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Action-effect binding and agency

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ABSTRACT

The sense of agency is a pervasive phenomenon that accompanies conscious acting and extends to the consequences of one's actions in the environment. Subjective feelings of agency are typically explained in terms of predictive processes, based on internal forward models inherent to the sensorimotor system, and postdictive processes, i.e., explicit, retrospective judgments by the agent. Only recently, research has begun to elucidate the link between sense of agency and more basic processes of human action control. The present study was conducted in this spirit and explored the relation between short-term action-effect binding and explicit agency judgments. We found evidence for such a link in that the participants' short-term action-effect binding predicted subsequent agency ratings. This offers a new perspective on the sense of agency, providing an additional mechanism (together with predictive and postdictive processes) that may underlie its formation.

1. Introduction

The sense of agency, i.e., the feeling of control over one's own actions and, through these actions, also over one's environment, is a crucial mental state for human beings and their functioning in society (Haggard & Tsakiris, 2009; Haggard, 2017). Agency allows the correct identification of actions as "own" or "other" which helps to distinguish between the self and the external world (Gallagher, 2000; Haggard & Tsakiris, 2009; Moore, 2016). Agency has further been linked to feelings of responsibility for actions (Frith, 2014; Moore, 2016) and abnormal experiences of agency are associated with severe mental illnesses, such as passivity symptoms in schizophrenic patients (Blakemore, Smith, Steel, Johnstone, & Fritz, 2000; Franck et al., 2001; Haggard, 2017; Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Oestreich et al., 2016).

Because of its strong impact on action and action-related processing, the concept of agency has received much scientific attention in recent years (Chambon, Sidarus, & Haggard, 2014; Haggard & Chambon, 2012; Haggard, 2017; Moore, 2016; Synofzik, Vosgerau, & Newen, 2008; Synofzik, Vosgerau, & Voss, 2013). Previous studies mostly targeted two distinct sets of processes that contribute to agency: (1) predictive processes thought to be based on internal forward models inherent to our sensorimotor system, i.e., sensory attenuation (Beck, Di Costa, & Haggard, 2017; Schwarz, Pfister, Kluge, Weller, & Kunde, 2018; Weller, Schwarz, Kunde, & Pfister, 2017) and intentional binding (temporal and spatial; Haggard, 2017; Haggard & Tsakiris, 2009; Kirsch, Pfister, & Kunde, 2016; Ruess, Thomaschke, Haering, Wenke, & Kiesel, 2017), and (2) postdictive processes, i.e., explicit reasoning employed by the agent to infer authorship for an action (Wegner & Wheatley, 1999; Wegner, 2003).

More recent evidence suggests that despite predictive and postdictive processes, additional factors, for instance the fluency of

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action selection, might also contribute to agency (Chambon et al., 2014; Sidarus & Haggard, 2016; Sidarus, Chambon, & Haggard, 2013; Wenke, Fleming, & Haggard, 2010). These studies suggest that dysfluent action selection, e.g., when response-incompatible subliminal primes precede an imperative signal, lead to reduced feelings of control over an action's outcome (Sidarus et al., 2013; Wenke et al., 2010). This provides first evidence that basic processes of action selection, initiation, and/or evaluation might play a role in the formation of agency. The present study follows this line of reasoning by investigating a possible link between basic processes of action control – i.e., action decisions, action planning, initiation, and execution – and corresponding judgments of agency.

