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COGNITIVE NEUROSCIENCE

COMMENTARY
Modulation of the pre-supplementary motor area reduces the sense of agency (Commentary on Cavazzana *et al.*)

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The sense of agency is the capacity to control one's own actions and, through them, events in the outside world (Haggard & Chambon, 2012). The proposition 'I did that' is an important aspect of our everyday lives. For example, this sense associates a light turning on to one's action when pressing a switch. Abnormalities in this sense can lead to illnesses such as psychosis (increased sense of agency) and depression (decreased sense of agency). Despite a large amount of theoretical work on the sense of agency, the neural correlates are poorly understood. Only a handful of imaging and brain stimulation studies have attempted to investigate how different brain areas contribute to the emergence of this feeling. In this issue of *EJN*, Cavazzana *et al.* (2015) describe evidence showing that modulation of activity in the pre-supplementary motor area (pre-SMA) using transcranial electrical brain stimulation can reduce the sense of agency. This is an important finding as it highlights a possible causal link between the activity of the pre-SMA and one's sense of agency, and thus could have clinical implications.

One way of studying the sense of agency is through 'explicit agency attribution tasks'. In these tasks a person judges whether they did or did not cause a specific event. For example, a computer program presents a tone whenever the person presses a button. Immediate presentation of the tone following the participant's key press creates the sense that they caused the presentation of the tone (e.g. agency). If the tone is presented with a delay the sense of agency is reduced. This suggests that the sense of agency is computed by comparing the prediction of action outcome(s) with actual outcomes. Figure 1A is a diagram of how this process might work.

In addition to explicit measures of the sense of agency there are also several implicit measures, such as intentional binding. Intentional binding refers to the temporal compression between a voluntary action and its sensory effect (Haggard & Tsakiris, 2009). In the task of Cavazzana *et al.* (2015), an effect (e.g. a tone) is presented after a certain delay, rather than immediately, subsequent to the participant's key press. The participant is then required to report the time on a clock indicating when they pressed the button or when the tone was presented. The sense of agency leads to an overestimation of time of action and an underestimation of time (Haggard & Tsakiris, 2009). Cavazzana *et al.* (2014) adapted this task for children and presented a series of letters instead of a clock. Participants were required to report the letter presented on the screen at the time of their key press or at the time of the presentation of the tone. Cavazzana *et al.* (2015) used this novel method to test healthy adults in combination with a non-invasive brain stimulation paradigm. Anodal and cathodal transcranial direct current stimulation was used to modulate activity of the pre-SMA. Although it has been shown that anodal and cathodal stimulation cause excitation and inhibition of neuronal activity, respectively (Nitsche & Paulus, 2000), the results of Cavazzana *et al.* (2015) did not differentiate between the polarity of stimulation, i.e. both polarities reduced the sense of agency. One possible explanation for this is based on the contribution of the SMA and pre-SMA in the perception of time (Lewis & Miall, 2003; Allman *et al.*, 2014). Transcranial direct current stimulation of the pre-SMA might have changed the expected duration of the delay and consequently reduced the sense of agency. Figure 1 illustrates this possibility. The strongest sense of agency occurs when sensory feedback and predicted outcomes match (Fig. 1B). Changes to the outcome prediction lead to a weakening of the sense of agency (Fig. 1C). As illustrated, this effect is not dependent on the direction of change of the predicted outcome. Moore *et al.* (2010) demonstrated a similar reduction in the sense of agency by stimulating the pre-SMA using transcranial magnetic stimulation. Their stimulation method, however, prevented them from studying both excitation and inhibition of neuronal activity. Application of transcranial direct current stimulation enabled Cavazzana *et al.* (2015) to extend their findings and show that both anodal and cathodal stimulation both lead to similar behavioural outcomes. This is important as it shows that, regardless of the direction of the effect of stimulation, modulation of activity of the pre-SMA reduces the sense of agency.

In summary, the findings of Cavazzana *et al.* (2015) constitute considerable progress towards understanding the brain network contributing to the sense of agency and highlight the important role of brain areas involved in time perception. More work, such as dynamic causal modelling and psychophysiological interaction, will be required to elucidate the brain network(s) involved and also studies using behavioural manipulations to disentangle the effects of time perception from the sense of agency.

