded from the sample. One did not follow the instructions and another made too many errors ($> 50\%$), leaving 30 participants in the final analyses. All data of Experiment 1 (and Experiment 2) are stored at the Mendeley data repository.

2.1.2. Materials & procedure

2.1.2.1. Practice phase. In the first block of the practice phase, participants learned the associations between the targets and the subsequently required actions. At the start of each trial, participants heard the spoken Dutch target word “ja” (which means “yes”), which was played binaurally through a headset. Either a high pitch or a low pitch male voice expressed the target. Participants were instructed to press the left button with the index finger of the left hand when they heard a high pitch voice, and to press the right button with the index finger of the right hand when they heard a low pitch voice (or vice versa depending on the mapping condition, which was counterbalanced between-subjects). Participants were told to respond as fast and accurately as possible (at least within a time-window of 1000 ms). On the first 10 trials participants received feedback on the correctness of their responses. In total, participants were given 50 trials to learn the target-response associations. A Cedrus R530 response pad was used as a response interface.

After participants completed the association-learning block, they took another three blocks to practice the intentional binding task by using a rotating clock presented on the computer screen (see below for more details). In the first block of the practice part with the intentional binding task, participants were required to report the timing of a presented tone at a random moment in time (Tone only block: 46 trials). In the second block participants were required to report the timing of a tone that was presented at a random time interval after the presentation of the voice pitch. The time interval between voices and tones was chosen randomly from reaction times in the association learning procedure (Target-Tone block: 40 trials). In the last block of the practice phase, participants learned that their key presses in response to the targets would cause a tone to occur (frequency = 600 Hz, duration = 100 ms). Participants were asked to respond as fast and accurately as possible in order to produce the resulting tone. The tone was presented 250 ms after key-presses. Furthermore, participants were asked to report the timing of the tone (Target-action-tone: 50 trials).

2.1.2.2. Test phase. In the test phase, the previously described task was integrated with the intentional binding paradigm (Haggard et al., 2002). In the intentional binding paradigm, participants report the time at which they either pressed a button – in response to the target – or the time at which they perceived a tone.

Participants were presented with a circular clock face (radius = 8 cm) that rotated clockwise at a rate of 3000 ms per rotation starting from an unpredictable clock hand position (see Lynn, Muhle-Karbe, Aarts, & Brass, 2014). Between 0.5 and 1.5 rotations, the high or low pitch targets were presented through the headphones. A crucial difference compared to the practice phase was that the high pitch or low pitch target voices were not presented in both ears, but were presented in either the left or the right ear. Participants were again required to respond to the voice target with either their left or right hand, thus creating spatial compatibility (e.g., presentation in left ear, left response) and spatial incompatibility (e.g., presentation in left ear, right response). As in the practice phase participants were instructed to press the corresponding button as fast and accurately as possible to cause the tone to occur. The clock hand still continued rotating for a random interval between 1000 ms and 2000 ms after the presentation of the tone and then disappeared. Depending on the block condition, participants reported either the clock position when they pressed a button (agency-action block), or when they heard a tone (agency-outcome block).

There were two additional blocks. In the baseline-action block, participants pressed a button in response to the target, and judged the timing of their button-press *without* the presentation of a tone. In the baseline-outcome block, participants were *not* required to respond to the target. Instead, after the presentation of the target, they heard a tone and judged the time of the presentation of this tone. The time interval between the target and tone was selected randomly for each participant based on the RTs in the practice phase (Target-action-tone trials). The order of the blocks was counterbalanced across participants.

Each block consisted of 40 trials, starting with 5 practice trials that were not included in the analyses. If participants chose the wrong button, or they did not respond in time (1000 ms), then this trial would be repeated at the end of the corresponding block (thus the analyses included the RT and time judgment data of all experimental trials).

2.2. Results

2.2.1. Reaction times

A repeated measures ANOVA with congruency as a within-subjects factor (congruency: congruent vs. incongruent) and mapping as a between-subjects factor (mapping: low-right/high-left vs. high-right/low-left), revealed a main effect of congruency $F(1, 28) =$

135.35, $p < 0.001$, $\eta_p^2 = 0.83$. The mean RTs of the congruent condition were shorter than the mean RTs of the incongruent condition ($M_{\text{congruent}} = 517.80$, $SD = 66.79$; $M_{\text{incongruent}} = 567.10$, $SD = 68.69$), showing a strong Simon effect. There was no main effect of mapping, $F(1, 28) = 0.71$, $p = 0.408$, $\eta_p^2 = 0.03$, nor was there a significant interaction effect between the congruency and mapping conditions, $F(1, 28) = 3.17$, $p = 0.086$, $\eta_p^2 = 0.10$.