As sense of agency pertains to the perceivable consequences (or effects) of own actions, we consider effect-based accounts to human action control as particularly promising to study potential links between action control and agency (Hommel, 2015). A classical formulation of such effect-based accounts is ideomotor theory, i.e., the assumption that actions are represented in terms of their sensory consequences and that actions are selected and initiated by anticipating these sensory consequences (for empirical evidence, see e.g., Elsner & Hommel, 2001; Kunde, 2001; Pfister, Kiesel, & Hoffmann, 2011). The bi-directional relation between action and effect is evident in both, long-term associations of actions and their effects (Eder & Dignath, 2017; Elsner & Hommel, 2001; Hoffmann, Lenhard, Sebald, & Pfister, 2009; Wolfensteller & Ruge, 2011), as well as in short-term bindings of stimulus, response, and effect into an event file (Dutzi & Hommel, 2009; Janczyk, Heinemann, & Pfister, 2012; Moeller, Pfister, Kunde, & Frings, 2016). Now, if action control mechanisms affect the sense of agency, as is suggested by the impact of action selection fluency on agency, it seems plausible that action-effect binding might contribute to sense of agency.

To test this idea, the present study employed a simple two-step paradigm which is based on previous studies on short-term action-effect binding (Dutzi & Hommel, 2009; Janczyk et al., 2012). In the first step of each trial, participants were asked to press one of two keys which then randomly elicited one of two tones. In the second step, either the previous tone or an alternative tone was played, and participants were then asked to press either of the two keys again. In this procedure, participants' response choices can serve as a proxy for action-effect binding, as high frequency of tone-contingent choices – action repetition in the face of tone repetition, and action switches in the face of tone switches, i.e., choice consistency – can be explained parsimoniously with bindings of actions and effects into event files (cf. Hommel, 2004). Following this sequence of events, participants had to provide an agency rating regarding the first tone, i.e., they were asked to indicate, how strongly they believed to have caused that tone to appear during the first part of the trial. We hypothesized that action-effect binding should affect sense of agency. More specifically, action-effect binding should go along with higher agency ratings for this effect tone in a given experimental trial, i.e., consistent choices should be followed by higher agency ratings.

2. Methods

2.1. Participants

We recruited 34 participants (mean age 24.3 years ± 0.7 SEM; 27 female) to allow for a power of 0.80 when assuming a medium effect size of $d_z = 0.50$ when testing the mean regression coefficients against zero. We further assumed a two-tailed test despite the directional hypothesis. Participants received either course credit or monetary compensation (7 €) for their participation in the experiment. Due to technical issues during data acquisition, two participants had to be excluded from data analysis. All participants gave written informed consent and they received payment or course credit as compensation.

2.2. Apparatus and procedure

Participants were asked to sit in front of a computer screen with a standard German QWERTZ keyboard and headphones attached. They were instructed to respond with the index and middle finger of their left hand on the keys "1" and "2" of the number row, and to operate the computer mouse with the right hand.

Each trial was segmented into three parts as shown in Fig. 1. At the beginning of each trial (prime segment), a fixation cross was displayed for 1000 ms, followed by a line of five asterisk signs in the center of the screen which prompted the participants to choose between both response keys. Participants were asked to press both keys equally often, but to avoid strategies in selecting a key on any given trial. After choosing a key, a low (400 Hz) or high (800 Hz) pitch marimba MIDI sound was triggered randomly and was presented for 500 ms, either immediately after the keypress or after 1250 ms (based on Haering & Kiesel, 2015). This manipulation was based on findings suggesting that the integration of stimulus and response features into event files depends on the temporal spacing between two events (Akyürek, Riddell, Toffanin, & Hommel, 2007; but see also Dignath, Pfister, Eder, Kiesel, & Kunde, 2014), so that immediate effects should yield considerable binding whereas trials with delayed effects should yield less binding.

After an interval of 1000 ms, the probe segment started with the presentation of an exclamation mark together while a second low or high pitch tone presented for 500 ms. This tone could either match (tone repetition) or differ from (tone switch) the first tone in the prime segment. Upon the onset of the second tone, participants were to choose spontaneously between both response keys while not using strategies such as taking any of the previous events into account. Finally, participants were asked to rate how strongly they felt to have caused the first tone (in the prime segment) on a visual analogue scale with the computer mouse (agency rating; original wording in German: "Wie sehr fühlen Sie sich als Verursacher des ersten Tons?", English translation: "How strongly do you feel that you caused the first tone?"). Anchor points on either end of the scale were labelled as "überhaupt nicht" (English: "not at all") and "völlig" (English: "completely"). Error messages appeared if participants pressed a key too early, i.e., before the line of asterisk signs appeared.

