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# The time windows of the sense of agency

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ABSTRACT

The sense of agency depends on some internal cues that derive from action control, as well as external cues like contextual information and prior information (degree of contingency between an action and is effect). We assessed whether external agency cues are combined with internal agency cues to affect the sense of agency. In two experiments participants performed a movement (button press) that elicited, after a varying delay, an effect (ball appearing on a screen), and reported their sense of agency over the effect (full, partial or no-agency) while internal cues (premotor information) and external cues (contextual and prior information) were manipulated. We assessed the effect of agency cues on the delays at which the sense of agency varied. The delays were increased with premotor signals but were decreased with contextual information. These findings favour a model of integration of internal and external agency cues over time.



## 1. Introduction

Our actions are often accompanied by a sense of agency, the experience of controlling our own actions and their effects. Because the implementation of an action goes through several stages (an action is first planned, then initiated and finally completed) we have access to different conscious experiences that are tied to these different steps (Gallagher, 2010; Pacherie, 2008). Among these conscious experiences, the sense of agency over an effect is of particular importance because it informs us about the appropriateness of our actions on the external world. The sense of agency over an effect specifically reflects the extent to which our actions cause effects and is determined by the spatial and temporal relationships between an action and its effect. These relationships apply to distinct types of cues related to the control of action (internal agency cues) and to the perception of its resulting effect. Internal agency cues encompass various signals that are tied to the different stages of the control of an action. These signals include internal volitional signals, the predicted sensory signals of an action that are generated by the internal models of action (Feinberg, 1978; Frith, 2005; Frith, Blakemore, & Wolpert, 2000; Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005; von Holst & Mittelstaedt, 1950), as well as proprioceptive signals arising from the effector's movement (Balslev, Nielsen, Lund, Law, & Paulson, 2006; de Vignemont & Fourneret, 2004; Evans, 1982; Farrer, Franck, Paillard, & Jeannerod, 2003a; Marcel, 2003).

The sense of agency is also affected by additional external cues that do not derive from action control. For example, cognitive cues (*e.g.*, instructions, prior thoughts, beliefs) coherent with the subsequent effect can enhance the sense of agency when presented just before the onset of action (Aarts, Custers, & Wegner, 2005; Linser & Goschke, 2007; Sato, 2009; Sato & Yasuda, 2005; Wegner, Sparrow, & Winerman, 2004; Wegner & Wheatley, 1999). Likewise, implicit knowledge acquired from previous occurrences of an action and its effect and reflecting their degree of contingency (*i.e.,* the extent to which

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an action and an effect co-occur) also affects the sense of agency (Moore, Lagnado, Deal, & Haggard, 2009; Shanks & Dickinson, 1991; van der Weiden, Aarts, & Ruys, 2011).

It, however, remains unclear whether these external agency cues are combined with internal agency cues to affect the sense of agency or whether internal and external agency cues independently affect the sense of agency. To address this question, we propose a classification of external agency signals depending on their temporal properties because we think that these properties might be a key element in understanding how these external signals affect the sense of agency. We thus distinguished between contextual signals that are time locked to the action onset (*i.e.,* they are emitted around the onset of the action) and prior information that is conveyed by signals that are not time locked to the action onset because this information is derived from the subject's past experiences.

