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Experience of action depends on intention, not body movement: An experiment on memory for *mens rea*☆

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ABSTRACT

How do we know whether our own actions were voluntary or involuntary? Intentional theories of sense of agency suggest that we consciously perceive the intentions that accompany our actions, but reconstructive theories suggest that we perceive our actions only through the body movements and other effects that they produce. Intentions would then be mere confabulations, and not bona fide experiences. Previous work on voluntary action has focused on immediate experiences of authorship, and few studies have considered memory for voluntary actions. We devised an experiment in which both voluntary action and involuntary movement always occurred at the same time, but could either involve the same hand (congruent condition), or different hands (incongruent condition). When signals from the voluntary and involuntary movements involved different hands, they could therefore potentially interfere in memory. We found that recall of a voluntary action was unaffected by an incongruent involuntary movement. In contrast, recall of an involuntary movement was strongly influenced by an incongruent voluntary action. Our results demonstrate an "intentional capture" of body movement by voluntary actions, in support of intentional theories of agency, but contrary to reconstructive theories. When asked to recall both actions and movements, people's responses are shaped by memory of what they intended to do, rather than by how their body moved.

1. Summary

How do we know whether our own actions were voluntary or involuntary? Intentional theories of sense of agency suggest that we consciously perceive the intentions that accompany our actions, but reconstructive theories suggest that we perceive our actions only through the body movements and other effects that they produce. Intentions would then be mere confabulations, and not bona fide experiences. Previous work on voluntary action has focused on *immediate* experiences of authorship, and few studies have considered *memory* for voluntary actions. We devised an experiment in which both voluntary action and involuntary movement always occurred at the same time, but could either involve the same hand (congruent condition), or different hands (incongruent condition). When signals from the voluntary and involuntary movements involved different hands, they could therefore potentially interfere in memory. We found that recall of a voluntary action was unaffected by an incongruent involuntary movement. In contrast, recall of an involuntary movement was strongly influenced by an incongruent voluntary action. Our results demonstrate an "intentional capture" of body movement by voluntary actions, in support of intentional theories of agency, but contrary to reconstructive theories. When asked to recall both actions and movements, people's responses are shaped by memory of what they intended to do, rather than by how their body moved.

2. Results and discussion

How do we know whether our own actions were voluntary or involuntary? This question may seem bizarre, given the general intuition that voluntary actions involve a first person experience of authorship. However, this intuition is challenged by concepts of volition emerging from the recent psychology of action. *Intentional* theories suggest that people experience conscious intentions preceding and accompanying their actions (Chambon, Wenke, Fleming, Prinz, & Haggard, in press; Farrer et al., 2007; Frith, Blakemore, & Wolpert, 2000; Nahab et al., 2010). Intentions are

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thus mental states that are both directly relevant to action, and also produce perception-like experiences (Hallett, 2007). However, other *reconstructive* theories have used cases of ambiguous authorship to argue that volition is not a *bona fide* experience at all, but an inference generated post-hoc to make a coherent narrative about actions (Wegner, 2002; Wegner & Wheatley, 1999). On this view, the sense of intentional control over our actions involves a retrospective inference, for example based on feedback from our body movements, rather than a perceptual experience.

Previous experimental work focussed on *immediate* experiences of authorship. Few studies have considered the *retention* of information in memory about volition and authorship. Memory for volition is not just an academic detail, but has important applied aspects. For example, legal systems consider it of paramount importance whether an action was performed voluntarily or not: actions that are not voluntary are considered 'automatisms' for which one is less responsible or not responsible at all. When a defendant enters a guilty plea (i.e., "yes, I did it"), the law assumes that she has correctly *retained and recalled* that her original action was voluntary, and not merely an involuntarily body movement.

However, both the volitional signals stressed by intentional theories of agency, and the somatosensory signals stressed by reconstructive theories of agency, decay rapidly. Moreover, information about voluntary action and somatosensory feedback may interfere with each other in memory. Thus, while the differences between a voluntary and an involuntary movement are recognisable immediately, the distinction between the two may blur over time, so that people might be unable to recall whether a *past* action was voluntary or involuntary. Although the experience of voluntary actions and TMS-induced twitches of the same muscles were shown to be quite different (Haggard, Clark, & Kalogeras, 2002), no previous study, to our knowledge, has investigated retention and recall of whether an *earlier* action was voluntary or involuntary. We therefore devised an experiment in which signals from the voluntary action and involuntary movement could potentially interfere in memory. Importantly, the two theories of agency described above differ in their predictions about false memories for voluntary action: these should be relatively common according to reconstructive theory, but rare according to intentional theories.