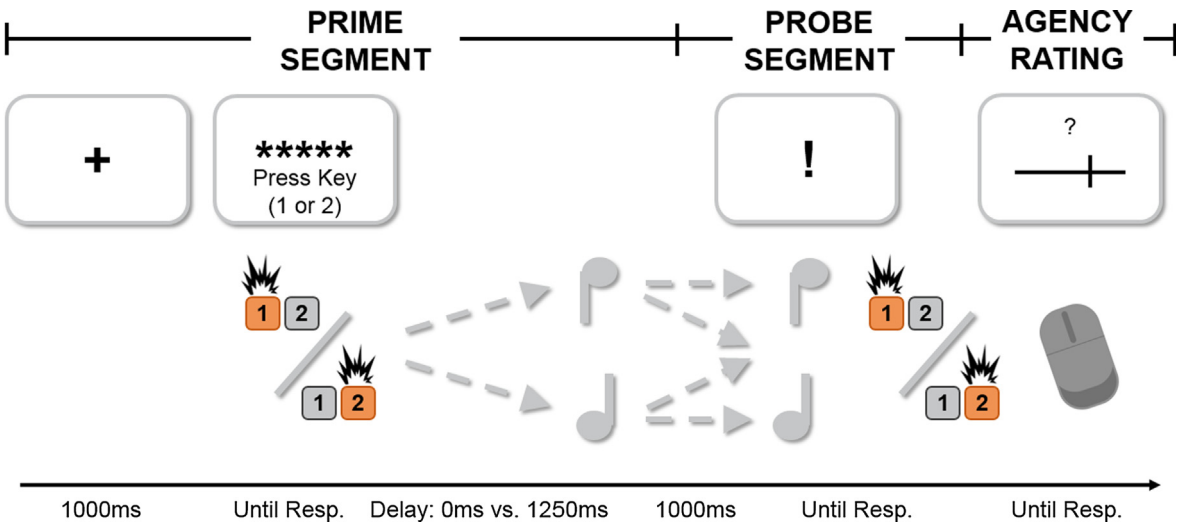

Fig. 1. Procedure. A fixation cross appeared for 1000 ms, followed by a screen with five asterisk signs. Participants then chose to press either of two keys which elicited either a low or high pitch tone at random. The tone was presented for 500 ms either immediately after button press or after a delay of 1250 ms. After an interval of 1000 ms, a low or high pitch tone was presented again for 500 ms, which could be either identical to the previous tone (tone repetition) or a different tone (tone switch), while simultaneously an exclamation mark appeared on the screen. Participants responded to the tone by pressing one of the two keys at their own choice. At the end of each trial, participants were asked how strongly they felt that they had caused the first tone to appear.

To deter participants from simply pressing a key in the probe segment without listening to the probe tone, catch trials were interspersed in which no sound was presented in the probe segment. Participants were instructed not to press any key during those probe segments, and the trial proceeded directly to the agency rating after an interval of 1000 ms. An error message appeared if participants pressed a key during the probe segments of these catch trials.

The experiment consisted of a practice block of 10 trials at the beginning which were excluded from further analysis, followed by 4 main blocks of 72 randomized trials each (64 test trials and 8 catch trials) with short rest periods in between each block.

2.3. Data analysis

To establish the hypothesized effect of action-effect delays on binding, the percentage of response repetitions was analyzed with a 2 × 2 within-subjects analysis of variance (ANOVA) with the factors *tone sequence* (tone repetition vs. tone switch) and *action-effect interval* (0 ms vs. 1250 ms).

