



ELSEVIER

Contents lists available at SciVerse ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Short Communication

When moving without volition: Implied self-causation enhances binding strength between involuntary actions and effects

Myrthel Dogge^a, Marloes Schaap^a, Ruud Custers^a, Daniel M. Wegner^b, Henk Aarts^{a,*}^a Department of Psychology, Utrecht University, PO Box 80 140, 3508 TC Utrecht, The Netherlands^b Department of Psychology, Harvard University, 33 Kirkland St., Cambridge, MA 02138, USA

ARTICLE INFO

Article history:

Received 21 July 2011

Available online 23 November 2011

Keywords:

Voluntary vs. involuntary movement

Agency

Intentional binding

Implied self-causation

Inferential processes

ABSTRACT

The conscious awareness of voluntary action is associated with systematic changes in time perception: The interval between actions and outcomes is experienced as compressed in time. Although this temporal binding is thought to result from voluntary movement and provides a window to the sense of agency, recent studies challenge this idea by demonstrating binding in involuntary movement. We offer a potential account for these findings by proposing that binding between involuntary actions and effects can occur when self-causation is implied. Participants made temporal judgements concerning a key press and a tone, while they learned to consider themselves as the cause of the effect or not. Results showed that implied self-causation (vs. no implied self-causation) increased temporal binding. Since intrinsic motor cues of movement were absent, these results suggest that sensory evidence about the key press caused binding in retrospect and in line with the participant's sense of being an agent.

© 2011 Elsevier Inc. All rights reserved.

1. Introduction

Humans engage in voluntary actions, which enable them to manipulate and control their environment, instead of being enslaved by it. Voluntary action is usually accompanied by a sense of agency that is central to social belief systems regarding whether one can influence the external world (Aarts & van den Bos, 2011; Haggard & Tsakiris, 2009; Wegner, 2002). A key mechanism underlying sense of agency is the association between one's actions and action-consequences that is produced by a general associative mechanism involving internal prediction models of sensorimotor control (Frith, Blakemore, & Wolpert, 2000). This linkage causes systematic distortions in the temporal experience of voluntary movements (Haggard & Tsakiris, 2009). Specifically, people perceive their voluntary actions and resulting consequences as if they are temporally bound together in conscious awareness; a phenomenon that is referred to as intentional binding (Haggard, Clark, & Kalogeras, 2002).

In the last decade intentional binding has become one of the most widely used implicit measures to study consciousness of action (Haggard & Tsakiris, 2009). Especially the notion that perceptual attraction between actions and effects results from voluntary movement (i.e. when movement is self-initiated and motor cues can predict the sensory effects), but not from involuntary movement (i.e. when movement is triggered externally and motor cues cannot predict the sensory effects) is taken as good evidence for considering the intentional binding effect as a marker of agency. While this finding has been often replicated (Haggard & Clark, 2003; Haggard et al., 2002; Tsakiris & Haggard, 2003), recent studies have reported binding in the absence of voluntary action (Moore, Wegner, & Haggard, 2009; Strother, House, & Obhi, 2010). These findings challenge

* Corresponding author.

E-mail address: h.aarts@uu.nl (H. Aarts).

the idea that temporal binding only results from voluntary action, and hence represents an implicit measure of the sense of agency.

The present study examines temporal binding between action (a key press) and effect (the occurrence of a tone) in involuntary movement and offers a general account for how binding can arise in the absence of volitional control of action. Specifically, based on the role of inferential influences in binding action to effect (Moore & Haggard, 2008) and the pivotal role of cognition in biasing the process involved in experiences of agency and self-causation (Aarts & Van Den Bos, 2011; Van Der Weiden, Aarts, & Ruys, 2010; Wegner, 2002), we investigate whether implied self-causation can cause participants to bind action and effect together in time even though the action is involuntarily triggered. In other words, we explore whether temporal binding can occur for involuntary actions in individuals who are encouraged to consider their action to cause effects while lacking actual causation.