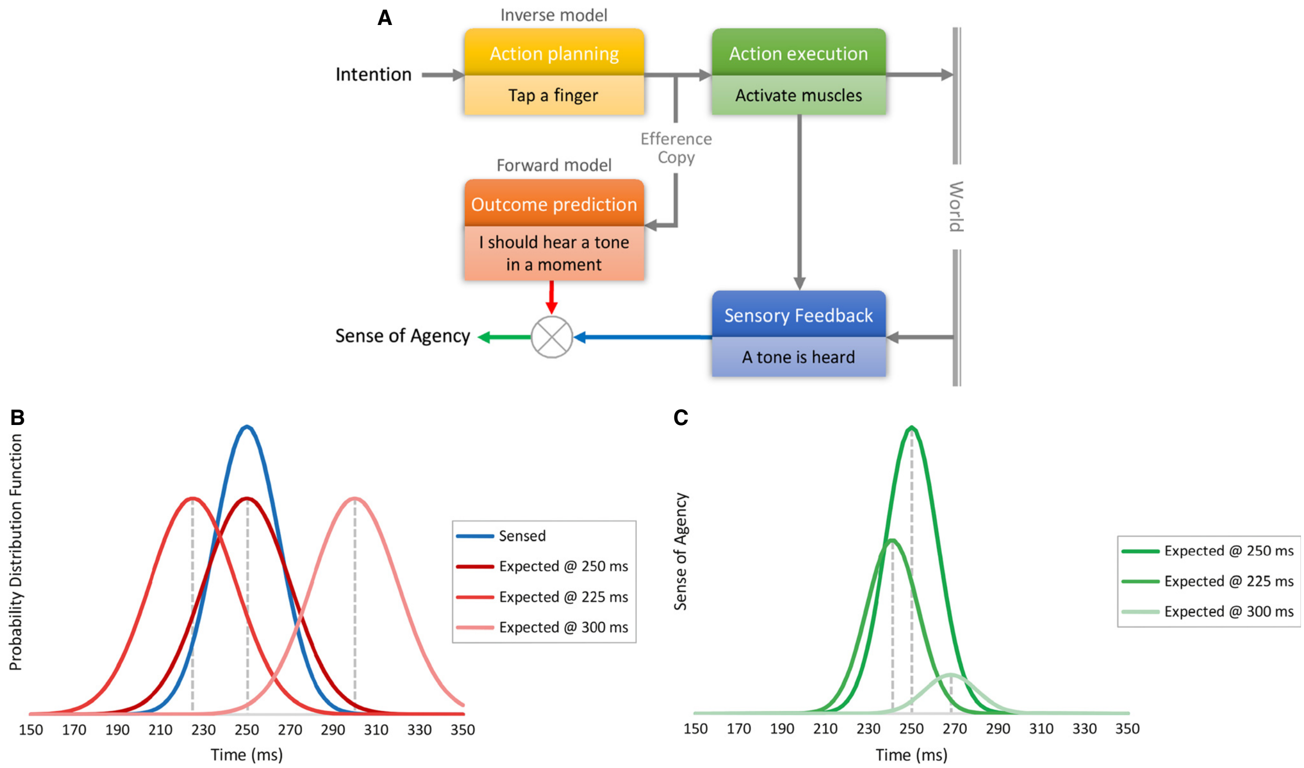

FIG. 1. (A) Diagram showing how performed intentions lead to a sense of agency (SoA). In this example, the *World* is a computer that presents a tone after a key press. The SoA can be modulated by presenting the tone after a variable delay. *Intention* refers to tapping a button. *Action Planning* ('Inverse Model') plans the action to ensure accurate execution. *Action Execution* performs the planned action by sending signals to the muscles of the finger. Importantly, an *Efference Copy* of the planned action is sent for *Outcome Prediction* ('Forward Model'). Through *Sensory Feedback*, the person hears the tone presented immediately or after a delay created by the *World*. The signals generated by *Outcome Prediction* (red arrow) and *Sensory Feedback* (blue arrow) are subsequently compared to create an SoA. Depending on definitions, the notation ⊗ can represent a differentiator (signal of *Outcome Prediction* minus signal of *Sensory Feedback*). Therefore, the SoA will be strongest when this difference is zero (absolute match between the two signals). Alternatively, the notation ⊗ can represent a multiplier, in which case, the higher value of this multiplier the stronger the SoA. Modified from Haggard & Chambon (2012). (B) Probability distribution function of the sensed signal (250 ms after key press) and expected signal at the same time as the sensed signal (expected at 250 ms), 25 ms earlier than the sensed signal (expected at 225 ms) and 50 ms later than the sensed signal (expected at 300 ms). Differences in the time of expected signals can be caused by electrical brain stimulation. Signals are displayed as the mean and a representative SD accounting for noise (Javadi *et al.*, 2014). (C) Multiplication of sensed signal and expected signal. This plot shows that a stronger SoA is generated when the means of the sensed and expected signals match. Changes in the mean of the expected signal (−25 and +50 ms in this example) attenuate the SoA.

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