In our study participants freely chose to make a keypress action with the left or right hand. At the same time, Transcranial Magnetic Stimulation (TMS) was used to impose an involuntary movement on the left or right hand, at random. Thus voluntary action and involuntary body movement were either congruent (on the same hand) or incongruent (on different hands). We probed source memory for recent voluntary actions and involuntary movements, by unpredictably asking "which hand did you move/did the TMS make move 1/3/5 trials ago?" This provides a situation where volitional and somatic signals must both be retained in memory, and may potentially interfere in the incongruent condition. In this situation, models of action awareness based on strong somatic feedback and weak access to intention would predict a form of 'somatic capture of volition': judgements about which hand was used for voluntary action would be biased by which hand was twitched by TMS. In contrast, models based on easy access to strong intentional signals, with only a minimal role for somatic feedback, would predict 'intentional capture': judgements about which hand was twitched would be biased by which hand made voluntary keypress actions.

3. Methods

3.1. Participants

We tested 16 subjects (all right handed, 9 females, mean age 25.07 years, SD=4.48). One subject was excluded was due to highly stereotyped responding (see later).

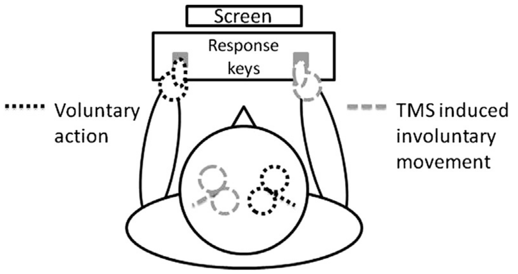

Fig. 1. Experimental setup, showing an example incongruent trial. In this trial, the participant freely chose to make a voluntary action with the left hand. At the same time, a TMS coil held over the left motor cortex caused an involuntary movement of the right hand. Thus, voluntary action and involuntary movement were incongruent. On other, congruent, trials, voluntary action and involuntary movement involved the same hand.

3.2. Procedure

Each trial began with a central fixation cross (500 ms), followed by an on-screen cue specifying a free-choice trial, a forced-choice trial requiring a left hand response, or a forced-choice trial requiring a right hand response. These cues were given as central text, and an arrow display immediately below ('free trial', 'left' or 'right'; ('< − >', '< −', '− >')). At the same time as the text and arrow cue appeared, a sequence of 3 beeps began. The beeps occurred at 750 ms intervals. Participants were instructed to press a designated key on a computer keyboard at the same time as the third beep. On forced choice trials, they used the finger previously indicated by the instruction, while on free choice trials they could freely choose whether to press with their left or right index finger. At the same time as the third beep a single TMS pulse was given to either the left or the right motor cortex eliciting an involuntary movement in the contralateral index finger. The side of TMS was randomised across trials. As a result, each trial could involve voluntary action and involuntary movement of the same hand (congruent trial) or of different hands (incongruent trial – see Fig. 1).

After the third beep, the text and arrow cues disappeared. Five hundred ms later, a text instruction asked the participant to report verbally either which finger they *moved* for the voluntary action, or which finger had been *twitched*, either one, three or five trials previously (see Fig. 2). Note that "one trial previously" means the trial before the one just completed. The participant's unspeeded 'left' or 'right' verbal report was recorded by the experimenter.

Each participant performed 180 free-choice trials, and 40 forced choice trials with each hand. The forced choice trials were randomised along with the free-choice trials. Forced-choice trials were included for methodological reasons, and were not relevant to our core research question. Including forced-choice trials discouraged participants from predeciding in advance which hand to use in free-choice trials, and from using specific sequences of free choices (e.g., L, R, L, R, L, R). The requirement to respond to the forced-choice stimuli would help to constrain the process of free-choice decisions to the time immediately after the appearance of each cue, and would prevent participants from strategically 'pre-deciding' entire runs of free choices in advance. The forced-choice trials were not further analysed. The trials were delivered in 3 blocks of 80, with a short rest in between blocks.