Previous studies have emphasized the contribution of internal motor cues to intentional binding. In particular, it has been suggested that the temporal linkage of actions and subsequent effects is generated as a consequence of a comparison between the predicted and actual consequence that follows from a motor act. When the predicted and actual information match, people experience self-agency. Recent studies have provided evidence for this idea. For instance, Engbert, Wohlschläger, and Haggard (2008) revealed that binding is similar for auditory, visual and somatic effects, and as such, the entire motor system is involved in the sense of agency. In addition, temporal attraction between movements and subsequent consequences is augmented when people are exposed to reward related information before they perform a voluntary action (Aarts et al., *in press*). This supports the role of motor prediction processes in binding, because dopamine activations are shown to affect the neural substrates of internal preparation and control of motor movement, such as the supplementary and pre-supplementary motor areas (Nachev, Kennard, & Husain, 2008; Sperduti, Delaveau, Fossati, & Nadel, 2011). Furthermore, disturbance of internal forward models, such as in people suffering from schizophrenia, is associated with diminished intentional binding strength resulting from motor predictive processes (Voss et al., 2010).

The idea that intentional binding depends on motor predictive processes suggests that binding should not occur when internal motor cues are absent (i.e. when prediction of action-consequences is not possible, such as in involuntary movement). Consistent with this claim, no binding is observed when an effect is preceded by a passive movement induced by transcranial magnetic stimulation (Haggard & Clark, 2003; Haggard et al., 2002), or when people observe an outcome caused by others (Engbert, Wohlschläger, Thomas, & Haggard, 2007; Engbert et al., 2008). Whereas motor prediction processes resulting from voluntary action seem important for intentional binding to occur, recent research suggests that voluntary action may not be the key to intentional binding, and hence motor predictive processes might not be a precondition for this effect. For instance, one study has revealed binding in participants who had no objective role in bringing about the outcome of an action (Moore, Lagnado, Deal, & Haggard, 2009; Moore, Wegner, et al., 2009). Participants engaged in an involuntary key press that was followed by a either a low or a high pitch tone. Prior to the movement one of these tones could be presented as a prime. The interval between the press and the tone was perceived to be smaller (i.e. binding occurred), when the prime matched the outcome. The authors explain this result by proposing that prior conscious thought (in this study induced by priming), strengthens the feeling that actions and effects are related. This influence of conscious thought is especially strong in the absence of other intrinsic (motor) cues to agency, such as when one engages in an involuntary movement.

Another study revealed that temporal judgements of actions and effects produced by others are similar to those produced by oneself in the context of shared actions (Strother et al., 2010). In this study participants performed the intentional binding task in pairs. Both participants were instructed to prepare and execute a key press during each trial, provided that the other participant had not pressed the key first. If participants were not the first to produce a press they were instructed to passively move their finger in concert with the other's press. Similar binding for self-generated and other-generated actions was observed, even when only one participant of the pair was instructed to plan and generate the action. These results are interpreted in the context of shared action representations; observing the act of another person activates the representations of these actions in the observer's brain which mediates binding.

Although the perceptual attraction between involuntary actions and effects is interpreted differently in the two above-mentioned studies, they may share a common theme. That is, the observed binding might have resulted from the suggestion that participants had a causal role in producing the outcome, even though they did not have such a role in reality. This implied self-causation might have resulted from prior thoughts about the tone (Moore, Lagnado, et al., 2009; Moore, Wegner, et al., 2009) and from the goal to produce the tone together with the other participant (Strother et al., 2010). In other words, contextual cues may induce people to experience a sense of agency and allow them to consider themselves to be the cause of effects following their involuntary movement. The present study investigates this idea by examining whether implied self-causation can generate temporal binding in the absence of voluntary action.

One account that can explain how implied self-causation affects binding between involuntary actions and effects, focuses on the idea that consciousness of action arises from inferential processes. On this view, people use sensory evidence about an action to retrospectively generate the experience of a movement (Aarts, Custers, & Marien, 2009; Wegner & Wheatley, 1999). That is, when prior thoughts of an effect correspond to the actual effect that follows an (involuntary) action, this consistency is used to infer feelings of agency (Ebert & Wegner, 2010). In line with this idea, we suggest that implying self-causation might augment binding by increasing the perceived causal relationship between the thought, action and following effect.

The idea that not only predictive processes but also inferential processes play a role in intentional binding is supported by research on voluntary action (Moore & Haggard, 2008; Moore, Lagnado, et al., 2009; Moore, Wegner, et al., 2009). For instance, one study showed that both the predicted and the actual sensory consequence of an action contribute to binding,

by varying the probability by which a key press produced a tone (Moore & Haggard, 2008). When the probability that the press caused the tone to occur was high, intentional binding was observed even on trials on which the tone did not occur, suggesting that participants predicted the consequence of their actions. In contrast, when the probability of the effect following the action was low, binding occurred only on trials on which a tone was produced. These trials involve an inferential element as motor predictive processes were absent but the occurrence of the tone retrospectively changed the perceived time of action.