2.2.2. Accuracy

The number of errors of button presses were submitted to a repeated measures ANOVA and the results showed a main effect of congruency, $F(1, 28) = 41.20$, $p < 0.001$, $\eta_p^2 = 0.60$. Participants committed more errors in the incongruent condition than in the congruent condition ($M_{\text{congruent}} = 2.87$, $SD = 3.29$; $M_{\text{incongruent}} = 12.53$, $SD = 9.94$). The interaction effect between congruency and mapping was not significant, $F(1, 28) = 0.05$, $p = 0.826$, $\eta_p^2 = 0.002$, and mapping did not have a main effect on the error number, $F(1, 28) = 0.14$, $p = 0.709$, $\eta_p^2 = 0.005$.

2.2.3. Temporal binding

For each trial, judgment error (in milliseconds) was calculated as the difference between the perceived time of an event and its actual time of occurrence. A positive difference in judgment error between agency trials and baseline trials corresponds to delayed awareness of the event, and a negative difference in judgment error between agency trials and baseline trials corresponds to anticipatory awareness. To reduce the influence of extreme perceptual delays and anticipations, trials were omitted from the analyses (0.35% of total) on which the perceived time of an event was more than 750 ms later or earlier than the actual occurrence of the event (see Dogge et al., 2012). The mean judgment errors were subjected to a repeated measures ANOVA with agency, judgment and congruency as within-subjects factors (agency: single event vs. agency event; judgment: action vs. tone; congruency: congruent vs. incongruent) and mapping as a between-subjects factor (mapping: low-right/high-left vs. high-right vs. low-left). These analyses yielded a significant interaction effect between agency and judgment $F(1, 28) = 13.02$, $p = 0.001$, $\eta_p^2 = 0.32$. Replicating the standard intentional binding effect (Haggard et al., 2002), judging the onset of the action in the agency trials (vs. baseline action trials) produced a positive judgment error (mean shift = +36.59 ms; $SD = 74.66$). In addition, judging the onset of the tone in the agency trials (vs. baseline tone trials) produced a negative judgment error (mean shift = -38.70 ms; $SD = 78.81$). In other words, an overall intentional binding effect of 75.29 ms (i.e. the difference between the above mentioned judgment shifts) was found.

However, we did not find an interaction effect between congruency, agency, and judgment: $F(1, 28) < 0.001$, $p = 0.991$, $\eta_p^2 = 0.002$, indicating that intentional binding effect was equally strong in the congruent and incongruent trials (effect size for differences on IB between the congruent and incongruent conditions was virtually absent; $d_z = 0.002$). All other tests did not reach statistical significance (p 's > 0.200). Fig. 1 displays the shifts in perception for action onset and tone occurrence in the congruent and the incongruent condition.

To provide statistical evidence for the absence of a difference on intentional binding between the congruent and the incongruent trials, we conducted a Bayesian analysis (Wagenmakers, 2007) in experiment 1. An estimated Bayes factor (null/alternative) suggested that the data were in favor of the null hypothesis ($BF_{01} = 5.14$); there was no significant difference on intentional binding between the congruent trials and the incongruent trials.

2.3. Discussion

The findings of the first experiment are clear-cut: Participants showed a strong Simon effect, such that incongruent trials impaired performance - (speed and accuracy of responding) compared to congruent trials. This pattern of results concurs with the time-course analysis of the Simon effect: Spatially located stimuli that are congruent with the instructed responses to these stimuli facilitate the unconditional route of automatic responding. When spatially located stimuli are incongruent with the instructed responses to these stimuli, response conflicts emerge that require volition or self-control to guide the correct action, thereby delaying responding.

In addition to the strong Simon effect, we also established a clear intentional binding effect: Participants displayed a temporal contraction in perception between action and effect. However, the intentional binding effect was clearly independent of the congruency of the trials, as revealed by the complete absence of an interaction effect. That is, temporal binding between action and effect occurred for both automatic stimulus-driven actions and self-controlled actions relying on volition.

Before we draw any conclusions about the possible implications of these findings for research on the sense of agency, we deemed it important to provide an independent replication of these effects.

