Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Cognition 107 (2008) 693–704
COGNITION
www.elsevier.com/locate/COGNIT

Brief article

Who is causing what? The sense of agency is relational and efferent-triggered

Kai Engbert [a,*], Andreas Wohlschläger [a], Patrick Haggard [b]

[a] *Max Planck Institute for Human Cognitive and Brain Sciences, Department of Psychology, Stephanstraße 1A, 04103 Leipzig, Germany*
[b] *Institute of Cognitive Neuroscience and Department of Psychology, University College London, London, UK*

Received 22 March 2007; revised 30 July 2007; accepted 31 July 2007

Abstract

The sense of agency ("I did that") is a basic feature of our subjective experience. Experimental studies usually focus on either its attributional aspects (the "I" of "I did that") or on its motoric aspects (the "did" aspect of "I did that"). Here, we combine both aspects and focus on the subjective experience of the time between action and effect. Previous studies [Haggard, P., Aschersleben, G., Gehrke, J., & Prinz, W. (2002a). Action, binding and awareness. In W. Prinz, & B. Hommel (Eds.), *Common mechanisms in perception and action: Attention and performance* (*Vol. XIX*, pp. 266–285). Oxford: Oxford University Press] have shown a temporal attraction in the perceived times of actions and effects, but did directly not study the relation between them.

In three experiments, time estimates of an interval between an action and its subsequent sensory effect were obtained. The actions were either voluntary key press actions performed by the participant or kinematically identical movements applied passively to the finger. The effects were either auditory or visual events or a passive movement induced to another finger.

The results first indicated a shortening of the interval between one's own voluntary action and a subsequent effect, relative to passive movement conditions. Second, intervals initiated by observed movements, either of another person or of an inanimate object, were always

* Corresponding author. Present address: Technical University Munich, Department of Sports Science, Sports and exercise Psychology, Connollystrasse 32, 80809 Munich, Germany. Tel.: +49 177 34 34 624.
E-mail address: kaiengbert@hotmail.com (K. Engbert).

doi:10.1016/j.cognition.2007.07.021

perceived like those involving passive movements of one's own body, and never like those involving active movements. Third, this binding effect was comparable for auditory, somatic and visual effects of action. Our results provide the first direct evidence that agency involves a generalisable relation between actions and their consequences, and is triggered by efferent motor commands.

Keywords: Intentional binding; Agency; Time estimation; Action; Volition; Action; Self and other

1. Introduction

The sense of agency, of controlling one's own actions, is a basic feature of everyday life, and indeed of human nature. However, the precise conditions under which the sense of agency occurs, and its precise phenomenology are poorly understood. This may be largely because introspection about our own actions is rather uninformative. In recent years, laboratory studies of the sense of agency have attempted to shed more light in this area.

These studies generally focus on one of two subcomponents of the sense of agency that can be described as attribution and association. To clarify this point, we take the basic content of agency as "I did that". Studies focusing on the "I" component of this content deal with the attributional side of agency, and are often described as self-recognition studies. Participants typically make explicit judgements about whether they or another agent was responsible for a given event, such as a visual object triggered by a key press (Wegner & Wheatley, 1999), or visual feedback from a movement (Daprati et al., 1997; Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005; van den Bos & Jeannerod, 2002).

A second approach focuses on the "did" aspect of "I did that". This considers agency as a dyadic association between an action and a consequence or effect. Such associations have been studied in animal operant learning (Dickinson, 1980; Thorndike, 1911), but few studies have considered how they produce an experience of agency in humans. Two key findings have placed linkage across time at the heart of this approach. First, the mental representation of the action predicts the later effect (Elsner & Hommel, 2001; James, 1890). Second, the strength of association, and thus the feeling of agency, operates over a limited time window. As the interval between an action and its sensory effect increases, subjects become less likely to agree that they caused the sensory effect (Wegner & Wheatley, 1999).