Based on these findings, we hypothesize that implied self-causation (vs. no implied self-causation) augments temporal binding between involuntary actions and subsequent effects. To test this hypothesis, participants performed the intentional binding task. They made temporal judgements of an involuntary key press and a tone while they were either encouraged or not to consider themselves as the cause of the tone.

2. Method

2.1. Participants and design

Fifty healthy young adults ($M_{\text{age}} = 21.48$; $SD = 2.86$) were assigned to the cells of a 2 (judgment: key press vs. tone) \times 2 (agency: single-event vs. agency) \times 3 (type of movement: voluntary movement vs. involuntary movement and implied self-causation vs. involuntary movement and no implied self-causation) mixed design, with judgement and agency as within subject variables and type of movement as a between subject variable. All participants received a small payment in return for their participation.

2.2. Task and materials

To assess the role of implied self-causation in binding of involuntary movement, we employed the intentional binding paradigm as described by Haggard et al. (2002). In the involuntary movement conditions participant's right index finger was attached to a key by means of a duct tape. The involuntary press was induced via a magnetic motor system that caused a short depression of the key in response to I/O signals sent by the computer. Participants engaged in the involuntary key press under conditions of implied self-causation or no implied self-causation. To examine the different contributions of these two conditions to the temporal binding effect we added the standard condition in which participants produced voluntary movements. In all three conditions the same key device was used.

2.3. Intentional binding procedure

In a series of trials, participants attended to a clock (diameter = 2 cm) with a clock hand (2 mm) rotating clockwise with a period of 2560 ms. The clock face (presented on the computer screen) was marked with conventional intervals (5, 10, 15, etc.). The initial position of the clock hand was random and rotation was initiated automatically. Depending on the trial type, participants pressed a key that caused a tone to occur (500 Hz, presented for 100 ms on a headphone), pressed the key and heard no tone, or only heard the tone. At the end of each trial, they reported the position of the clock hand at the moment they pressed the key or heard the tone, using the numbers 0 through 59 in intervals of 1.

The task consisted of four different types of trials. In one type of trial participants engaged in a key press during the second rotation of the clock hand. This key press was followed by a tone after an interval of 250 ms. Participants were then asked to judge the onset time of their key press. A second type of trial was identical to the first type of trial, with one exception; in this trial type participants judged the position of the clock hand at the moment they heard the tone. We refer to these two types of trials as agency trials. In a third trial type, participants engaged in a key press but did not hear a tone. They were instructed to report the onset of their key press. Finally, in a fourth type of trial no key presses were made, the tone occurred in isolation and participants judged the onset of the tone. We refer to these last types of trials as single-event trials. The task was divided into four blocks; each included one type of trial. Each block contained 40 trials, corresponding to a separate condition in a 2 (judgment: key press vs. tone) \times 2 (agency: single event vs. agency) within-subjects design. The order of blocks was randomized.

Following the procedure suggested by Haggard et al. (2002), for each trial a judgment error (in milliseconds) was calculated as the difference between the perceived time of an event and its actual time of occurrence. A positive judgment error corresponds to delayed awareness of the event, and a negative judgment error corresponds to anticipatory awareness. To reduce the influence of extreme perceptual delays and anticipations, trials on which the perceived time of an event was more than 250 ms later or earlier than the actual occurrence of the event were omitted from the analyses (2.1% of all trials).

2.4. Self-causation manipulation

Implied self-causation was manipulated as part of the task. First, in the voluntary movement condition participants voluntarily produced the action and received instructions in line with the original intentional binding task as described by Haggard and colleagues (2002). In the involuntary movement and implied self-causation condition participants engaged

in an involuntary key press, while they were encouraged to perceive themselves as a cause for producing the tone. In order to achieve this, participants learned to define their key press as a causative action that triggers the tone. That is, they were told that their key press would cause a tone to occur. Finally, in the involuntary movement and no implied self-causation condition, participants also pressed the key involuntarily. However, in contrast to the implied self-causation condition, no additional information was given (i.e. no self-causation was implied). All participants understood and performed the task according to the instructions.

