

Agency in the face of error

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Experiencing oneself as the cause of an action is a fundamental building block for a sense of self. A recent study by Sato and Yasuda provides evidence that motor prediction contributes to the experience of agency. Their findings demonstrate that agency is experienced not only for intended, but also for erroneous, unintended actions. This extends our knowledge on the phenomenology of action, and raises questions about the relation between explicit reports and agency-related changes in sensation and perception.

Our experience of having a self is puzzling to cognitive scientists and neuroscientists. On the one hand, the sense of being an 'I' dominates our phenomenological experience [1,2]. On the other hand, it has proven impossible to identify a unique functional principle or brain substrate underlying our sense of self [3]. Rather, our unitary 'self-experience' seems to arise from the interaction of several cognitive subsystems, including memory [4], emotion [5], perception [6], and action [7,8]. The contribution of action has long been neglected. However, action has recently become a central topic in research addressing the sense of self [9–15] because there is converging evidence that the ability to experience oneself as the cause of an action ('self-agency') might be the fundamental building block supporting the sense of self in general. In a recent article [16], Atsushi Sato and Asako Yasuda report a series of elegant and thought-provoking experiments in which they explored the role of prediction for the experience of agency.

Action effects and experienced agency

At the beginning of each of Sato and Yasuda's experiments, the participants acquired an arbitrary mapping between two actions (left and right button press) and two auditory consequences (high or low tone). Thus, they learned that their action consistently produced a particular auditory effect at a particular time. In the second phase, two factors were varied: the congruency of the auditory effect in relation to the acquired action-effect mapping and the temporal delay between action and effect. The tone following each action either corresponded to the earlier acquired mapping (congruent) or not (incongruent). The temporal delay between action and effect varied between 0 ms and 600 ms. Participants were told that the auditory effects could be the result of their own action or the experimenter's action. Participants reported to which extent they felt the tone to be a consequence of their own action.

The results showed that the congruency between the action and its auditory effect, and the temporal delay contributed independently to the experience of agency. This experience was more intense when an action was followed by a congruent tone, and was reduced when the tone was incongruent. This pattern of results was found for self-paced actions (see Figure 1a, left), as well as for actions that were performed in response to stimuli (Figure 1b, left). In addition, the experience of agency became less intense as the temporal delay between an action and its predicted consequence increased. Again, this was observed in a self-paced task (Figure 1a, right) and in a reactive task (Figure 1b, right).

The authors interpret these findings as evidence that the experience of agency depends on a comparison between the predicted and the actual sensory consequences of an action. This is in line with the internal model theory of motor control, which postulates that for each action that is executed a prediction of its sensory consequences is generated. This prediction is compared with the actual consequences of an action. The larger the discrepancy the less likely it is that one experiences oneself as causing the action [17]. Accordingly, an incongruent auditory action effect lead to a discrepancy, because the pitch was not as predicted. Temporal delays lead to a discrepancy, because the action effect was expected at a different point in time.

It is surprising that the experience of agency was affected in a similar way no matter whether the action was freely chosen (self-paced task) or performed in reaction to an external signal (reactive task). This could imply that the extent to which a person freely chooses an action does not modulate her or his experience of agency. Thus, a common mechanism might generate the experience of agency in active and reactive tasks. However, closer inspection of the data points towards differences between the two types of tasks. The effects of a temporal delay between action and effect were more pronounced when actions were performed in response to a stimulus than when actions were freely chosen (compare Figure 1b, right with Figure 1a, right). This raises an interesting possibility: in reactive tasks actors might completely lose the experience of agency when there is a long delay between action and effect, whereas in 'active' tasks the experience of agency is preserved to a considerable extent (note that the asymptote in Figure 1b approaches zero, whereas the asymptote in Figure 1a approaches approximately 50). It seems as though participants were willing to wait indefinitely for an action effect when they deliberately chose to produce it.

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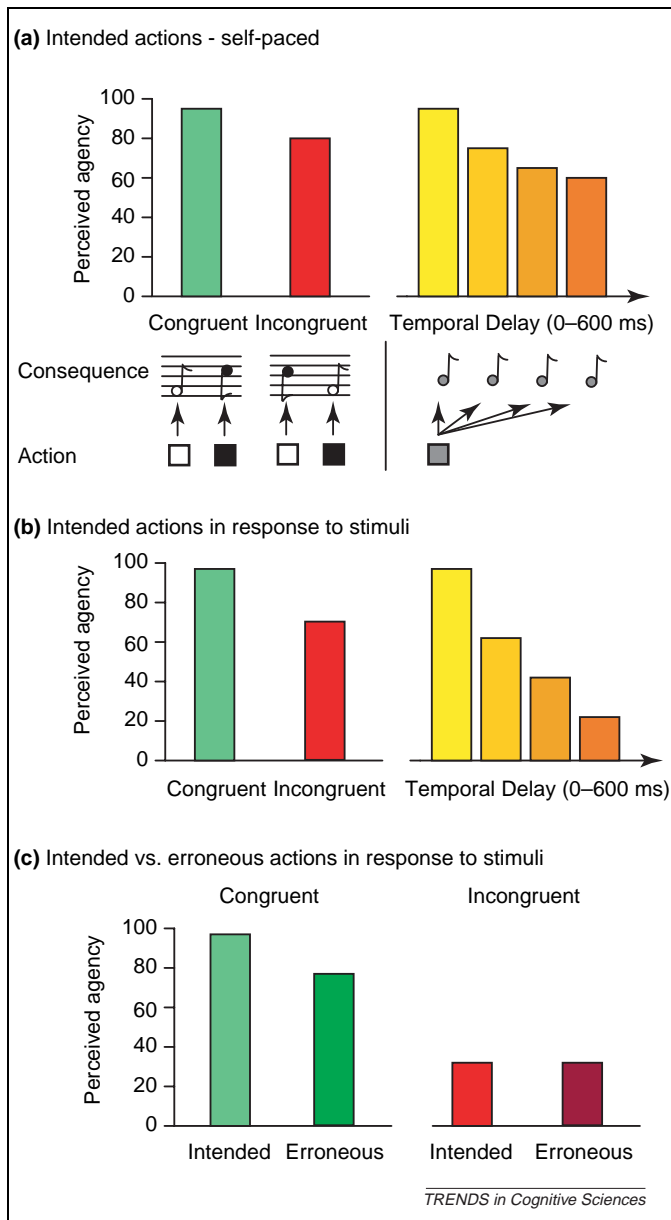