A series of recent studies suggested that temporal attraction between action and effect is part of the phenomenology of agency itself, not just a precondition for it. Haggard, Aschersleben, Gehrke, and Prinz (2002a) asked participants to press a key, which produced an auditory stimulus a short interval afterwards. Participants used a rotating clock hand (Libet, Gleason, Wright, & Pearl, 1983) to estimate when they made the action on each trial, or, in separate blocks, when they heard the tone. The results showed a strong temporal attraction between action and tone, relative to baseline control conditions in which actions occurred without tones, or tones occurred without actions. Because no such temporal attraction occurred for involuntary movements evoked by transcranial magnetic stimulation, the effect was called intentional binding, and taken as an implicit measure of agency (Haggard, Clark, & Kalogeras, 2002b).

However, subjects in such event-judgement studies focus on just the action or its effect. The task does not require them to represent both events, and the relation between them. Therefore, these studies cannot provide direct evidence that sense agency involves representing the *relation between* action and effect. Here we investigated the relational aspect of agency directly in three interval estimation experiments. Interval estimates avoid some methodological difficulties associated with the Libet-clock method (Libet, 1985; Pockett & Miller, 2007) and capture the relation between action and effect more directly than estimates based on the perceived time of a single event. Accordingly, we hypothesised that the action-effect interval would be estimated as shorter when the participant was acting intentionally compared to the control conditions where they were not.

Experimental studies require comparing an agency condition to a non-agency control condition. In the attribution or self-recognition approach, the control condition is provided by trials where the subject sees the action of another person, rather than their own action (Daprati et al., 1997; Sirigu et al., 2004). In psychophysical studies of binding, the control condition typically involves an involuntary movement lacking any efferent motor command, though these have generally not been physically comparable with the movements in the agency condition (e.g., Haggard et al., 2002b). Thus, one's own agency can be compared either to the agency of another person, or to one's own non-agentic body movements. Interestingly, few studies have combined both traditions to investigate the attributional and motoric aspects of agency in parallel (but see Engbert, Wohlschläger, Thomas, & Haggard, in press; Tsakiris et al., 2005). Accordingly, the present experiments focus on three outstanding issues regarding human sense of agency, all of which can appropriately be addressed using interval estimates. First, we have tested directly whether agency involves a change in the represented *relation between* action and effect. Second, we have investigated the generality of sense of agency, by investigating different effects of the same class of action. Third we have investigated the conditions necessary for agency by manipulating both the social attribution of action to agents, and the presence of an efferent motor command in a factorial design. Taken as a whole, the results confirm that a distinct chain of phenomenal experience is triggered by efferent signals in the motor system, relating actions to their subsequent effects, and providing a basic sense of agency.

2. Experiment 1

2.1. Methods

Experiment 1 compared estimates of intervals between actions and subsequent auditory effects, using a 2×2 factorial repeated measures design. The factors were: whether the subject actually performed the action, or merely observed an action made by another agent, and whether the interval began with an intentional action or a passive, involuntary movement. We call these factors and their levels "Person" (self/other) and "Agency" (active/passive), respectively. In the self/active condition, participants pressed a lever themselves. In the self/passive condition, the lever and the participant's finger was moved by a computer-controlled stepper motor. In the other/active condition, participants merely observed while the experimenter 'pressed' the lever. In fact, to increase experimental control and avoid subtle cues, the experimenter's finger was moved passively by the motor. Debriefing of participants at the end of the experiments confirmed that they were not aware of this: all thought the experimenter moved intentionally. Finally, in the other/passive condition, the experimenter's hand was replaced on the lever by a rubber hand. The lever was then moved by the motor. We chose to replace the experimenter's hand by the rubber hand to ensure that there was clear visual information to distinguish between the active and passive movements in the other condition. The other passive condition was obviously passive because no biological agent was involved. The other active condition allowed attribution of intentional actions to the experimenter (even though the movements were in fact passive to ensure comparability with the remaining conditions).

These four conditions were tested in different blocks, in counterbalanced order. The four blocks therefore differed in the information available about the action. In the self/active condition, participants had both efferent and proprioceptive information about their own action. In the self/passive condition, proprioceptive but not efferent information was available. In the other/active condition, participants had only visual information about the experimenter's action, though the instruction and setup was designed to promote an 'intentional stance' (Dennett, 1987). In the other/passive condition, visual information was identical, but the intentional stance was discouraged both by instruction and the absence of any biological agent.