Following this analysis, agency ratings were analyzed via regression coefficient analysis (RCA; Lorch & Myers, 1990; Pfister, Schwarz, Carson, & Janczyk, 2013) with separate regression slopes for the predictors *choice* (consistent vs. inconsistent) and *action-effect interval* (0 ms vs. 1250 ms; an interaction of both factors was not included in the models for not capturing substantial variance). Choices were considered consistent if participants chose to repeat their response in tone repetition trials and chose to switch their response in tone switch trials during the probe segment. Catch trials (11.1%) and trials during which an error occurred (3.3%) were excluded from data analysis. Raw data and analyses scripts are available on the Open Science Framework, osf.io/yj5ed.

3. Results

3.1. Response repetitions

The percentage of response repetitions are shown in Fig. 2. Response repetitions differed between tone repetitions and tone switches, $F(1, 31) = 31.49$, $p < .001$, $\eta_p^2 = 0.50$, with higher response repetition rates after tone repetitions than after tone switches. Furthermore the action-effect interval also affected the percentage of response repetitions, $F(1, 31) = 8.82$, $p = .006$, $\eta_p^2 = 0.22$, in that response repetitions were higher without delay between keypress and subsequent tone presentation compared to trials with a delay of 1250 ms. The interaction of both factors proved also significant, *tone sequence x action-effect interval*, $F(1, 31) = 8.70$, $p = .006$, $\eta_p^2 = 0.22$, with a more pronounced impact of tone sequence in trials without action-effect intervals compared to long action-effect intervals. Critically, the difference in response repetition rates dependent on tone sequence indicates the establishment of short-term action-effect binding within trials during the experiment.

3.2. Action-effect binding and agency

Mean agency ratings as a function of choice consistency and action-effect interval are shown in Fig. 2 and the results of the RCA

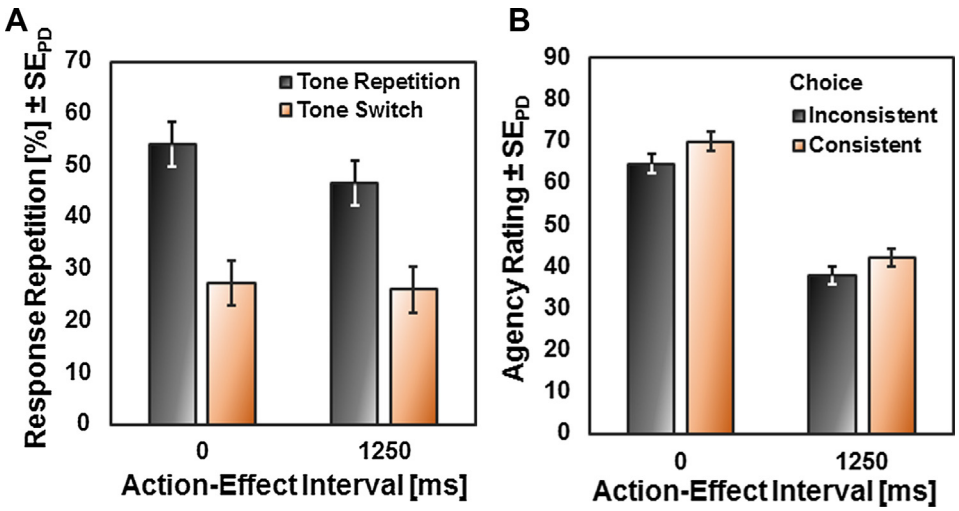

Fig. 2. (A) Percentage of Response Repetitions. Data analysis revealed significant differences in the percentage of response repetitions dependent on *tone sequence* (tone repetition vs. tone switch) and *action-effect interval* (0 ms vs. 1250 ms), as well as a significant interaction between both factors. (B) Agency Ratings. Mean agency ratings as a function of *choice consistency* (inconsistent vs. consistent) and *action-effect interval* (0 ms vs. 1250 ms). Error bars depict standard errors of paired differences (SE_{PD}; Pfister & Janczyk, 2013).