Before starting the main task participants complete 40 forced-choice practice trials, 20 for each side. The institutional ethics committee approved the procedure and each participant gave informed consent and completed a TMS safety screening form. No adverse events occurred during the experiment.

4. Data acquisition

The tasks were presented using Cogent 2000 (Laboratory of Neurobiology, Functional Imaging Laboratory, and Institute of Cognitive Neuroscience, University College London; http://www.vislab.ucl.ac.uk/cogent_2000.php) in Matlab 2011b (The MathWorks, Natick, MA.). Two Magstim 200 stimulators (Whitland, UK) each with a figure-of-eight coil were used to stimulate the primary motor cortices of the left and right hemispheres.

For each participant we first determined the location (hot spot) that elicited the highest response to the TMS pulse in the slightly-contracted first dorsal interosseus muscle, by searching the contralateral sensorimotor area in a 1 cm grid. Once the hot spot was found the motor threshold was determined as the lowest stimulator output required to elicit a MEP of at least 50 μV in three of

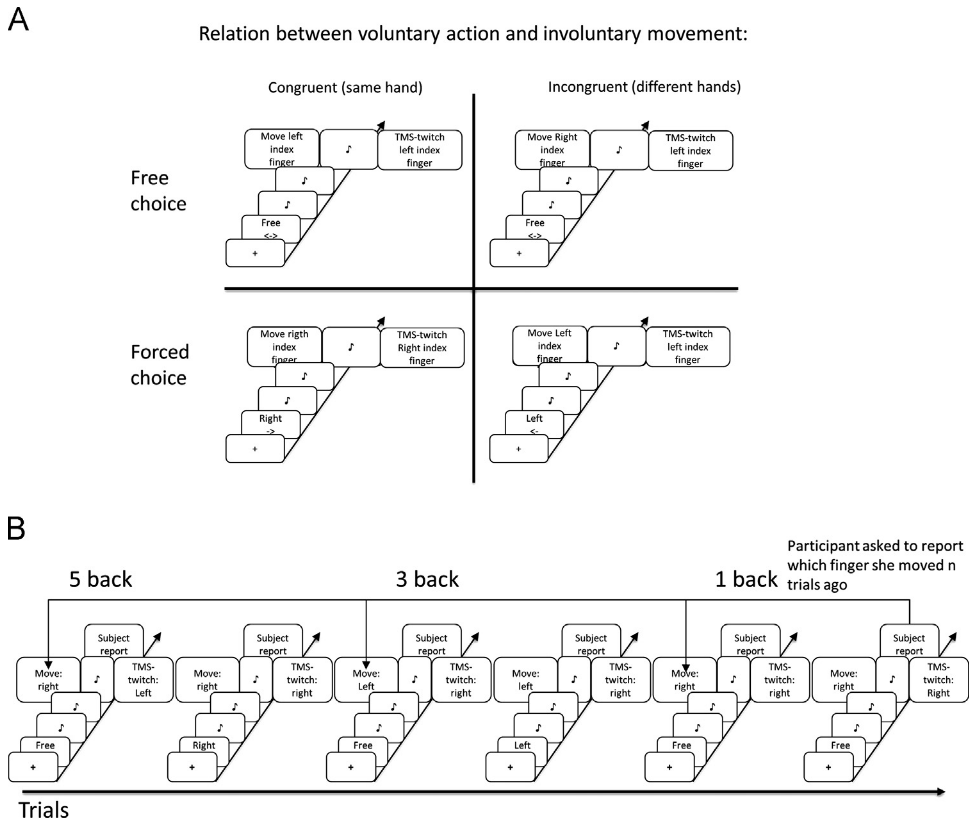

Fig. 2. (A) Trial design. An instruction indicated whether participants should make voluntary actions with the left or right hand (forced choice trials), or should freely choose which hand to use (free choice). Actions were synchronised with the third of a series of pacing tones. A TMS pulse was delivered to either the left or right hemisphere at the time of the third tone, producing involuntary movement of the right or left hand respectively. When voluntary action and involuntary movement involved the same hand, the trial was classed as congruent, otherwise it was classed as incongruent. (B) Recall task. Participants were asked after 1, 3 or 5 intervening trials which hand they had used to make the voluntary action, or which hand had been involuntarily moved by TMS, on the to-be-recalled trial.

five successive trials (Rossini et al., 1994). This was done separately for each hemisphere. MEPS were digitised at 5 kHz. For the left hemisphere thresholds ranged from 40% to 59% of stimulator output (mean, 47.5%) and for the right hemisphere thresholds ranged from 45% to 59% of stimulator output (mean, 50.2%). Finally, TMS output in the experimental conditions was set at 120% of relaxed threshold. One subject reported that the TMS-induced twitches interfered with her voluntary actions, for her the stimulator output was therefore reduced to 100% of relaxed threshold.