3. Results

The mean judgement errors were subjected to a repeated measures ANOVA with judgment (key press vs. tone) and agency (single-event vs. agency) as within subject variables, and type of movement (voluntary movement vs. involuntary movement and implied self-causation vs. involuntary movement and no implied self-causation) as a between subjects variable. This analysis revealed an interaction between judgement and agency, $F(1,47) = 25.92$, $p < .001$. The awareness of the key press was shifted towards the tone in comparison to a baseline condition in which the action produced no effect (mean shift = 6.46 ms, $SE = 3.71$). In addition, the awareness of the tone was shifted towards the action as compared to when the tone occurred in isolation (mean shift = -44.25 ms, $SE = 9.79$). In other words, an overall intentional binding effect of 50.71 ms (i.e. the difference between the abovementioned perceptual shifts) was found.

Importantly, the interaction between judgement and agency was qualified by a significant three-way interaction involving type of movement, $F(1,47) = 3.72$, $p = .03$. To clarify the three-way interaction and test our specific hypothesis concerning the influence of implied self-causation on intentional binding, we conducted further analyses. Specifically, we examined simple effects of agency for both judged events (i.e. key press and tone) within each type of movement condition. In the voluntary movement condition, we replicated the standard intentional binding effect (Haggard et al., 2002): Participants perceived actions that were followed by a tone as significantly later than actions that did not produce a tone, $F(1,47) = 10.72$, $p = .002$. In addition the awareness of the tone was significantly shifted backwards in time when this tone was preceded by a key press as opposed to when it occurred alone, $F(1,47) = 15.28$, $p < .001$. In the involuntary movement and implied self-causation condition only a significant shift of the effect, $F(1,47) = 10.79$, $p = .002$, but not of the action $F(1,47) = .11$, $p = .742$ was observed. Finally, in the involuntary movement and no implied self-causation condition both the shift of the action, $F(1,47) = .26$, $p = .613$ and the effect, $F(1,47) = 1.12$, $p = .296$ were not significant. In line with our hypothesis, these findings show that implying self-causation enhanced intentional binding in participants who engaged involuntary in pressing the key and hearing the tone and thus lacked actual causation. Fig. 1 displays the mean shifts of the action and the tone as a function of type of movement.

4. Discussion

The present study examined whether involuntary actions and external events are temporally bound together in conscious awareness when it is suggested to participants that they caused the events to occur. Specifically, we established that

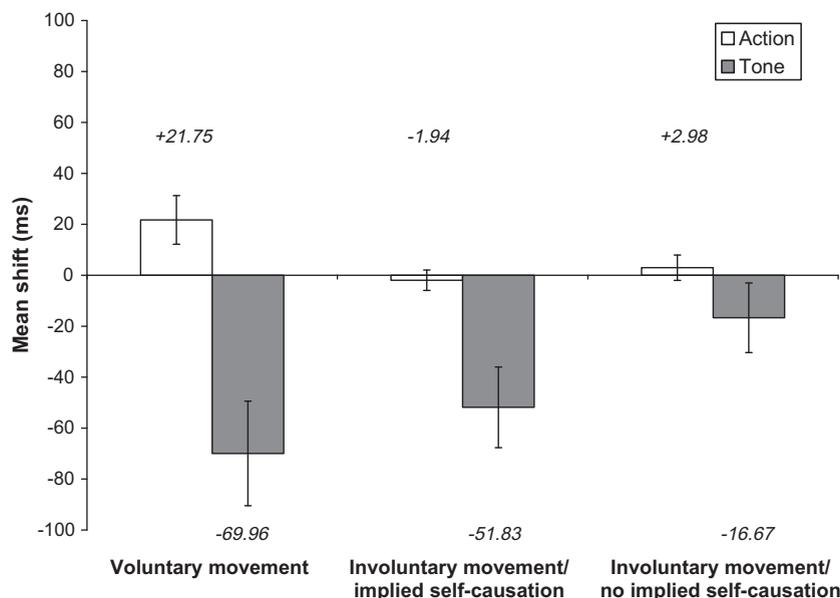


Fig. 1. Mean shift as a function of judged event (key press vs. tone) and type of movement (voluntary movement vs. involuntary movement and implied self-causation vs. involuntary movement and no implied self-causation). The shifts (indicated by numbers above the bars) correspond to the difference in mean judgement errors between single-event and agency-trials. Error bars represent standard errors.

perceptual attraction between a passive key press and a tone is augmented when self-causation is implied as opposed to when participants do not perceive themselves as a cause of the tone.