Twenty-four paid right-handed volunteers (6 Male) aged between 20 and 36 years (mean age 26.3 years) participated on the basis of informed consent and with local ethical approval. The right index finger either of the participant, the experimenter or a rubber hand was attached to a lever using Velcro. The lever could easily be depressed by the subject, or could be moved via a computer-controlled stepper motor. The lever displacement was 10 mm. After each movement of the lever an auditory tone (100 ms, 1 kHz, 76 dB) was presented via stereo loudspeakers.

Participants made unspeeded verbal judgements of the duration of the interval between the movement and the tone in milliseconds, and these were recorded by an experimenter. They were reminded that 1 s would correspond to a judgment of 1000, 0.5 s to 500 etc. Moreover, participants were told that none of the intervals would be longer than one second. That is, only judgments between "1" and "1000" were counted as a valid answer. Within this range, every judgement was allowed and participants were encouraged to use a full range. In fact, only three action-effect intervals occurred: 200, 250 and 300 ms. Each interval was presented 42 times per block, in random order. No reference intervals or training were given, because we were not interested in the accuracy of interval estimation so much as systematic biases in interval estimation between conditions.

2.2. Results

Interval estimates which were above or below two standard deviations from each participant's mean were excluded, as were trials in which participants reported not having paid attention during testing. The number of excluded trials from both conditions never exceeded 2 % of a participant's data. The remaining data were comparable with previous studies of interval estimation (Wearden, 1999), showing a monotonic relation between actual and estimated interval duration, and between actual interval duration and variability of estimated interval duration (see Table 1). A within-subjects ANOVA with factors of "Interval" (actual length of the interval, 200, 250 or 300 ms), "Person" (self or other) and "Agency" (active or passive) was conducted on estimated interval durations. There was an expected main effect of "Interval" $F(2,23) = 44.570$, $p < .001$, due to the monotonic relation between the actual interval and participant's estimates.

The effects of "Person" and "Agency" are of greater interest and are shown in Fig. 1. There was a main effect for "Person" $F(1,23) = 6.522$, $p = .018$. Participants generally judged the interval as shorter when it began with a movement of their own body, compared to movements they merely observed. Moreover, there was a significant main effect for "Agency" $F(1,23) = 4.451$, $p = .046$, and a highly significant interaction between "Person" and "Agency" $F(1,23) = 9.482$, $p = .005$. Inspection of the figure shows that the interaction arose because the difference between active and passive movements was limited to the self conditions; that are those movements which involved the participant's own body. The interaction was explored further using paired t-tests in a simple effects approach. This indicated that intervals initiated by the participant's intentional actions (self/active) were judged to be significantly shorter than those intervals following a passively induced movement (self/passive) $t(23) = -3.006$, $p = .006$. For movements that were merely observed, this difference was not present $t(23) = .994$, $p = .331$. That is, subjects judged intervals initiated by an action of the experimenter to have similar duration to those initiated by a movement of a rubber hand.

Table 1
Mean perceived interval duration (ms) in each experiment

Interval	Experiment 1			Experiment 2			Experiment 3		
	200 ms	250 ms	300 ms	200 ms	250 ms	300 ms	200 ms	250 ms	300 ms
Self									
Active	194 (96)	254 (118)	293 (135)	225 (93)	293 (118)	359 (154)	216 (90)	292 (125)	353 (166)
Passive	269 (120)	332 (144)	370 (165)	351 (171)	424 (202)	487 (230)	328 (143)	426 (199)	484 (225)
Other									
Active	288 (125)	338 (136)	372 (145)	340 (158)	425 (201)	488 (232)	334 (164)	410 (203)	481 (240)
Passive	261 (116)	332 (141)	380 (156)	332 (158)	439 (227)	494 (247)	321 (147)	406 (194)	464 (215)

The number in parenthesis is the mean across subjects of the standard deviation across trials of each interval estimate, and gives an indication of the consistency of repeated estimates.

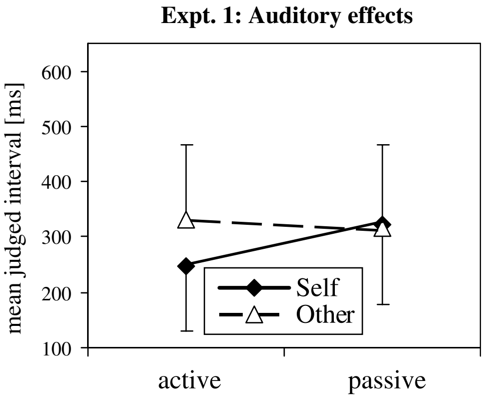

Fig. 1. Results of Experiment 1. Error bars show the SE across subjects. Separate SEs across subjects were calculated at each of the three interval durations, and then averaged.

