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Both motor prediction and conceptual congruency between preview and action-effect contribute to explicit judgment of agency

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ABSTRACT

The sense of agency is the sense that one is causing an action. The inferential account of the sense of agency proposes that we experience the sense of agency when we infer that one's own thoughts are the cause of an action. According to this account, the inference occurs when a thought appears in consciousness prior to an action, is consistent with the action, and is not accompanied by conspicuous other causes of the action. Alternatively, a predictive account of the sense of agency proposes that sensory prediction based on efferent (motor) information plays a critical role in generating the sense of agency. The present study investigated whether the sense of agency depended primarily on the conceptual congruence between preview information (*i.e.*, to elicit a thought) and actual sensory feedback as suggested by the inferential account, or whether it depended primarily on the sensory-motor congruence between prediction and actual sensory feedback as suggested by the predictive account. The results indicated that both of these factors did contribute to the sense of agency, although sensory-motor congruence appears to have a more robust impact.

1. Introduction

In everyday life, we often believe that conscious experience of intending to do something causes our actions. As we intend to point to something, we move our finger. When we intend to eat, this seemingly causes a relevant action such as opening the refrigerator. It seems too self-evident to require further investigation. However, it may not always be true. In the seminal paper, Libet, Gleason, Wright, and Pearl (1983) showed that awareness of the intention to move the right hand occurs not *before* but *after* the onset of preparatory brain activity that sets this action into motion. Later study showed that awareness of an intention is tied not the general aspects of action preparation but to the selection of a specific motor program (Haggard & Eimer, 1999). A more recent study has demonstrated that the outcome of a decision can be predicted by brain activity in the prefrontal and parietal cortex, up to 10 s before it enters awareness (Soon, Brass, Heinze, & Haynes, 2008). These results clearly showed that conscious intention arises not before but after neural preparation of selected action. As a result, conscious intention cannot cause our actions, because logically a cause cannot occur after its effect.

Although, precisely speaking a conscious intention cannot cause an action, nevertheless, we often feel that our intention has caused some act to occur. Thus, the critical problem concerns why, despite evidence to the contrary, we feel this way. What kind of mechanism underlies these feelings of action causality, namely the distinct sense that one has caused this action to occur, *i.e.*, the sense of agency (Gallagher, 2000)? In this vein, Wegner (2002) proposed that the experience of willing and causing an action arises from interpreting one's thought as the cause of their action, irrespective of whether or not this inference is correct. According to Wegner (2002), such an inference occurs when a thought appears in consciousness just prior to an action, is consistent with the action, and is not accompanied by other plausible causes of the action. This confluence of factors

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enables one to experience conscious will and to ascribe authorship of this action to ourselves. Consistent with the theory of apparent mental causation, participants reported more enhanced sense of agency when conscious thoughts occurred just prior to actions than when these thoughts followed the observed actions or their effects (Wegner, Sparrow, & Winerman, 2004; Wegner & Wheatley, 1999). Moreover, participants reported an enhanced feeling of agency, when the prior thoughts were consistent with actions, or action-effects than when they were inconsistent with actions, or action-effects (Wegner et al., 2004). However, if other potential causes of an action were provided, participants tended to believe that the action was performed by someone else, even if, in fact, they themselves caused the action (Wegner, Fuller, & Sparrow, 2003).

According to this theory, it is the conceptual congruency between preview information and subsequent sensory outcomes (effects) which determines a sense of agency. In this approach, as suggested by Wegner et al. (2004), efferent information, internal to the motor system, does not play any special role in generating the sense of agency. However, there is disagreement on this issue. An alternative hypothesis emphasizes a critical role for efferent information in generating the sense of agency. According to this hypothesis, when we move the right hand, a motor command is sent to the muscles, and simultaneously an efference copy of this command is sent to an internal predictive model, *i.e.*, a forward model (Wolpert, Ghahramani, & Jordan, 1995, 2001). The forward model makes predictions about both the next behavior of the motor system, and the sensory consequences of this motor behavior. A forward dynamic model makes predictions about the next state of the system, and this prediction compared with the desired state. This comparison enables rapid error correction before sensory feedback is available. By contrast, the forward sensory model makes predictions about the sensory consequences of a movement, and this prediction is compared with the actual sensory consequence of a movement. This prediction can be used to attenuate the sensory effect of self-generated movement, and thereby enables differentiating self-produced from externally generated sensory signals (Blakemore, Frith, & Wolpert, 1999; Blakemore, Wolpert, & Frith, 1998, 2000; Houde, Nagarajan, Sekihara, & Merzenich, 2002; Martikainen, Kaneko, & Hari, 2005; Sato, 2008; Weiskrantz, Elliott, & Darlington, 1971). Sensory prediction made by a forward model also contributes to the experience of agency. Sato and Yasuda (2005) showed that the sense of agency decreased significantly as the discrepancy between the predicted and actual sensory feedback increased, irrespective of who was the actual author of the action-effect.

The purpose of the present study was to compare predictions of an inferential approach to the sense of agency with a predictive approach. Specifically, we investigate whether the sense of agency depended primarily on the conceptual congruency between previewed and actual sensory feedback as suggested by the inferential account, or whether the sense of agency depended primarily on the sensory-motor congruence between predicted and actual sensory feedback as suggested by the predictive account. If prediction of sensory consequence of an action based on efferent information does not make any contribution to the sense of agency, then participants should experience a high sense of agency when a prior thought, but not efferent (motor) information is available. Moreover, this sense of agency should be unaffected by whether or not efferent information is available. Alternatively, if a predictive account is correct and sensory prediction does contribute to the sense of agency, then one's sense of agency should be significantly reduced when a prior congruent thought is provoked but no efferent information is available, compared to when both efferent (motor) information and prior thought are available. Experiments 1 and 2 investigated these possibilities in situations where preview information was explicitly given through instructions.

Experiment 3 used a different paradigm in which preview information was conveyed by priming stimuli instead of instructions with the aim of establishing a subliminal thought. In Experiment 3, both the conceptual congruency between a prior thought and an effect and the motor predictability of sensory consequence of action were manipulated to directly investigate whether the inferential or predictive account of agency is considered valid. If the sense of agency depends solely on the conceptual congruency between prime and effect, only the main effect of conceptual congruency should be significant. In contrast, if the sense of agency depends solely on the prediction made by forward model, only the main effect of motor predictability should be significant.

2. Experiment 1

Wegner et al. (2004) showed that a sense of agency was enhanced as long as consistent-previews occurred immediately before the stipulated time of a motor act, even when this act itself was prevented, *i.e.*, in that participants were told not to move their arms or make other motions incongruent with the previews. Do these results suggest that efferent (motor) information plays no role in generating the sense of agency? One goal of Experiment 1 was to answer this question. To this end, an experimental paradigm similar to that of Wegner et al. (2004) was used.

A second goal pursues the relationship between a sense of agency and sensory attenuation. Previous studies showed that self-produced sensation was attenuated compared to externally produced sensation (Blakemore et al., 1998, 1999; Houde et al., 2002; Martikainen et al., 2005; Sato, 2008). Can such a sensory attenuation be observed even when efferent information is not available as long as prior thought about action is congruent with observed action? Or, can sensory attenuation not be observed when efferent information is not available, thus suggesting that a different process underlies each of sense of agency and sensory attenuation? The second goal of Experiment 1 was to address this issue.

2.1. Method

2.1.1. Participants

Twelve healthy right-handed female volunteers participated in this study. They were on average 21.33 years old