The observation that binding can occur in the absence of voluntary movements is in agreement with recent studies (Moore, Lagnado, et al., 2009; Moore, Wegner, et al., 2009; Strother et al., 2010). At first sight, this finding seems to contradict the prevailing notion that intentional binding represents a sense of agency that is conditional on volitional control of action. However, the absence of the operation of volition – i.e. when action is not self-initiated and motor cues cannot predict the sensory consequences of one's action – does not necessarily exclude the sense of agency. Prior research has provided evidence for this claim. For instance, people can be fooled into believing they have caused an outcome that was produced by another agent when they think about this outcome prior to its occurrence (Aarts, Custers, & Wegner, 2005; Wegner & Wheatley, 1999). This finding has been explained in the light of inference processes. That is, participants used sensory evidence of the action to retrospectively generate the experience of a movement. A similar explanation can be applied to the results presented here as participants made involuntary movements and had no intrinsic motor cues to predict effects. Instead implied self-causation caused participants to represent their key press in terms of producing the tone, prior to the passive key press. When the actual tone occurred, they more likely felt agency over causing the tone based on the consistency between their thoughts and the external event. Our findings, then, provide a common psychological process pertaining to experiences of self-causation that renders people to bind action and effects together in time, even when their action is involuntary triggered.

An alternative explanation that could be offered for our results is that participants have been slightly active in the involuntary movement conditions, despite the instruction to passively follow the automatic movement of the key. Logically, participants would be most likely to actively move their finger when the key was pressed externally in the implied self-causation condition because the instructions in this condition stressed that participants produced the outcome. It should be noted, though, that our results show that implied self-causation caused only partial binding between involuntary actions and resulting outcomes. That is, participants perceived the tone as if it was shifted towards the key press, but did not perceive their action as shifted towards the tone. If the participants had been active in motor movement, a shift of the action would be expected as a consequence of predictive motor processes which causally link the key press to the tone. Evidence in support of this reasoning comes from the voluntary movement condition in the present study, in which a perceptual shift of the action did occur. Since such a shift was not observed in the involuntary movement and implied self-causation condition, the notion that participants were involved in an active movement is unlikely. This notion is in line with other research showing that only active (voluntary) movement compared to passive (involuntary) movement produces delayed awareness of action initiation (e.g., Obhi, Planetta, & Scantlebury, 2009).

The finding that implied self-causation led participants to engage in anticipatory awareness of effects of their involuntary action rather than delayed awareness of the action itself coincides with results reported for agents who engage in passive movements in shared key presses with other agents (Strother et al., 2010). As noted above, the absent shift of the action might result from a lack of motor processes. In contrast to the action shift, the shift of the tone could take place without intrinsic motor cues, because the combination of the actual occurrence of the tone and the implied self-causation of the task could be used to retrospectively infer a sense of agency over the effect. An intriguing possibility following from this line of reasoning is that perception of actions and perception of effect differ in their sensitivity for predictive and inference processes during operant action. That is, the temporal (delayed) awareness of actions might rely more strongly on predictive than inference processes, while the opposite pattern applies to the temporal (anticipated) awareness of effects. Future research has to explore this possibility.

The present study demonstrated how inference processes can be used to retrospectively cause a perceptual shift of a tone in the absence of voluntary action. A recent study (Moore & Haggard, 2008) has reported another way in which inference processes can produce (partial) binding. In this study participants voluntarily pressed a key which had a low probability of causing a tone. Although here motor processes were active, the absence of a causal relationship between the key press and the tone prevented a prediction of the effect based on these motor cues. The results supported this idea because no shift of the key press was observed when the tone did not occur. However, when the tone did occur, the action was perceived as if it was shifted towards the tone. In this case, sensory evidence of the effect was used to infer sense of agency over action in retrospect. Combined, the present and these earlier findings demonstrate two qualitatively different routes through which inference processes can affect intentional binding: by shifting awareness of action towards effects or shifting awareness of effects towards actions.

The present study also concurs with other research examining intentional binding in the context of experienced causality. For instance, a recent study has shown that binding diminishes when participants are told that a tone is triggered by a confederate's key press, even if they voluntarily pressed the key and caused the tone to occur themselves (Desantis, Rousset, & Waszak, 2011). Here we demonstrated the opposite pattern. Specifically, we revealed that binding strength can be enhanced in participants who play no causal role in producing an effect, provided that they were encouraged to experience self-causation over producing the tone. Together, these findings suggest that knowledge and experiences of causality can modulate the contribution of sensorimotor processes responsible for intentional binding.

To conclude, it is prevalently thought that an action needs to be voluntary in order to produce the intentional binding effect. However, we show that binding can occur in involuntary action and that implied self-causation is a compelling force that may suffice to bind actions and effects in time, thereby facilitating the perception of action coherence, awareness of behavior and the sense of agency.