5. Data analysis

We analysed only those judgements that referred to free-choice trials, since we were primarily interested in source memory for voluntary actions. Free choice trials were classified as congruent if voluntary action and involuntary movement had occurred on the same hand, or incongruent otherwise. Because we had no hypothesis about hemispheric specialisation, we collapsed data across left and right hands, as an effect of no interest. Our main dependent variable was percentage of correct recall. In addition, we analysed MEP amplitudes. For each trial the difference between the maximum and minimum value (peak-to-valley) for the MEP 15–50 ms after the TMS pulse was taken as the MEP amplitude. Finally, we measured the latency of the voluntary action with respect to the go-signal (onset of the third beep).

To check for stereotyped responding, the number of runs (i.e., successive repetitions of a single voluntary action choice) for each participant was calculated. A low number of runs indicate that the participant did not switch between left and right, but rather repeated a single action choice across trials. The mean number of runs was 94.33, SD 21.86. One participant produced very few runs, (48, 2.12SD below the mean, suggesting a stereotyped pattern of responding) and was therefore excluded.

6. Results

The mean percentage of congruent trials was 49.3% (SD 4.2%). This value did not differ from the 50% level expected from an unbiased random choice mechanism, such as chance. Chi-squared testing of individual participants' choices revealed that no participant contributed significantly more congruent trials than expected by chance. Two participants contributed more incongruent trials than might be expected by chance, but two such results in our sample of 15 might be expected from the 5% type I error rate used for each individual test.

Accuracy on the recall task is shown in Fig. 3. The data were analysed using a repeated measures ANOVA with factors of n-back (recall of a target event 1,3 or 5 trials ago), the event that the participant was instructed to recall (voluntary action or twitch), and whether, on the to-be-recalled trial, voluntary action and twitch were on the same hand or on different hands (congruent, incongruent). We found a predicted main effect of n-back $F(2,28)=33.25$, $p<0.001$, GES$=0.25$[1], with recall decreasing monotonically with elapsed trials We also found marginal main effect of congruence in the predicted direction, with better recall for congruent than for incongruent trials $F(1,14)=4.58$, $p=0.0506$, GES$=0.018$. More interestingly, there was an interaction between

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[1] GES=Generalised eta-squared.

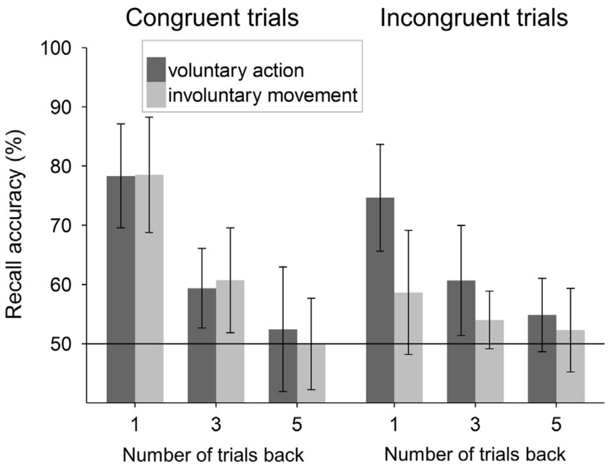

Fig. 3. Mean recall accuracy as a function of number of intervening trials, event recalled, and congruence/incongruence between voluntary action and involuntary movement. Error bars show 95% confidence intervals. Chance level is 50%.