3. Experiments 2 and 3

3.1. Methods

We performed two further experiments using the same group of 24 subjects, to assess the generality of the results across different sensory modalities of the effect, and to assess whether agency over one's own body was comparable to agency over external events (Michotte, 1963). In Experiment 2, the to-be-judged interval was initiated as before, but the consequence of the action was a passive movement of the participant's left index finger. This was attached to a second lever in the apparatus, which moved under computer-control in the same way as the lever under the right finger. The participant's left and right index fingers and forearms were visible all the time Thus; Experiment 2 provided additional somatic information regarding the effect. In Experiment 3, the effect was a visual event. For comparability with Experiment 2, and symmetry with the initiation of the interval, this was the movement of a rubber finger that was attached to the left lever. Other details were as before. The sound emitted by the movement of the lever was identical throughout the experiments. That is, Experiments 2 and 3 investigated whether *additional* proprioceptive or visual information regarding the effect might influence sense of agency, as measured by interval estimates.

3.2. Results of Experiment 2

Pre-analysis was as before, and exclusion rates were again below 2%. Our analysis focuses on the effects of "Person" and "Agency". ANOVA revealed significant main effects of "Person" $F(1,23) = 7.674$, $p = .011$. and "Agency" $F(1,23) = 23.235$, $p < .001$, and a significant interaction between these $F(1,23) = 16.378$, $p = .001$. Paired *t*-tests indicated that participants generally judged the interval as shorter when they acted themselves compared to movements that were passively induced $t(23) = -5.505$, $p < .001$. For observed movements, no difference between intervals initiated by rubber hand movements and the experimenter's movements was found $t(23) = .648$, $p = .523$.

3.3. Results of Experiment 3

The pre-analysis of the data was as before. Exclusions did not exceed 2%. ANOVA revealed significant main effects of "Person" $F(1,23) = 21.824$, $p < .001$ and of "Agency" $F(1,23) = 11.024$, $p = .003$, and a significant interaction between these $F(1,23) = 19.422$, $p < .001$. Paired t-tests indicated a significant difference between active and passive intervals in the self condition $t(23) = -4.310$, $p < .001$, but not the other condition $t(23) = -.220$, $p = .828$. The results of Experiment 2 and Experiment 3 are shown in Fig. 2.

Finally, we performed a further ANOVA involving data from all three experiments, and including "Experiment" as an additional factor. This showed a significant main effect of "Experiment", $F(1,2) = 6.940$, $p = .002$. Post-hoc t-tests confirmed that this arose because intervals terminated by a sound were perceived as shorter than intervals terminated by visual or somatic stimuli. Thus, there was a significant difference in estimates between Experiments 1 and 2, $t(23) = 2.961$, $p = .007$, and between Experiments 1 and 3, $t(23) = -2.730$, $p = .012$. Experiments 2 and 3 did not differ significantly, $t(23) = -.630$, $p = .535$. This pattern of results was not predicted. It could perhaps reflect differences in the perceptual centres of the three effect stimuli (Morton, Marcus, & Frankish, 1976), though the difference is rather larger than a classic perceptual centre effect. Moreover, the finding seems at variance with Wearden, Edwards, Fakhri, and Percival (1998) who report that a tone appears to last longer than a light of the same duration. They suggested that auditory stimuli caused a relative increase in the rate of a central pacemaker. We