3. Experiment 2

3.1. Method

3.1.1. Participants

Forty-two university students ($M_{\text{age}} = 21.80$ years, $SD = 2.78$; 24 females) were recruited. All participants were right-handed and reported having no hearing problems. Informed consent was obtained from all individual participants included in the study.

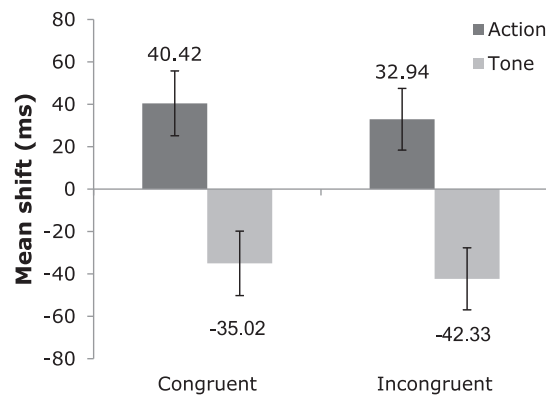


Fig. 1. Mean shift as a function of judged event (key press vs. tone) and type of trial (congruent vs. incongruent). The shifts (indicated by numbers above the bars) correspond to the difference in mean judgement errors between baseline and agency-trials. Error bars represent standard errors.

3.1.2. Procedure¹

In Experiment 2 participants performed a similar task as in Experiment 1 with minor improvement of the instructions in the practice phase. The test phase was identical to Experiment 1.

3.2. Results

3.2.1. Reaction times

A repeated measures ANOVA with congruency (congruent vs. incongruent) as a within-subjects factor and mapping (low-right/high-left vs. low-left/high-right) as a between-subjects factor on mean RTs, showed a main effect of congruency, $F(1,40) = 142.95$, $p < 0.001$, $\eta_p^2 = 0.78$. A reliable Simon effect was shown: Participants responded faster in the congruent condition than in the incongruent condition ($M_{congruent} = 545.47$, $SD = 71.86$; $M_{incongruent} = 596.35$, $SD = 74.35$). There was no main effect of mapping, $F(1, 40) = 0.40$, $p = 0.531$, $\eta_p^2 = 0.01$, nor was there a significant interaction effect between the congruency and mapping conditions, $F(1, 40) = 3.92$, $p = 0.055$, $\eta_p^2 = 0.09$.

3.2.2. Accuracy

The number of errors were submitted to a repeated measures ANOVA and the results showed a main effect of congruency, $F(1, 40) = 31.98$, $p < 0.001$, $\eta_p^2 = 0.44$. Participants committed more errors in the incongruent condition than in the congruent condition ($M_{congruent} = 4.45$, $SD = 6.31$; $M_{incongruent} = 16.21$, $SD = 16.45$). Mapping did not have a main effect on the error number, $F(1, 40) = 2.56$, $p = 0.117$, $\eta_p^2 = 0.06$. The interaction effect between congruency and mapping was not significant, $F(1, 40) = 0.35$, $p = 0.555$, $\eta_p^2 = 0.01$.

3.2.3. Temporal binding

Mean judgment errors were submitted to a repeated measures ANOVA with agency (baseline condition vs. agency condition), judgment (action vs. tone) and congruency (congruent vs. incongruent) as within-subjects factors and mapping (low-right/high-left vs. low-left/high-right) as a between-subjects factor.

The results revealed a significant interaction effect between agency and judgment: $F(1, 40) = 15.94$, $p < 0.001$, $\eta_p^2 = 0.29$, see Fig. 2. Similar to the findings in Study 1, the awareness of the key press was shifted towards the tone (action agency condition) in comparison to the baseline condition in which the action produced no effect (mean shift = +40.45 ms, $SD = 121.14$). In addition, the awareness of the tone was shifted towards the action (tone agency condition) as compared to the baseline condition where the tone occurred in isolation (mean shift = -53.58 ms, $SD = 87.11$). The overall intentional binding effect was 94.03 ms (i.e. the difference between the abovementioned perceptual shifts).