Figure 1. Overview of main results in Sato and Yasuda's experiments [16]. (a) In the first experiment participants performed intentional actions at their own pace. The actions were followed by a tone that was congruent or incongruent with a previously acquired mapping between action and tone. The experience of agency (reported on a scale from 0 to 100) was reduced on incongruent trials (left). With increasing delay between an action and the tone the experience of agency gradually declined (right). (b) Similar effects of congruency (left) and temporal delay (right) were observed in the second experiment where participants produced actions in response to stimuli. (c) The third experiment showed that congruency affected the experience of agency not only for intended actions, but also for erroneous, unintended actions.

Intentions, errors, and experienced agency

Another important question Sato and Yasuda addressed is to which extent the experience of agency occurs for actions that are not intended such as when one commits an error. After learning the action-tone mapping, participants performed a letter version of the Eriksen flanker task, in which participants react to a target surrounded by flankers that are associated with the same or a different response as the target [18]. This task produces high error rates when responses are speeded.

Using this clever technique the authors were able to demonstrate that the congruency between action and effect and the delay between them had an effect on the experience of agency both for intended and for erroneous actions (see Figure 1c). This result supports the authors' assumption that the experience of agency depends on the discrepancy between predicted and actual sensory consequences, regardless of whether an action is intended or is a mistake. However, an additional result qualifies this interpretation: when there was no temporal delay, the experience of agency was less intense for erroneous actions than for intended actions. Thus, the full-fledged experience of agency requires an action to be intended and its effects to be both congruent and temporally contingent.

Alternative explanations

Although there is converging evidence supporting the authors' interpretation that the experience of agency is linked to internal models predicting the consequences of actions [13,14,19], their results could also be interpreted within a different framework. Some researchers in the field of voluntary action postulate that the sense of agency does not rely on predictive mechanisms, but on a post-hoc evaluation of performed actions [20]. In particular, Wegner [21] has proposed that the 'illusory' feeling of causing an action arises based on priority (thought precedes action), consistency (thought consistent with action), and exclusivity (no alternative causes). In Sato and Yasuda's experiments priority was always given, because an intention to act preceded the consequence. Exclusivity was never given, because participants believed that another agent could cause the perceived action consequences. Consistency was manipulated in different ways. It was absent or reduced when the action effect was incongruent, when there was a temporal delay between action and effect, and when an erroneous action was made. The results indicate that any lack of consistency lead to a decrease in the experience of agency. The finding that unintended actions were associated with a relatively strong experience of agency could be explained by the assumption that priority can be sufficient for the feeling of causing an action. Thus, when an intention precedes an action effect, agency is experienced to some extent even when the action effect is not consistent with the intention.

A further explanation for experienced agency for unintentional actions is suggested by recent studies on error monitoring [22,23]. It is well known that after an erroneous action is selected internal monitoring mechanisms signal that one has committed an error. Such error signals are based on the detection of a conflict that occurred while choosing between several action alternatives rather than on the comparison between the predicted and actual consequences of a specific action selected for execution. Agency for erroneous actions could be experienced because an error-monitoring signal is used to re-adjust the system. The readjustment could serve as a direct indication of agency, or it could influence post-hoc evaluations of performed actions.

The next step towards understanding agency

In addition to studies using explicit judgments of agency at least two further lines of research have used implicit perceptual measures. Haggard and his colleagues have demonstrated that an action and its effect are perceived as being closer in time when the consequence is intended [24]. Blakemore and collaborators have shown that the same sensation is experienced as less intense when arising from a self-performed action than when arising from an other-performed action [25]. It is not yet clear whether such changes in sensation and perception are caused by the same mechanisms that inform explicit judgments of agency [17]. Finding an answer to this question would greatly extend our knowledge about the experience of agency.

To conclude, Sato and Yasuda's experiments show that intentions and motor predictions contribute to the experience of agency. Their study is the first to investigate the experience of agency for unintended actions. Further studies like theirs will allow us to better understand the experience of agency in the face of error.

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The wagon-wheel illusion in continuous light

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The fact that a perceptual experience akin to the familiar wagon-wheel illusion in movies and on TV can occur in the absence of stroboscopic presentation is intriguing because of its relevance to visuo-temporal parsing. The wagon-wheel effect in continuous light has also been the source of considerable misunderstanding and dispute, as is apparent in a series of recent papers. Here we

review this potentially confusing evidence and suggest how it should be interpreted.

Some years ago we wrote a paper that described and analyzed an intriguing perceptual phenomenon, pointing out its possible implications [1]: when the spokes of a wheel or other stimuli with elements that move continuously in one direction are observed in sunlight, the elements are sometimes seen to be moving in the opposite direction. Because of the general similarity to the

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