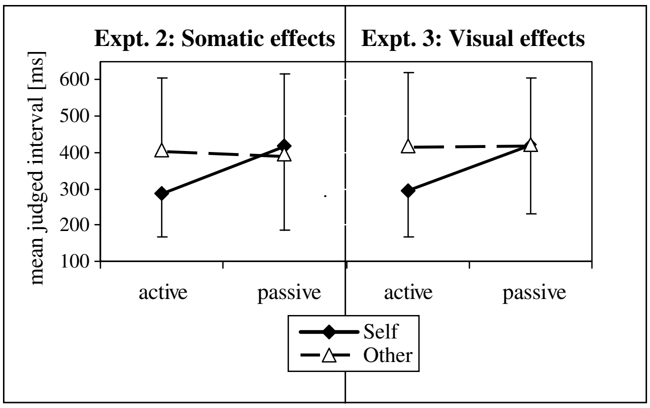

Fig. 2. Results of Experiment 2 and 3. There was no significant interaction between experiments. Error bars show the SE across subjects. Separate SEs across subjects were calculated at each of the three interval durations, and then averaged.

speculate that the interval *prior* to an auditory stimulus (as in our Experiment 1) is retrospectively compressed in subjective time, as an adjustment for the dilation of subjective time caused by post-stimulus pacemaker acceleration. The combined pre-stimulus compression and post-stimulus dilation would maintain a constant rate of flow of subjective time over the longer term (cf. Yarrow, Haggard, Heal, Brown, & Rothwell, 2001). More importantly for our hypotheses, there were no significant interactions involving the ''Experiment'' factor, while the main effects of ''Person'' and ''Agency'', and the interaction between them, were all highly significant, as expected from the analysis of individual experiments.

3.4. Discussion

We have found a reliable and general effect of participant's voluntary action on subjective time. Specifically, the perceived duration of an interval between voluntary action and an ensuing sensory effect was shorter than that between a comparable involuntary movement and the same effect. Intervals initiated by observed movements, either of another person or of an inanimate object, were always perceived like those involving passive movements of the participant's own body, and never like those involving active movements. Our study has four important implications for the sense of agency: Agency is relational, generalises over several different types of effect, is efferent-triggered and is epistemologically private, rather than shared. We now discuss these in turn.

3.4.1. Agency is relational

First, our study offers the first direct evidence that the sense agency involves a specific representation of the relation between intentional actions and their effects. Previous accounts of intentional binding were based on judgements about the time of a single event in each block, either action or effect (Haggard et al., 2002a). In these studies, the subject need not attend to the event they do not judge, and need not represent the relation between events. Studies using behavioural measures such as reaction time (Elsner & Hommel, 2001) confirmed an association between action and effect, but could not show that this relation formed part of the conscious experience of agency. The field of operant learning describes how animals acquire representations of the relation between their action and subsequent effects. This capacity allows them to interact with and control their own environment. To this extent, the intentional binding effects may be a reflection in conscious experience of a basic system for representing relations between actions and effects.

3.4.2. Agency is a general class of experiences, not a particular experience

Second, our results show a common effect of intentional binding which relates an action to any of several possible effects. Previous binding studies used auditory effects, while previous self-recognition studies used visual feedback (Daprati et al., 1997). Here, we found comparable intentional binding for auditory, visual and somatic effects. In particular, the relation between an action and one's own body (Experiment 2) was experienced in the same way as the relation between an action and external visual and auditory effects. This indicates that the body is not epistemologically special from the effect point of view. The relation between our actions and our body may be experienced in the same way as the relation between our actions and the external world.

Taken together, these properties of relationality and generality suggest that the sense of agency is not so much a single experience, or quale, as a framework or syntax within which several different experiences may be accommodated. Agency appears as a general principle for organising experiences of action.

3.4.3. Agency requires efferent motor commands

Third, our results offer direct evidence that an efferent motor command is required for a sense of agency. The relation between action and effect was profoundly different when subjects controlled the initial action themselves from when an identical passive displacement was applied to them, or when they observed another's movement. In previous studies, intentional actions were compared to control conditions involving muscle twitches evoked by TMS (Haggard et al., 2002b), or to pressing down on the subject's finger (Tsakiris & Haggard, 2003). Though similar, these were not strictly physically comparable with the intentional actions. Here, passive movements applied via the response lever itself, and observed movements of the same response lever did not produce the robust intentional binding that occurred when subjects actively moved the lever themselves. We conclude that an efferent motor command is necessary for a sense of agency, and that proprioceptive or visual information compatible with an action are not sufficient. Our result reflects a genuine property of human agency, not merely folk-psychological concepts of what agency is, because we used an implicit measure, rather than an explicit judgment of agency (Synofzik, Vosgerau, & Newen, 2007). In addition, our result is at variance with recent reconstructive or inferential accounts of agency (Wegner, 2002). On such accounts, people infer agency when they merely thought of performing an action, and then perceive the action's consequences, as in the I-Spy experiment (Wegner & Wheatley, 1999). Our results suggest that the motor instruction to perform the action has a crucial effect on experience, and generates a true sense of agency. From the action point of view, one's own internal efferent control is quite unlike other events in one's own body or other's bodies. These results are in line with recent findings on timing estimates in social interactions (Engbert et al., in press).