congruency and volition $F(1,14)=6.006$, $p=0.028$, GES$=0.019$. This interaction was explored with post-hoc *t*-tests. Recall of voluntary actions was unaffected by whether the involuntary movement on the target trial was on the congruent or incongruent hand: mean congruent-incongruent difference$=0.0067$ (95%CI: -5.958; 5.972), $t(14)=0.002$, $p=0.998$, $r^2=0.0006$. In contrast, recall of involuntary movement was significantly worse when the voluntary action was performed by the other hand compared to the same hand: mean congruent-incongruent difference -8.084 (95%CI: -12.81; -3.36), $t(14)=-3.67$, $p=0.0025$, $r^2=0.7$. Thus, recall of involuntary movements was captured by incongruent voluntary actions, but recall of voluntary actions was not captured by incongruent involuntary movements. The results of the post-hoc testing are confirmed by inspection of the confidence intervals in Fig. 3. When voluntary action and involuntary movement were incongruent, recall of the involuntary movement was never significantly above chance, even after a single intervening trial. That is, making an incongruent voluntary action with the other hand effectively removed information in memory about which hand had been twitched. Finally, there was also an interaction between congruency × n-back $F(2,28)=5.061$, $p=0.013$, GES$=0.038$, due to a more rapid decay of performance in the incongruent condition. There were no other significant interactions or main effects.

We next investigated whether the recall of involuntary movements depended on the amplitude of the evoked twitch, by comparing MEP amplitudes for involuntary movements that were correctly and incorrectly recalled. No significant difference was found (mean MEP correct, 2.38 mV, incorrect 2.40 mV, $F(1,14)=0.0193$, $p=0.8916$), nor was there any effect of congruence, nor any interaction. (all $ps>=0.085$). Similarly, we tested whether the ability to recall the source hand of a voluntary action depended on the MEP size. No significant difference was found, nor was there any effect of congruence, nor any interaction (all $p>=0.149$). Finally, we compared the latency of voluntary actions that were correctly recalled vs those that were incorrectly recalled. We found no difference, no effect of congruence, and no interaction. (all $p>=0.104$). Thus, recall performance, and the degree of interference in memory between voluntary action and involuntary movement appeared to be independent of the key physical parameters of both voluntary and involuntary movement.

7. Discussion

We wanted to investigate if memory for action depends more on the intention to act, or on somatic feedback from the body. To do this, we developed a novel paradigm in which both voluntary action and involuntary movement were always present, and in which we could assess the mutual interference between these two events in memory. We asked the participants to recall the source, i.e., either the left or right hand, of either a voluntary action or an involuntary movement they had recently made. We found that source memory for voluntary action was unaffected by an incongruent involuntary movement, while source memory for involuntary movements was strongly affected by incongruent voluntary actions. Because participants made forced-choice responses, errors in recall on incongruent trials could be interpreted as biasing or capture of one signal by the other. We found highly asymmetric interference in memory for actions, with voluntary actions biasing source memory for involuntary movement, but not vice versa.

Could this effect simply reflect a difference in signal strength between voluntary actions and involuntary movements? Differences in signal strength could arise either at the perceptual stage, or in memory itself. An alternative explanation of our results might be attempted in either case. We therefore consider these possible alternative explanations in turn.

7.1. Perceptual factors

Could our results be due to failure to *perceive* the involuntary movement? This seems unlikely: the TMS-evoked twitches were always suprathreshold, and salient for the participants. Could the twitches nevertheless have been *masked* by voluntary actions? Because masking is greatest between signals that overlap in space and time, this view would predict particularly poor perception of the MEP in congruent trials, and also effects of MEP amplitude and voluntary latency. None of these three predictions was supported by our data. Alternatively, the poor recall in the incongruent condition might reflect division of attention. Participants might allocate attention to the hand making the voluntary action. They cannot allocate attention to the involuntary movement in the same way, because they cannot anticipate which hand will be twitched. Thus, on incongruent trials their attention may be focussed on the hand that will act, rather than the hand that twitched. This explanation also seems unlikely, because pilot data showed that recall of involuntary movements was close to ceiling when probed *immediately*, without subsequent intervening trials. Moreover, previous studies confirm that participants are able to immediately judge the amplitude (Haggard & Whitford, 2004) and timing of TMS-evoked twitches, even in the presence of a simultaneous intention to act (Haggard & Clark, 2003). In addition, if recall of involuntary movements had been limited by perceptual or attentional factors, larger twitches would presumably be better recalled than smaller twitches, yet our analyses did not find this. We therefore suggest that poor recall of involuntary movements in the incongruent condition is due to a bias or capture in memory, and not simply due to poor perception or attention.