However, we again did not find an interaction effect between congruency, agency, and judgment: $F(1, 40) = 0.11$, $p = 0.747$, $\eta_p^2 = 0.003$. Thus, the intentional binding effect was independent of the congruency of the trials (effect size for differences on IB between the congruent and incongruent condition is $d_z = 0.050$). There were no other main or interaction effects, (p 's > 0.091). Fig. 2 presents the perceptual shifts in action occurrence and tone occurrence for the congruent and the incongruent condition. A Bayesian analysis again suggested that the data were in favor of the null hypothesis ($BF_{01} = 5.70$); there was no significant difference on IB between the congruent trials and incongruent trials.

¹ Considering the observation that previous studies on the Simon tasks and intentional binding task are conducted in the absence or presence of an experimenter, for exploratory reasons we manipulated experimenter presence (absent vs. present) as a between-subjects variable in Experiment 2. There was a main effect of the experimenter presence on the RTs: Participants responded faster when the experimenter was absent compared to the condition when the experimenter was present. No other meaningful differences in results of the Simon task or the Intentional binding task emerged depending on whether the experimenter was present or not (which might be useful information for future research projects in itself). We chose to report this manipulation as a footnote for purposes of both research transparency and readability.

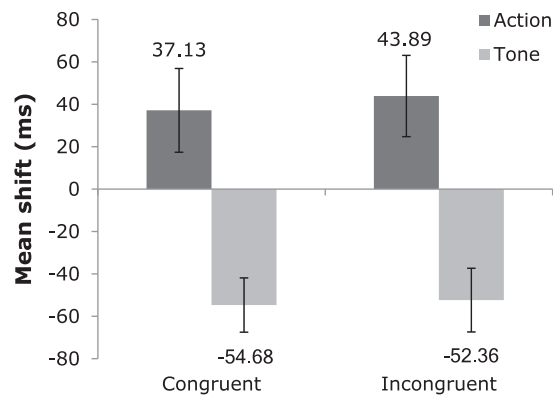


Fig. 2. Mean shift as a function of judged event (key press vs. tone) and type of trial (congruent vs. incongruent). The shifts (indicated by numbers above the bars) correspond to the difference in mean judgement errors between baseline and agency-trials. Error bars represent standard errors.

4. General discussion

In the present study, we combined an auditory Simon task and the intentional binding paradigm to test potential differential effects of congruency on the sense of agency. Based on previous research, congruency might change the sense of agency according to two competing accounts: (1) a volition model in which incongruent trials require volition and an act of self-control to select the proper action and causing a subsequent effect, while congruent trials represent automatic processes that cause action selection to be stimulus-driven; and (2) a metacognitive model in which incongruent trials are experienced to be more difficult in order to select the proper action, while congruent trials are experienced as more easy and fluent the process of action selection. The volition model would predict a higher sense of agency (increased intentional binding) for incongruent trials, while the metacognitive model would predict a lower sense of agency (reduced intentional binding) for incongruent trials.

In general, the results showed a classic Simon effect: participants showed a better performance on congruent trials than incongruent trials. Furthermore, we established a temporal binding effect: the onset of an action (here, a key press) was perceived to occur later and the resulting effect (here, a tone) to occur earlier than when the two events occurred alone. The intentional binding effect appeared to be independent of the type of trials. That is, actions and effects were perceived to occur more closely together in time for both congruent and incongruent trials. The present findings thus do neither support a volitional model of agency nor a metacognitive model of agency. Below we briefly discuss these findings in the context of theory and research aimed at examining and testing the role of volition in the relation between action selection and the sense of agency.

Previous research on the role of volition and the sense of agency has relied on methods that compared conditions of voluntary action selection versus conditions of involuntary movement (such as TMS or a finger pull device) that fully bypass the action selection process. Whereas taking away the action selection process may clearly demonstrate the role of volition in agency (see Hughes et al., 2012; for a critical analysis), in the present research we took a different take by examining differences between stimulus-driven (habitual) and self-controlled (willful) action selection. Specifically, we capitalize on the notion that the Simon task is able to modulate the process of action selection, such that congruent trials follow an automatic effect, and incongruent trials a more controlled effect. Although several models have been put forward to account for the Simon effect, most models agree on the assumption that incongruent trials automatically activate irrelevant response code that requires volitional control to prevent it from execution and to minimize conflict (De Jong et al., 1994; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kornblum et al., 1990; Ridderinkhof, 2002; for an overview see Proctor & Vu, 2006). In line with this notion, recent brain-imaging studies suggests that specific brain regions (such as the anterior cingulate cortex and prefrontal cortex) are implicated in the Simon task that are sensitive to detection of response conflict and subsequent exertion of self-control to execute the proper action and to cause a resulting effect (Kerns, 2006; Liu, Banich, Jacobson, & Tanabe, 2004; Nachev, Kennard, & Husain, 2008). Thus, incongruent trials evoke goal-directed behavior that is more strongly subject to self-control than the congruent trials that are more strongly under control of stimuli.