3.4.4. Sense of agency is epistemologically private, and not socially shared

Finally, our implicit measures of agency applied only to the participant's own action, and not to observed actions of another agent. We found no evidence that an 'intentional stance' towards the agency of others (Dennett, 1987) altered the primary experience of actions and effects by binding them together. That is, although the generalisability of binding to different effect types was high (previous paragraph), we found low generalisability to other agents. Debriefing of our subjects showed that they clearly believed that the experimenter made voluntary actions just as they did. However, this understanding did not alter the relation they perceived between the experimenter's action and subsequent effects. Whereas the participants perceived their own agency, they did not simulate the agency of others as being equivalent to their own experience. This contrasts with previous evidence that the experience of another's action reflected an attribution that the other person intended to produce an effect (Wohlschläger, Haggard, Gesierich, & Prinz, 2003). That evidence was based on event-timing studies, using a constant interval between action and effect. We speculate that the greater predictability of those studies could have favoured a ''simulation'' of agency. In interval-estimations, in contrast, the length of the interval varies and hence predictability is reduced. Our present results suggest that efferent information plays a key role in phenomenal sense of agency. If this information is not available, a 'mirror' process may simulate this phenomenal experience, but only when predictability is high (cf. Jacob & Jeannerod, 2005; Jeannerod, 2006).

Internal predictive models play a major role in recent theories of motor control (Wolpert & Ghahramani, 2000). An internal model is used to predict the consequences of a motor command, allowing error correction in advance of delayed sensory information. In addition, the prediction can be delayed to allow comparison with feedback when this becomes available. This computational framework has recently been extended to cover the conscious experience of action and its pathologies (Frith, Blakemore, & Wolpert, 2000). For example, the sense of agency might arise when sensory information corresponds to the prediction made from motor commands: if what actually happened corresponds to my motor commands, then ''I did that''. However, there have been few attempts to test the framework against experimental measures of action experience. Our results offer experimental support to two aspects of the framework. First, both framework and data emphasise the relation across time between action and effect. In the model, information about agency requires delaying predictions by an estimate of the system response time, including sensory delays. Our result confirms this temporal aspect. Second, our results agree with the framework regarding the key contribution of motor command signals for the experience of agency.

Finally, our study avoids some of the methodological problems of previous event timing studies. First, timing judgements in the present study used an internal standard rather an external metric (e.g., the clock of Libet et al., 1983). This removes the need to synchronise events between internal perceptual streams and the external stream of the clock. Synchronisation across perceptual streams is difficult, depends strongly on how subjects allocate attention to those streams, and probably accounts for a large part of the inter-subject variability in event-timing estimates (Haggard, 2005). Second, the use of a clock in event-timing studies opens the possibility that subjects make actions in response to seeing clock arrive at particular positions. This would weaken the relevance of such studies to the problem of voluntary initiation of action or 'free will'. Interval estimation may offer more potential for studying internally-generated actions.

To conclude, the present experiments indicate a pervasive relational and efferent-triggered aspect of human agency. This is shown by attraction across time between one's own voluntary actions and effects, to a greater extent than for control conditions involving passive movements or observed actions. Our results show strong connections between sense of agency and the experience of time. They also suggest that the sense of agency derives from the efferent processing in brain circuits responsible for internally-generated actions.

Acknowledgements

This research was supported by ESRC Grants R000239946 and RES-000-23-1571 to P.H.

References

Daprati, E., Franck, N., Georgieff, N., Proust, J., Pacherie, E., Dalery, J., et al. (1997). Looking for the agent: an investigation into consciousness of action and self-consciousness in schizophrenic patients. *Cognition, 65*, 71–86.