This question makes sense within a model of the sense of agency that enables formulating predictions about the integration of internal and external agency cues over time. This model postulates that the sense of agency is the result of processes of causal perception by which an effect is perceived as causally linked to the action (Wegner & Wheatley, 1999; Wegner, 2003; Kawabe, Roseboom, & Nishida, 2013). There is clear evidence that the perception of a causal link between two external objects and the sense of agency share the same property of temporal contiguity. Increasing the delay between an action and its effect strongly diminishes the sense of agency over that effect (Farrer, Bouchereau, Jeannerod, & Franck, 2008; Knoblich & Kircher, 2004; Leube et al., 2003; Sato & Yasuda, 2005; Shanks & Dickinson, 1987, 1991; Shanks, Pearson, & Dickinson 1989). Likewise, when observing a moving object that stops close to another stationary object and the latter starts to move after a certain amount of delay, one perceives a causal relation between the two moving objects (*i.e.,* the first moving object is perceived as causing the movement of the second stationary object). But this is only the case if the second object starts to move within a specific time window (*i.e.,* within a minimum delay after the first object has stopped, Michotte, 1946, 1963). In that case, the causal perception depends on a time window within which the signals related to the two objects have to be integrated in order for the two objects to be perceived as causally linked. There is evidence that the sense of agency also depends on the integration of an action and its effect over time (Kawabe, Roseboom, & Nishida, 2013; Wolpe, Haggard, Siebner, & Rowe, 2013). Recently, Kawabe et al. (2013) have shown that the sense of agency depends on processes of temporal grouping between an action and an effect that are similar to those involved in grouping sensory signals. This led to the hypothesis that the sense of agency depends on a time window (starting from the onset of action and extending over a certain period) within which the signals related to the action (*i.e.*; internal agency cues) and to the effect (effect-related signals) have to be integrated. If the delay between an action and its effect increases, the integration of the effect with the action would be less likely because this effect would occur outside this time window; as a consequence the sense of agency over that effect would be affected. Kawabe et al. (2013) have also shown that additional external signals emitted when the action takes place affect the sense of agency by impacting the temporal grouping between an action and its effect. We further suggest that additional external agency cues that occur within the time window of integration would be combined with internal agency cues.

The present study assessed whether the sense of agency depends on the integration of an action and its effect within a time window and whether additional external agency cues affect this integration. We conducted two studies in which participants were required to perform a movement (a button press) that elicited an effect (apparition of a ball on a screen) and to report their sense of agency over that effect while the delay between their movement and the effect was varying. One major difficulty when assessing the sense of agency is to obtain measures that accurately reflect the participants' conscious experiences. Requiring participants to quantify the intensity of their agency might yield unreliable measures of agency as our agency experiences are not quantifiable in nature. Likewise, asking participants to make a self/other distinction might not be appropriate as they might feel that their actions have partially caused the effect, and therefore they might not be satisfied with a forced choice between 'self' (or full-control) and 'other' (or no-control) responses. Offering participants the additional choice of reporting a "partial control" response (in addition to full or no control) has proven to better capture the sense of agency (Farrer et al., 2003b, 2008). Participants were therefore given the choice between three responses: (full control) 'the action fully triggered the ball'; (partial control) 'the action partially triggered the ball' and (no-control) 'the computer triggered the ball'.

We also manipulated internal and external agency cues given to the subjects. Internal agency cues were manipulated by having conditions with or without premotor signals (internal volitional and predicted sensory signals). External agency cues were manipulated by having conditions with or without contextual information (a sound coherent with the action-effect) or conditions with distinct prior information (*i.e.*, distinct degrees of movement-effect contingency). Experiment 1 examined the effects of both premotor and contextual information and experiment 2 examined the effects of both premotor information and prior information.

We computed and compared the delays at which the sense of agency over an effect varied (from full control over the effect to partial control over the effect; and from partial control to no-control). We reasoned that (1) if the sense of agency depends on a time window within which the action is integrated with the effect, manipulating the internal agency cues given to the subjects (presence or absence of premotor signals) should affect the time window of integration, this would result in differences in the delays at which the sense of agency varies. (2) We also hypothesised that if external agency cues are integrated with internal agency cues over time, then the delays at which the sense of agency varies should be affected by additional external cues. (3) We further hypothesised that depending on their temporal properties; different external cues would differently affect these delays. Specifically, we tested the hypothesis that only external cues that occur within the time window can be combined with the internal agency cues. Therefore, only contextual external cues would affect the delays at which the sense of agency varies.