Why, then, did incongruent trials not modify the intentional binding effect compared to congruent trials? One simple answer is that stimulus-driven and self-controlled action selection affects the sense of agency in the same way. This answer relies on the idea that both types of action selection involve similar motor prediction processes that are assumed to underlie the intentional binding effect. That is, incongruent as well as congruent trials could have triggered a predictive signal of sensory action-outcomes (the tone) that shapes a sense of agency when the prediction is consistent with actual sensory feedback. On that view, congruent actions are more automatic and more bound to the stimulus, but the actual source of behavior emanates from the intention or goal to act in the first place, and therefore is not completely involuntary. Accordingly, the congruent trials in the Simon task may not represent a fully automatic process, but installed goal-directed responding that animated people to anticipate the consequences of their automatic stimulus-driven action. This line of reasoning concurs well with approaches that consider habits as a product of goal-dependent processes that run off automatically once triggered by the context at hand (Aarts & Dijksterhuis, 2000; Bargh, 1989; Hommel et al., 2001).

Whereas the explanation alluded to above focuses on the capacity of congruent trials to shape the sense of agency by allowing

participants to anticipate action-effects, it may also be equally likely that the incongruent trials failed to increase intentional binding. Such failure might arise from the notion that incongruent trials have been shown to decrease self-attributions of agency experiences. The source of the decreased experiences of agency in incongruent trials may emanate from different psychological processes, such as experienced disfluency (Chambon & Haggard, 2012; Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Wenke et al., 2010) or perceived difficulty (Wang, Damen, & Aarts, in preparation); effects that are generally conceptualized as a ‘metacognitive’ account of agency. However, in the current study we also did not find that incongruent trials reduced intentional binding. One possible explanation for this is that intentional binding derives from pre-reflective, sensorimotor processes, while explicit agency attributions build on retrospective reflection and introspection (David, Newen, & Vogeley, 2008; Synofzik, Vosgerau, & Newen, 2008). Though it has been suggested that there should be a close relationship between implicit and explicit measures of agency, different agency cues might modulate different levels of sense of agency (Dewey & Knoblich, 2014). Moreover, it might be the case that the facilitated effect of self-control processes on intentional binding interfered with, or was canceled out by the reduced explicit agency attribution.

A promising avenue for future research is therefore attempting to disentangle or independently explore the two opposite processes retrospective reflection (i.e. pre-reflective sensorimotor processes versus retrospective reflection of agency attributions). For example, a future study may solely focus on the facilitation of responding, possibly through action preparation. Furthermore, future studies may use framing methods to manipulate how participants perceive the incongruent trials: Either emphasizing that one’s own actions in these trials (a) are strongly controlled by external forces (suggesting no control) or (b) require willpower to overcome these external forces (suggesting self-control). Such avenues might offer a better understanding of how and when pre-reflective and attributional measure of agency are related, and how their contributions are weighted in arriving at a sense of agency (Moore & Haggard, 2008; Moore & Obhi, 2012; Synofzik et al., 2008).

5. Conclusion

People commonly experience self-controlled behavior to be accompanied by feelings of intentionality and agency, compared to behavior that is more automatic and habitual (Aarts et al., 1998; Knobe, 2006; Nadelhoffer, 2005). Because these experiences seem to be socially well-shared, society appreciates agency as a result of self-control. Our findings suggest that the sense of agency could be produced both by more automatic stimulus-driven actions and self-controlled actions relying on volition. Importantly, the present study cannot rule out whether (a) automatic stimulus-driven action selection abolished the role of motor prediction; or (b) intentional binding depended on a combination of the motor prediction and the retrospective attribution processes. Future research therefore needs to address more carefully how to differentiate between stimuli-driven versus self-controlled behavior, and how pre-reflective, implicit measures of agency and explicit attribution measures of agency are affected by the two modes of action selection. The present study might offer a test and starting point to examine this important and intriguing issue to shed more light on the voluntary nature of human behavior.

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Conflict of interest

There are no conflicts of interest to report for any of the authors.

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