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Priming of actions increases sense of control over unexpected outcomes ☆

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ABSTRACT

Sense of agency (SoA) refers to the feeling that we are in control of our own actions and, through them, events in the outside world. SoA depends partly on retrospectively matching outcomes to expectations, and partly on prospective processes occurring prior to action, notably action selection.

To assess the relative contribution of these processes, we factorially varied subliminal priming of action selection and expectation of action outcomes. Both factors affected SoA, and there was also a significant interaction. Compatible action primes increased SoA more strongly for unexpected than expected outcomes. Outcome expectation had strong effects on SoA following incompatible action priming, but only weak effects following compatible action priming. Prospective and retrospective SoA may have distinct and complementary functions.

1. Introduction

The sense of agency (SoA) refers to the feeling of controlling one's actions and, through them, events in the outside world (Haggard & Tsakiris, 2009). The SoA has both a statistical, objective aspect and a phenomenological, subjective aspect. First, instrumental action implies a link between action and its sensory consequences (Thorndike, 1898). The SoA is indeed sensitive to the statistical contingency between action and outcome (Moore & Haggard, 2008; Moore, Lagnado, Deal, & Haggard, 2009; Sato, 2009). However, it is generally agreed that there is a phenomenal experience of agency, in addition to the statistical computation of contingency. The phenomenology known as SoA comprises the experience of being the author of one's actions, and thus feeling that one is responsible for their outcomes. SoA is an essential feature of normal human mental life and of human society. In particular, it underpins the societal concept of responsibility for action (Spence, 2009), and the legal system. Moreover, many psychiatric disorders, including schizophrenia and OCD, involve an altered SoA.

The SoA can, in fact, be erroneous even in healthy people. Wegner and Wheatley (1999) demonstrated that under certain conditions people can self-attribute actions performed by others. Based on this evidence, they suggested that SoA results from a retrospective process of inferring agency from the match between "prior thoughts" and an observed outcome (Wegner, 2004; Wegner & Wheatley, 1999). This allows the subject to attribute agency over a specific outcome either to oneself or to another agent. However, outcomes can only be attributed once they are known. Additionally, this account cannot explain the component of agency that exists independent of attribution. For example, one can feel more or less in control of a bicycle, even if it is always clear that it is oneself and not someone else riding the bicycle. That is, this theory provides an account of attribution, rather than an account of instrumentality.

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Computational models of sensori-motor control (e.g. Wolpert, Ghahramani, & Jordan, 1995) have provided a formal basis for an alternative view of SoA. The model suggests that an efference copy of motor commands is used to predict sensory reafferences, or action outcomes. These are then compared to actual sensory descriptions of outcomes. The discrepancy between these two signals is associated with a respective decline in perceived control (Blakemore, Wolpert, & Frith, 2002). These sensori-motor predictions can become more precise as the contingency between sensory events and specific actions is learned, resulting in a more accurate experience of control. SoA is stronger for outcomes that are highly contingent on an executed action (Moore & Haggard, 2008; Moore, Lagnado, et al., 2009; Sato, 2009), as well as for highly predictable outcomes (Moore & Haggard, 2008; Moore, Lagnado, et al., 2009).

The work reviewed above might suggest that SoA is simply a matter of monitoring outcomes to confirm that actions were successful. However, people may feel low levels of agency despite achieving the intended outcome. For example, Metcalfe and Greene (2007) showed that participants could accurately report a low level of control even when performance in a task was high. Thus, other signals may contribute to SoA, in addition to action outcomes. Recent frameworks highlight the integrative nature of SoA, stressing the variety of cues to agency (Gallagher, 2012; Haggard & Tsakiris, 2009; Moore & Fletcher, 2012; Synofzik, Vosgerau, & Newen, 2008; Wegner & Sparrow, 2004). Nevertheless, it remains quite unclear how these different signals would be integrated computationally.

