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Brief article

Feelings of control: Contingency determines experience of action

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ABSTRACT

The experience of causation is a pervasive product of the human mind. Moreover, the experience of causing an event alters subjective time: actions are perceived as temporally shifted towards their effects [Haggard, P., Clark, S., & Kalogeras, J. (2002). Voluntary action and conscious awareness. *Nature Neuroscience, 5*(4), 382–385]. This temporal shift depends partly on advance prediction of the effects of action, and partly on inferential "postdictive" explanations of sensory effects of action. We investigated whether a single factor of statistical contingency could explain both these aspects of causal experience. We studied the time at which people perceived a simple manual action to occur, when statistical contingency indicated a causal relation between action and effect, and when no such relation was indicated. Both predictive and inferential "postdictive" shifts in the time of action depended on strong contingency between action and effect. The experience of agency involves a process of causal learning based on statistical contingency.

1. Introduction

The evolution of human intelligence has allowed not just deeper understanding of the world, but a greater capacity to act on it. Such operant actions imply the ability to know that one is performing an action, and to represent its consequences (Dickinson & Balleine, 2000). Research on the epistemic content and conscious experience of action has identified two distinct processes underlying this ability.

According to ideomotor theories (e.g. James, 1890), actions are internally represented by reference to their external consequences. On this view, making an operant action involves a prediction of the action goal, an idea supported by recent models of computational motor control (Berti et al., 2006; Blakemore, Wolpert, & Frith, 2002). Alternatively, the conscious experience of operant action may be inferred from sensory evidence (Wegner, 2002). In particular, spatial and temporal correlations between thoughts, physical movement, and external events may lead to us to infer that we have caused an external event.

Voluntary actions have strong effects on the subjective passage of time (Haggard, Clark, & Kalogeras, 2002). Temporal effects provide a common measure allowing the predictive and inferential contributions to experience of action to be compared directly. When a voluntary action, but not an involuntary movement, is followed by an external event, people perceive the action as shifted in time towards its effect, and the effect as shifted earlier in time towards the action that caused it (Haggard et al., 2002). This 'intentional binding' involves a predictive element, because omitting the effect does not prevent the shift in perceived time of action, as long as the probability of an effect given an action is sufficiently high (Moore & Haggard, 2008). It also involves an inferential "postdictive" element, because the tone's occurrence shifts the perceived time of action, even when tone-probability is low (Moore & Haggard, 2008).

This suggests that the human mind builds internal models of action–effect relations, which determine the *experience* of action. Here, we investigate whether rules

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thought to govern causal learning in animals might also underlie the experience of agency in humans. Contingency is an index of the causal relation between events, and predicts patterns of operant learning in animals (Hammond, 1980). Contingency is defined here as the probability of an effect (E) given an action (A), minus the probability of E in the absence of A. This index is known as Δp (Allan, 1980)

$$\Delta p = \mathrm{P(E|A)} - \mathrm{P(E|\sim A)},$$

where $\Delta p > 0$, the effect is more probable in the presence than in the absence of action. Conversely, where $\Delta p < 0$ the effect is less probable in the presence than in the absence of action. Contingency underlies performance of goal-directed action and explicit causal judgements (Shanks & Dickinson, 1991), but its role in conscious experience of action itself has not been investigated. The Δp measure represents the statistical relation between actions and their effects. To calculate this relation, one needs to take into account what happens in both the presence *and* absence of voluntary action. Traditional epistemology holds that humans know about their own voluntary actions directly, and in a self-intimating way (Descartes, 1641/1979; Libet, Gleason, Wright, & Pearl, 1983). On this view, consciousness of action is a corollary of the motor processes engaged *during* action programming. In contrast, if Δp influences action awareness, this would suggest that the experience of any individual action depends on a causal model built up through extensive background knowledge acquired during both the presence and absence of voluntary movement.

We performed an experiment to assess whether the conscious experience of action depended on the background contextual understanding of regularities in the external world, as expressed by Δp, or only on immediate processing in the motor system. If background contextual understanding contributes to action experience, then conditions with high Δp should induce strong binding. Conversely, if immediate processing of the motor system alone determines action experience, then binding should be insensitive to changes in Δp.

2. Method

2.1. Participants

38 participants (21 females; mean age of 26 years) took part in the experiment, which lasted approximately 1 h.

2.2. Procedure

Participants chose on each trial whether to press a key with their right index finger. The element of choice was included because computing Δp requires trials with and without actions. They viewed a rotating clock hand (period 2560 ms, see Libet et al., 1983), and used this to judge the time of their actions (Wundt, 1908). If they decided to press, they did so at a time of their choosing within the first revolution of a clock hand. If they decided not to press, they simply remained still until the end of the trial. At the end of the trial, participants entered the clock time at which they pressed the key, or a dummy value if they had not pressed. Participants were asked to try to ensure that roughly half of the trials involved key presses.

A tone could also occur on each trial. If the participant acted, a tone could follow 250 ms later. A tone could also occur if they did not act. In this case, it occurred at a random time within the second revolution of the clock hand. The probability of the tone given the action and the probability of the tone in the absence of action both varied across experimental conditions (see Table 1 for details).

Participants were randomly assigned to one of two tone-probability groups (19 participants in each). For the *low tone-probability group*, the probability of the tone in the presence of action was 0.5. For the *high tone-probability* group, probability of the tone in the presence of action was 0.75. Both groups performed two experimental conditions. In the *contingent condition* Δp was 0.5, and in the *non-contingent condition* Δp was 0 (Table 1). Thus, although the groups differed in terms of the probability of the tone given action, the manipulation of contingency defined by Δp was equal in both (see Fig. 1 for details of trial structure in each condition).

Within each condition, trials in which the participant decided to press the key were coded as 'action only' or 'action + tone'. By analysing these separately, we estimated the predictive and the postdictive inferential components of the conscious experience of action. If an action is not followed by a tone, but the probability of a tone given action is high, the experience of action may be influenced by the prediction that the tone *might* occur (Moore & Haggard, 2008). Conversely, if any particular action *is* followed by a tone, action experience may be retrospectively altered by occurrence of the tone. This postdictive inferential process would be absent on trials where the tone does not occur. We investigated the sensitivity of both predictive and inferential processes to contingency, by independently manipulating the probability of tones given action and the probability of tones given no action.

Participants in each tone-probability group completed three blocks of 40 trials each in the contingent condition and three blocks in the non-contingent condition. Ordering of contingent/non-contingent blocks was randomised for each participant. Participants also completed two baseline blocks of 20 trials each, at the start and at the end of the session. In baseline blocks, participants pressed the key at a

Table 1
Mixed factorial design used in the study.

		Between subjects factor	
		Low tone-probability group	High tone-probability group
Within subjects factor	Contingent $\Delta p = 0.5$	P(T|A) = 0.5 P(T|∼A) = 0	P(T|A) = 0.75 P(T|∼A) = 0.25
	Non-contingent $\Delta p = 0$	P(T|A) = 0.5 P(T|∼A) = 0.5	P(T|A) = 0.75 P(T|∼A) = 0.75