are shown in Fig. 3. The RCA revealed significant contributions of both factors, choice, $b_{choice} = 5.04$, $t(31) = 2.32$, $p = .027$, $d_z = 0.41$, and action-effect interval, $b_{action\text{-}effect\ interval} = -22.04$/s, $t(31) = -5.02$, $p < .001$, $d_z = -0.89$. That is, consistency of response choices predicted subsequent agency ratings with consistent choices being associated with higher agency than inconsistent choices. As choice consistency represents a proxy for action-effect binding, these results indicate that short-term action-effect binding is linked to a stronger sense of agency. Likewise, the action-effect interval predicted subsequent agency ratings, with long intervals being associated with lower agency ratings than immediate action-effect couplings.

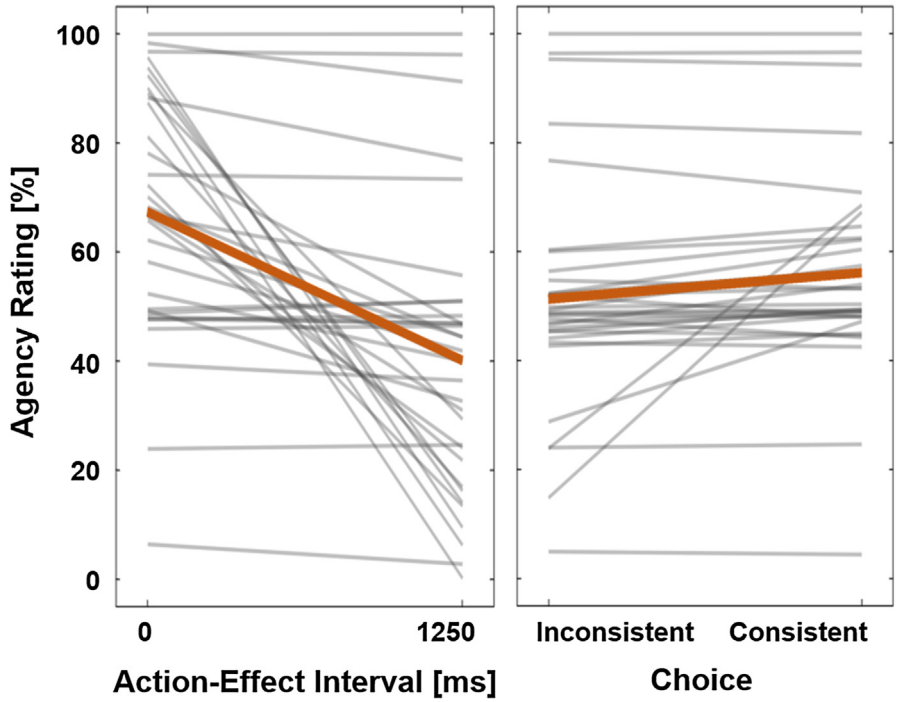

Fig. 3. Results of the Regression Coefficient Analysis (RCA). Grey lines indicate the individual regression lines for each participant whereas orange lines show the average regression line resulting from the RCA. Action-effect interval and choice consistency both predicted subsequent agency ratings, with instantaneous effect presentation being associated with higher agency ratings than long action-effect intervals (1250 ms), and consistent choices, indicative of action-effect binding, being associated with higher agency ratings than inconsistent choices. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

Previous evidence suggests that action control might play a role in the formation of agency (Chambon et al., 2014; Hommel, 2015). Indeed, the binding of action and effect is central to modern accounts on effect-based action control (Hommel, 2004). In this study, we set out to directly investigate the association of binding mechanisms and the sense of agency. To this end, we combined a paradigm on short-term action-effect binding (Dutzi & Hommel, 2009; Janczyk et al., 2012) with agency ratings and analyzed the participants' choice consistency and its relation to agency ratings. We found evidence for short-term action effect binding in terms of increased response repetitions for tone repetitions relative to tone switches. This consistency bias has been explained by a retrieval of recent action-effect bindings (Dutzi & Hommel, 2009). Importantly, the formation of short-term action-effect bindings predicted subsequent agency ratings with evidence for the presence of action-effect binding being associated with higher agency as compared to trials without such evidence. Moreover, action-effect intervals also predicted subsequent agency ratings with no interval being associated with higher agency than long intervals (1250 ms).