One candidate signal that may influence SoA appears to be generated already at the action selection stage (Chambon & Haggard, 2012; Chambon, Wenke, Fleming, Prinz, & Haggard, 2013; Fukui & Gomi, 2012; Wenke, Fleming, & Haggard, 2010). Wenke et al. (2010) first showed that the fluency, or ease, of selecting between action alternatives can affect the subjective experience of agency. In this study, participants made a left or right key-press in response to a target arrow. The key-press triggered the appearance of a coloured circle. Critically, subliminal presentation of a prime arrow prior to the conscious target resulted in a facilitation of action selection for identical, i.e. compatible, prime and target directions, while opposite, i.e. incompatible, directions disrupted action selection (Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach, 2003). Results showed that participants felt more control over colours that followed compatibly-primed actions, than for colours that followed incompatibly-primed actions.

Importantly, the effect of action selection fluency on control ratings cannot be explained by monitoring reaction times (Chambon & Haggard, 2012). Previous studies have shown that increasing the interval between masked priming and the instruction stimulus reverses the polarity of the priming effect on reaction times (NCE; Eimer & Schlaghecken, 1998, 2003; Lingnau & Vorberg, 2005). For short asynchronies (less than 70 ms) the typical "positive compatibility effect" (PCE) of priming is seen, with reduced RTs and errors for compatible, compared to incompatible, priming conditions. However, for longer delays, a "negative compatibility effect" (NCE) emerges: compatibility between prime and target now leads to increases in RTs and errors, compared to incompatible priming. Chambon and Haggard (2012) used this method to dissociate the role of prime–target compatibility and reaction time monitoring in the effects of selection fluency on SoA. They found that judgements of control were always higher for compatible than incompatible primes, even when an NCE timing was used so that compatible primes impaired motor performance relative to incompatible primes. This suggests that priming effects on SoA were indeed independent of motor execution, consistent with their arising at a premotor stage.

A recent neuroimaging study has further highlighted the interrelation between prospective and retrospective cues. In an fMRI adaptation of the Wenke et al. (2010) paradigm, it was found that activity in the angular gyrus (AG) increased in incompatible priming trials, compared to compatible trials, at the time of action selection (Chambon et al., 2013). Additionally, AG activity was negatively correlated with control ratings, i.e. more activity in AG was associated with a lower sense of control. In fact, previous studies have suggested that the AG and the inferior parietal cortex more broadly play a key role in the neural computations of SoA. For example, several studies have shown AG activation when action outcomes are not as expected (Farrer & Frith, 2002; Farrer et al., 2003, 2008; Nahab et al., 2011; Sperduti, Delaveau, Fossati, & Nadel, 2011). Therefore, it seems the AG is involved in prospective agency, as well as outcome-based agency. This region could potentially integrate both prospective and retrospective cues to agency (Chambon et al., 2013).

The common activation of AG for prospective and outcome-based agency raises the question of how a single SoA can be computed from these various different cues. One view suggests that SoA is computed by integrating various cues in a Bayesian optimal way (Moore & Fletcher, 2012). Relatively few studies of agency judgement have investigated this possibility. However, indirect measures of SoA based on intentional binding, i.e., the perceived temporal attraction between action and outcome, have been used to do so. Wolpe, Haggard, Siebner, and Rowe (2013) provided direct evidence for such cue integration, suggesting that the temporal percept of an instrumental action is based on a weighted average of action signals and outcome signals. They found that increasing uncertainty about the outcome tone, by decreasing its signal-to-noise ratio, reduced the perceived temporal contraction between the tone onset and the action that caused it.

Moore and Haggard (2008) devised a method for comparing predictive and retrospective outcome-based processes in intentional binding by comparing the perceived time of actions which either were or were not followed by tones, across blocks where the probability of a tone given an action was either low or high. When outcome probability was low, action binding was found only on trials where the tone actually occurred, suggesting a retrospective, outcome-based mechanism. Conversely, when outcome probability was high, prior knowledge of the action–outcome association lead to a predictive form of intentional binding, even on rare trials where outcomes were omitted. Interestingly, when both retrospective outcome-based and prior-prediction based information were available, binding was no greater than when each mechanism was available alone. This suggests that the two mechanisms may be combined by a weighting function, with the most reliable or most salient making the dominant contribution to SoA.