7.2. Memory trace strength

Next, we consider whether differences between in strength of memory traces for voluntary actions and involuntary movements could explain our results. According to this explanation, the memory trace for involuntary movements should have a lower strength than that for voluntary actions. This could either reflect a memory trace for the involuntary movement itself, or a memory trace for the source (left hand, right hand) where the movement was experienced. Several lines of evidence make either explanation implausible, and suggest that our results are not simply due to trace strength. First, recall rates in congruent trials were similar for both involuntary movements and for voluntary actions. This pattern of results suggests that involuntary movement signals and voluntary action signals do not differ in trace strength, but only in the susceptibility to bias by the other signal. Second, trace strength might be lower for weak signals than for strong signals, suggesting that smaller involuntary movements would be less well remembered. However, our analyses did not suggest any relation between these capture effects and physical parameters of movements. In particular, we found that MEP size was essentially identical for incongruent trials that were recalled correctly vs incorrectly (see Table 1). This effectively rules out explanations based on analogue memory traces linked to signal strength. Finally, our task did not require participants to remember the physical parameters of involuntary movements, but only their *source* in the left or right hand. Therefore, an efficient strategy might recode somatosensory signals about involuntary movement into a 1-bit categorical code *left*, or *right*. There is considerable evidence from studies of non-motor memory that contextual source information is indeed coded independently of trace strength (Rugg et al., 2012). Our pilot study, supplementary analyses, and discussion of perceptual factors above, all suggest that categorisation of involuntary movement signals as *left* or *right* should be unproblematic for our participants, and could not account for poor recall of involuntary movement. Moreover, our task would require voluntary actions to be categorised in exactly the same way, as *left* or *right*. Thus, the differential recall of voluntary actions and involuntary movements cannot easily be explained if the memory traces are coded as a categorical description of the source/context, rather than in an analogue form.

Several other potential alternative explanations of our effect can also be ruled out. First, memory for a previous action or movement is strongly affected by subsequent events (retroactive interference). However, the randomised design of our experiment ensured that the events occurring between the to-be-recalled trial and the moment of recall itself were fully balanced across conditions. Second, participants could potentially have delayed their voluntary actions, and then responded with the hand twitched by TMS. This strategy would reduce the number of incongruent trials, perhaps leading to changes in memory strength. However, we found no evidence that incongruent trials were under-represented. Third, participants' recall of twitches could have been captured by the click of TMS and cutaneous scalp sensation in the contralateral hemisphere. However, this account cannot readily explain why click capture would occur only in incongruent trials, and not in congruent trials, without additional implausible and ad hoc assumptions.

7.3. *Intentional capture*

We therefore interpret our result as a bias in memory, or “intentional capture” of involuntary movement. That is, when people are asked to recall involuntary movements, their memories are biased by intentional signals describing what they voluntarily choose to do at the time. This is not a simple response bias: the response categories in our study were ‘left’ and ‘right’, but the effect of interest was a bias to report whatever hand had made the voluntary action on that trial, rather than one specific hand. Interestingly, recent studies of visual memory have suggested that the precision of spatial information held in memory is reduced by interference from subsequent items (Zokaei, Gorgoraptis, Bahrami, Bays, & Husain, 2011). Our result could be explained within the same framework, if the degree of interference between voluntary action and involuntary movement were asymmetric. We suggest that ‘intentional capture’ arises because voluntary actions interfere more with the coding of involuntary movements than vice versa Tables 2 and 3.

Table 1
Mean (SD across participants) MEP amplitude (mV).

	Correct	Incorrect
Congruent	2.61 (0.85)	2.67 (0.91)
Incongruent	2.73 (0.87)	2.64 (0.86)

The involuntary movements studied here were generated by stimulating primary motor cortex, yet recall of these movements clearly differed from recall of voluntary actions. The component of voluntary action responsible for differential interference in memory cannot be due to low-level motor execution and somatic feedback alone, but must arise at a higher, intentional level. Our results are consistent with the view that an efferent signal arising upstream of M1 contributes to the superior source memory for voluntary actions, and biases memory for body movement.

Intentional theories give a strong role for intentions, relative to somatic signals, in the experience of and memory for action. Reconstructive theories propose the reverse. Our results clearly favour intentional over reconstructive theories, at least as regards the retention of information about actions in memory.