Dennett, D. C. (1987). *The intentional stance*. Cambridge, MA: MIT Press.

Dickinson, A. (1980). *Contemporary animal learning theory*. Cambridge: Cambridge University Press.

Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 229–240.

Engbert, K., Wohlschläger, A., Thomas, R., & Haggard, P. (in press). Agency, subjective time, and other minds. *Journal of Experimental Psychology: Human Perception and Performance*..

Frith, C. D., Blakemore, S-J., & Wolpert, D. M. (2000). Abnormalities in the awareness and control of action. *Philosophical Transactions of the Royal Society (B), 355*, 1771–1788.

Haggard, P. (2005). Conscious intention and motor cognition. *Trends in Cognitive Science, 9*, 290–295.

Haggard, P., Aschersleben, G., Gehrke, J., & Prinz, W. (2002a). Action, binding and awareness. In W. Prinz & B. Hommel (Eds.). *Common mechanisms in perception and action: Attention and performance* (Vol. XIX, pp. 266–285). Oxford: Oxford University Press.

Haggard, P., Clark, S., & Kalogeras, J. (2002b). Voluntary action and conscious awareness. *Nature, 5*, 285–382.

James, W. (1890). *The principles of psychology*. New York: Macmillan.

Jacob, P., & Jeannerod, M. (2005). The motor theory of social cognition: A critique. *Trends in Cognitive Science, 9*, 21–25.

Jeannerod, M. (2006). *Motor cognition: What actions tell the self*. Oxford, UK: Oxford University Press.

Libet, B., Gleason, C. A., Wright, E. W., & Pearl, D. K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential) – the unconscious initiation of a freely voluntary act. *Brain, 106*, 623–642.

Libet, B. (1985). Unconscious cerebral initiative and the role of conscious will in voluntary action. *Behavioral and Brain Sciences, 8*, 529–566.

Michotte, A. (1963). *The perception of causality* (T. R. Miles & E. Miles, Trans.). New York: Basic Books.

Morton, J., Marcus, S. M., & Frankish, C. (1976). Perceptual centres (P-centres). *Psychological Review, 83*, 405–408.

Pockett, S., & Miller, A. (2007). The rotating spot method of timing subjective events. *Consciousness and Cognition, 16*(2), 241–254.

Sirigu, A., Daprati, E., Ciancia, S., Giraux, P., Nighoghossian, N., Posada, A., et al. (2004). Altered awareness of voluntary action after damage to the parietal cortex. *Nature Neuroscience, 7*, 80–84.

Synofzik, M., Vosgerau, G. & Newen, A. (in press). Beyond the comparator model: A multifactorial two-step account of agency'. *Consciousness and Cognition*, in press..

Thorndike, E. L. (1911). *Animal intelligence: Experimental studies*. New York: Macmillan.

Tsakiris, M., & Haggard, P. (2003). Awareness of voluntary actions and their somatic effects. *Experimental Brain Research, 149*, 439–446.

Tsakiris, M., Haggard, P., Franck, N., Mainy, N., & Sirigu, A. (2005). A specific role for efferent information in self-recognition. *Cognition, 96*, 215–231.

van den Bos, E., & Jeannerod, M. (2002). Sense of body and sense of action both contribute to self-recognition. *Cognition, 85*, 177–187.

Wearden, J. H. (1999). ''Beyond the fields we know...'': Exploring and developing scalar timing theory. *Behavioural Processes, 45*, 3–21.

Wearden, J. H., Edwards, H., Fakhri, M., & Percival, A. (1998). Why ''sounds are judged longer than lights'': Application of a model of the internal clock in humans. *Quarterly Journal Experimental Psychology B, 51*(2), 97–120.

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.

Wohlschläger, A., Haggard, P., Gesierich, B., & Prinz, W. (2003). The perceived onset time of self-and other-generated actions. *Psychological Science, 14*(6), 586–591.

Wolpert, D., & Ghahramani, Z. (2000). Computational principles of movement neuroscience. *Nature Neuroscience*(suppl. 3), 1212–1217.

Yarrow, K., Haggard, P., Heal, R., Brown, P., & Rothwell, J. C. E. (2001). Illusory perceptions of space and time preserve cross-saccadic perceptual continuity. *Nature, 414*, 302–303.