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The influence of performance on action-effect integration in sense of agency

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ABSTRACT

Sense of agency refers to the subjective feeling of being able to control an outcome through one's own actions or will. Prior studies have shown that both sensory processing (e.g., comparisons between sensory feedbacks and predictions basing on one's motor intentions) and high-level cognitive/constructive processes (e.g., inferences based on one's performance or the consequences of one's actions) contribute to judgments of sense of agency. However, it remains unclear how these two types of processes interact, which is important for clarifying the mechanisms underlying sense of agency. Thus, we examined whether performance-based inferences influence action-effect integration in sense of agency using a delay detection paradigm in two experiments. In both experiments, participants pressed left and right arrow keys to control the direction in which a moving dot was travelling. The dot's response delay was manipulated randomly on 7 levels (0–480 ms) between the trials; for each trial, participants were asked to judge whether the dot response was delayed and to rate their level of agency over the dot. In Experiment 1, participants tried to direct the dot to reach a destination on the screen as quickly as possible. Furthermore, the computer assisted participants by ignoring erroneous commands for half of the trials (assisted condition), while in the other half, all of the participants' commands were executed (self-control condition). In Experiment 2, participants directed the dot as they pleased (without a specific goal), but, in half of the trials, the computer randomly ignored 32% of their commands (disturbed condition) rather than assisted them. The results from the two experiments showed that performance enhanced action-effect integration. Specifically, when task performance was improved through the computer's assistance in Experiment 1, delay detection was reduced in the 480-ms delay condition, despite the fact that 32% of participants' commands were ignored. Conversely, when no feedback on task performance was given (as in Experiment 2), the participants reported greater delay when some of their commands were randomly ignored. Furthermore, the results of a logistic regression analysis showed that the threshold of delay detection was greater in the assisted condition than in the self-control condition in Experiment 1, which suggests a wider time window for action-effect integration. A multivariate analysis also revealed that assistance was related to reduced delay detection via task performance, while reduced delay detection was directly correlated with a better sense of agency. These results indicate an association between the implicit and explicit aspects of sense of agency.

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1. Introduction

In daily life, we typically experience a feeling of control over our own actions and the resulting external outcomes. This subjective feeling of control is called the *sense of agency* (Gallagher, 2000). The sense of agency is a fundamental component of how people cognitively distinguish the self and other. The mechanism of sense of agency, along with its dynamics in both normal individuals and patients with mental disorders, has received much attention from researchers in multiple fields, such as psychology, neuroscience, psychiatry, and engineering.

Both low- and high-level processes are thought to contribute to sense of agency. Low-level processes refer to sensory processes, and are highlighted in the comparator model of sense of agency. This model proposes that sense of agency emerges from matches between individuals' predictions based on efference copies of motor signals and actual sensory feedback (Blakemore, Frith, & Wolpert, 1999; Blakemore, Wolpert, & Frith, 1998; Blakemore, Wolpert, & Frith, 2002; Frith, Blakemore, & Wolpert, 2000; Wolpert & Ghahramani, 2000). In other words, if a person's sensory feedback does not match this prediction or is absent entirely, that person's sense of agency would diminish. This sensory account has been used to explain disorders in sense of agency. For example, schizophrenia patients often show aberrant feelings of agency (Franck et al., 2001; Haggard, Martin, Taylor-Clarke, Jeannerod, & Franck, 2003; Koreki et al., 2015; Maeda et al., 2012), which are thought to be related to imprecise predictions about the sensory consequences of actions (Knoblich, Stottmeister, & Kircher, 2004; Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010).