A proponent of reconstructive theories might argue that our notion of confabulation is too strong. Our claim that ‘intentional capture’ supports intentional theories over reconstruction theories might then be invalid. A weaker form of reconstructive theory suggests that reconstruction of agency requires congruence between “prior thoughts” and subsequent actions. However, our research question was not concerned with whether actions can be confabulated, and not with whether prior thoughts can be confabulated. That is, our paradigm is sensitive to what Pacherie (2008) calls proximal intentions, close in time to the action. Prior thoughts, on the other hand, resemble distal intentions.

Strong reconstructivist insists that prior thoughts are confabulated, while weak reconstructivism requires only reconstruction of proximal intentions. In our study, we deal with intentions to move the left or the right hand. These would be relatively proximal, because they relate to a specific motor means used to achieve the action goal (Pacherie, 2008), and are specified only relatively late in the voluntary action chain (Haggard and Eimer, 1999). In a previous study, participants appeared to reconstruct intentional

Table 2
Mean (SD across participants) correct recall (%) as a function of number of intervening trials, event recalled, and congruence between voluntary action and involuntary movement.

n-Back	Incongruent		Congruent	
	Voluntary action	Involuntary movement	Voluntary action	Involuntary movement
1	74.7 (16.3)	58.6 (18.9)	78.3 (15.9)	78.5 (17.6)
3	60.7 (16.8)	54.0 (8.8)	59.4 (12.1)	60.7 (16)
5	54.8 (11.2)	52.3 (12.8)	52.4 (19)	50 (13.9)

Table 3
ANOVA results for the design shown in Table 1.

Effect	DFn	DFd	F	p-value	GES
Congruency	1	14	4.580	0.050	0.0184
Volition	1	14	1.948	0.185	0.0215
n-back	2	28	33.268	0.000***	0.2462
Congruency × volition	1	14	5.986	0.028*	0.0185
Congruency × n-back	2	28	5.061	0.013*	0.0379
Volition × n-back	2	28	0.679	0.515	0.0072
Congruency × volition × n-back	2	28	1.220	0.310	0.0123

movements of the left and right hands based on external verbal cues and visual feedback (Wegner, Sparrow, & Winerman, 2004). Therefore, we think that our paradigm should have been sensitive to reconstruction, had it occurred. In any case, our data suggest that some internal action-preparation signals are more important than afferent sensorimotor signals in memory for voluntary action.

Our results could be interpreted within a source-monitoring framework (Johnson, Hashtroudi, & Lindsay, 1993). Information about sources of voluntary action biased our participants' memories about the sources of an externally-caused involuntary movement. Abnormal source monitoring in schizophrenics has been linked to auditory hallucinations (with normal inner speech being erroneously heard as an external voice: (Waters et al., 2012)), and to abnormalities of voluntary action such as delusions of control (with consequences of voluntary actions being experienced as externally-caused: (Shergill, Samson, Bays, Frith, & Wolpert, 2005)). This previous work on recognition of actions focussed on immediate awareness, rather than memory. Nevertheless, schizophrenic patients' auditory and visual hallucination scores are known to be associated with biases in corresponding verbal and visual source memory (Brébion, Ohlsen, Bressan, & David, 2012). Therefore, biases in memory for volition in our task could shed light on the altered experience of volition in schizophrenia.

The law assumes that healthy adults can remember and report their own actions and intentions, or *mens rea*. Our results offer some support for this assumption: our participants knew and remembered what they voluntarily did. Indeed, this information seemed to influence their memory about what involuntarily happened to them. Crucially, however, we found no evidence for creation of false memories about voluntary actions. For example, an involuntary twitch of the left hand could not induce the false memory of making a voluntary action with the left hand when in fact there had been a voluntary action with the right hand. This may be surprising, given studies showing that simply imagining (Garry, Manning, Loftus, & Sherman, 1996), or observing (Lindner, Echterhoff, Davidson, & Brand, 2010) an action can induce the false memory of having performed it. However, those studies typically involve much longer memory delays than ours, and individuate actions by praxic/semantic classes (e.g., “shake the bottle”) rather than by the effectors or motoric means used to make them. We suggest that false action memories induced in this way may lack convincing motoric detail about *how* the action was performed.

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