Action control and the sense of agency are both research fields that have been studied extensively in the last decades (Eder, Pfister, Dignath, & Hommel, 2017; Frith, 2014; Haggard, 2017; Haggard & Tsakiris, 2009; Hommel, 2009; Kunde, 2001; Moore, 2016; Schwarz, Pfister, Kluge, et al., 2018; Schwarz, Pfister, Wirth, & Kunde, 2018; Weller et al., 2017), but mostly in parallel, rather than in conjunction (but see, e.g., Spengler, von Cramon, & Brass, 2009). Notable exceptions include studies on the impact of action selection fluency on agency that indicate a direct link between both lines of research (Chambon et al., 2014; Haggard & Chambon, 2012; Sidarus et al., 2013; Sidarus, Vuorre, Metcalfe, & Haggard, 2017; Wenke et al., 2010). Based on these previous studies, we employed a paradigm that directly connected action-effect binding with a subsequent agency judgement. Taken together, the present results provide strong evidence that action control mechanisms affect sense of agency, and thus offer an important extension to current models on agency which predominantly feature predictive and postdictive processes (e.g., Synofzik et al., 2008). Crucially, binding and retrieval during action control may offer an important mechanism that explains the formation of agency already during action execution itself.

But what exactly is the nature of the hypothesized mechanism? Event-files as studied in the present experimental paradigm are essentially multisensory representations of a certain action and action-related stimuli (Hommel & Wiers, 2017; Hommel, 2004; Moeller et al., 2016; Zmigrod & Hommel, 2013). Assuming that multisensory integration leads to spatial and temporal binding of the involved sensory signals, it is plausible to assume that the integration of action and effect in an event file lead to temporal attraction between both events (Kirsch et al., 2016; Kirsch, Kunde, & Herbort, 2018; Morein-Zamir, Soto-Faraco, & Kingstone, 2003; Recanzone, 2003; Van Beers, Sittig, & Denier, & van der Gon, 1999). Temporal attraction of action and effect, in turn, is often regarded as an implicit precursor of agency so that action-effect integration would affect agency rather directly via its influence on the perceived timing of action and following action effects (Haggard & Tsakiris, 2009).

The present design does not rule out potential alternative explanations, however, so that three theoretical possibilities could account for the observed link between binding and agency: (1) The above interpretation, i.e., short-term action-effect binding directly leads to higher agency ratings via implicit processes occurring during action execution itself; (2) Short-term action-effect binding leads to higher agency ratings not directly but indirectly via postdictive reasoning processes, i.e., action-effect binding is retrospectively translated into a stronger feeling of control over the action; and (3) sense of agency formed during action execution leads to action-effect binding. Moreover, please note that although the current experiment asks participants specifically to give an agency rating regarding the first tone in each trial, i.e., the tone they produced by pressing a key, we cannot rule out that the subsequent probe segment also affected agency ratings. The present study thus only represents a first step towards a common perspective for action control and sense of agency, providing evidence for a link between basic action control mechanisms and agency. Further studies will be needed to elucidate the precise nature of this link.

5. Conclusions

The present study provides evidence for a link between action control mechanisms and the sense of agency, in that the participants' short-term action-effect binding predicted subsequent agency ratings. This offers a new perspective on the sense of agency, providing an additional mechanism (together with predictive and postdictive processes) that may underlie its formation.

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