High-level/reconstructive processes also appear to play important roles in individuals' sense of agency (Synofzik, Vosgerau, & Newen, 2008). For example, Wegner, Sparrow, and Winerman (2004) reported that people feel an illusory sense of agency for another person's hands when they hear instructions for that person's movements in advance. Wegner (2003) suggested that the experience of agency could be based on postdictive inference. Furthermore, recent studies have shown that participants report a strong sense of agency when they obtain good task performance, even when the enhanced performance was clearly the result of external factors (Metcalfe, Eich, & Miele, 2013; Metcalfe & Greene, 2007; Sato & Yasuda, 2005; Wen, Yamashita, & Asama, 2015a) or their actual control over the effects was disturbed (Wen, Yamashita, & Asama, 2015b). Wen et al. (2015a) proposed that individuals' intent to achieve a goal plays an important role in forming a sense of agency. If an individual's actions result in a goal of theirs being achieved, they would feel a strong sense of agency over the effects of their actions; however, if the individual's actions cause them to fail to achieve this goal, their sense of agency would be diminished.

Moreover, prior research has reported that when sensory processes become unreliable, high-level processes based on performance (i.e., a performance-based inference) take over in judgments of sense of agency (Wen et al., 2015b). This phenomenon can be explained by cue integration theory (Moore & Fletcher, 2012), which proposes that both internal and external cues contribute to a sense of agency, and that these cues are integrated based on a Bayesian principle. Generally, internal cues based on sensory processes in normal individuals and situations are the most reliable, and thus are the strongest contributors to a sense of agency. However, when the reliability of these cues decreases, external cues such as performance-based inferences take a more dominant role (Moore & Haggard, 2008; Wen et al., 2015b).

In summary, both sensory (i.e., low-level) processes and high-level processes appear to contribute to a sense of agency, and are thought to be integrated according to a Bayesian principle (Moore & Fletcher, 2012; Synofzik, Vosgerau, & Voss, 2013). However, how these processes interact remains unclear; understanding their interaction is important for clarifying the precise mechanism of the sense of agency. One particular line of research concerning sensory processes (i.e., action-effect integration) relates to the "intentional binding effect." This phenomenon has been widely observed at the sensory level in agency tasks, and refers to a subjective compression of the interval between one's intentional action and its effect (Haggard, Clark, & Kalogeras, 2002). It is considered to reflect an implicit aspect of sense of agency (Moore, Middleton, Haggard, & Fletcher, 2012). The intentional binding effect might be influenced by both *action-related factors*, such as intention (e.g., Berberian, Sarrazin, Le Blaye, & Haggard, 2012; Vinding, Pedersen, & Overgaard, 2013), effort (Demanet, Muhle-Karbe, Lynn, Blotenberg, & Brass, 2013; Howard, Edwards, & Bayliss, 2016), and action selection (Barlas & Obhi, 2013), and *effect-related factors*, such as the attentional focus on the effect (Haggard & Cole, 2007) and the priming of the effect (Moore, Wegner, & Haggard, 2009). Recent studies have also shown that the intentional binding effect is influenced by negative emotions (e.g., Yoshie & Haggard, 2013), monetary outcomes (Takahata et al., 2012), beliefs (Desantis, Roussel, & Waszak, 2011), moral contexts, and moderation of outcomes (Moretto, Walsh, & Haggard, 2011). These findings suggest the possible influence of high-level processes on the sensory processes underlying the sense of agency. However, there are currently no studies exploring the possible interaction effects of high- and low-level factors on sense of agency.

To examine these issues, we used a delay detection paradigm, whereby participants continuously press keys to trigger external effects and receive feedback on their performance related to these effects. The subjective delay between participants' actions and the effects of those actions reflect a sensory action-effect integration, which helps in forming an implicit sense of agency (Bednark, Poonian, Palghat, McFadyen, & Cunnington, 2015; Moore et al., 2012). For this study, we created an assisted controlling mode for the computer program running the delay detection task, which was designed to improve participants' task performance by ignoring erroneous actions (Wen et al., 2015b). We then examined how this assistance influenced both delay detection and the sense of agency (Experiment 1) by comparing these two constructs between this assistance condition and a condition wherein a percentage of participants' commands were randomly ignored (Experiment 2). We hypothesized that improving participants' task performance would reduce delay detection, especially when the delay is relatively long. Additionally, we hypothesized that performance-based inferences would have more weight than would sensory processes in determining the sense of agency (Wen et al., 2015b). We also examined participants' explicitly rated agency to clarify how the integration of multiple cues from different levels of processing influences sense of agency.