Acknowledgments

The work in this paper was supported by a Belle Van Zuylen chair Utrecht Grant and a VICI-Grant 453-06-002 from the Dutch Organization for Scientific Research.

References

- Aarts, H., Custers, R., & Marien, H. (2009). Priming and authorship ascription: When nonconscious goals turn into conscious experiences of self-agency. *Journal of Personality and Social Psychology*, *96*, 967–979.
- Aarts, H., Custers, R., & Wegner, D. M. (2005). On the inference of personal authorship: Enhancing experienced agency by priming effect information. *Consciousness and Cognition*, *14*, 439–458.
- Aarts, H., Bijleveld, E., Custers, R., Dogge, M., Deelder, M., & Schutter, D. (in press). Positive priming and intentional binding: Eye blink rate predicts reward information effects on the sense of agency. *Social Neuroscience*.
- Aarts, H., & Van Den Bos, K. (2011). On the foundations of beliefs in free will: Intentional binding and unconscious priming in self-agency. *Psychological Science*, *22*, 532–537.
- Desantis, A., Rousset, C., & Waszak, F. (2011). On the influence of causal beliefs on the feeling of agency. *Consciousness and Cognition*, *20*, 1211–1220.
- Ebert, J. P., & Wegner, D. M. (2010). Time warp: Authorship shapes the perceived timing of actions and events. *Consciousness and Cognition*, *19*, 481–489.
- Engbert, K., Wohlschläger, A., & Haggard, P. (2008). Who is causing what? The sense of agency is relational and efferent triggered. *Cognition*, *107*, 693–704.
- Engbert, K., Wohlschläger, A., Thomas, R., & Haggard, P. (2007). Agency, subjective time and other minds. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 1261–1268.
- Frith, C. D., Blakemore, S. J., & Wolpert, D. M. (2000). Abnormalities in the awareness and control of action. *Philosophical Transactions of the Royal Society of London, series B*, *355*, 1771–1788.
- Haggard, P., & Clark, S. (2003). Intentional action: Conscious experience and neural prediction. *Consciousness and Cognition*, *12*, 695–707.
- Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature Neuroscience*, *5*, 382–385.
- Haggard, P., & Tsakiris, M. (2009). The experience of agency: Feelings, judgements and responsibility. *Current Directions in Psychological Science*, *18*, 242–246.
- Moore, J., & Haggard, P. (2008). Awareness of action: Inference and prediction. *Consciousness and Cognition*, *17*, 136–144.
- Moore, J. W., Lagnado, D., Deal, D. C., & Haggard, P. (2009). Feelings of control: Contingency determines experience of action. *Cognition*, *110*, 279–283.
- Moore, J. W., Wegner, D. M., & Haggard, P. (2009). Modulating the sense of agency with external cues. *Consciousness and Cognition*, *18*, 1056–1064.
- Nachev, P., Kennard, C., & Husain, M. (2008). Functional role of supplementary and pre-supplementary motor areas. *Nature Reviews Neuroscience*, *9*, 856–869.
- Obhi, S. S., Planetta, P. J., & Scantlebury, J. (2009). On the signals underlying conscious awareness of action. *Cognition*, *110*, 65–73.
- Sperduti, M., Delaveau, P., Fossati, P., & Nadel, J. (2011). Different brain structures related to self- and external agency attribution: A brief review and meta-analysis. *Brain Structure and Function*, *216*, 151–157.
- Strother, L., House, K. A., & Obhi, S. S. (2010). Subjective agency and awareness of shared actions. *Consciousness and Cognition*, *19*, 12–20.
- Tsakiris, M., & Haggard, P. (2003). Awareness of somatic events associated with a voluntary action. *Experimental Brain Research*, *149*, 439–446.
- Van Der Weiden, A., Aarts, H., & Ruys, K. I. (2010). Reflecting on the action or its outcome: Behavior representation level modulates high level outcome priming effects on self-agency experiences. *Consciousness and Cognition*, *19*, 21–32.
- Voss, M., Moore, J., Hauser, M., Gallinat, J., Heinz, A., & Haggard, P. (2010). Altered awareness of action in schizophrenia: A specific deficit in predicting action consequences. *Brain*, *133*, 3104–3112.
- Wegner, D. M. (2002). *The illusion of conscious will*. Cambridge, MA: MIT Press.
- Wegner, D. M., & Wheatley, T. (1999). Apparent mental causation. Sources of the experience of will. *American Psychologist*, *54*, 480–492.