The Power of Suggestion: Post-hypnotically induced changes in the temporal binding of intentional action outcomes

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RUNNING HEAD: HYPNOTICALLY INDUCED CHANGES IN TEMPORAL BINDING

Abstract

The sense of agency is the experience of initiating and controlling one's voluntary actions and their outcomes. Intentional binding (the compressed time interval between voluntary actions and their outcomes) is increased in intentional action but requires no explicit reflection on agency. The reported experience of involuntariness is central to hypnotic responding, where strategic action is experienced as involuntary. We report reduced intentional binding in a hypnotically induced experience of involuntariness, providing an objective correlate of reports of involuntariness. We argue that reduced binding results from the diminished influence of motor intentions in the generation of the sense of agency when beliefs about whether an action is intended are altered. Thus, intentional binding depends upon awareness of intentions, showing that changes in metacognition of intentions affect perception.

The sense of agency is the experience we have of initiating and controlling our voluntary actions and their outcomes (see Haggard & Eitam, 2015). Intentional binding refers to the subjective compression of the time between an intentional action and its outcome, consisting of a forward shift of the judged time of an action toward its outcome (action binding) and the backward shift of an outcome toward the action that caused it (outcome binding). (Haggard, Clark & Kalogeras, 2002). The effect is sensitive to intentional action but requires no explicit reflection upon agency and may reflect the additional contribution of intentions to causal binding (Buehner, 2012; 2015). Intentional binding has been shown to be affected in a number of disorders of agency, for example schizophrenia (e.g., Voss et al, 2010) and alien limb (Wolpe et al 2014) and to be reduced in coerced action (Caspar, Christensen, Cleeremans & Haggard, 2016).

The 'classical suggestion effect' of hypnosis is the experience of involuntariness of an action (Weitzenhoffer, 1980) and changes in the sense of agency are central to hypnotic responding (Polito, Woody & Barnier, 2013). Sense of agency may arise from the integration of internal, and external, predictive and retrospective cues (Moore & Fletcher, 2012; Synofzik, Vosgerau & Voss, 2013), and also general beliefs about agency. Indeed, retrospectively manipulating beliefs about agency can alter attributions of agency (Wegner, 2002). Hypnotic involuntariness may therefore reflect a relatively strong weighting of beliefs about hypnosis, and a relatively weak weighting of the internal signals provided by motor intentions.

However, highly hypnotisable participants might merely *report* that a hypnotically suggested movement feels involuntary– even though they may *experience* the action as similar to any other voluntary action. If so, phenomena sensitive to conscious intentions, such as intentional binding, should be normal following hypnosis. Alternatively, if movement under hypnosis represents a shift from relying on internal action signals to relying on experimenter-delivered beliefs about action, then implicit measures sensitive to the experience of intentional action might be altered in hypnosis for highly hypnotisable subjects. It has been shown that beliefs about whether or not one is the cause of an outcome influence intentional binding (Desantis et al, 2011). Here, we address for the first time whether binding is influenced by beliefs about whether or not an action was intended.

Method

Participants

Eighteen participants (4 males, mean age = 20.2, *SD* = 2.35) were selected for high score on the SWASH, a modified version of a standard test of hypnotisability, the Waterloo-Stanford Group Scale of Hypnotic Suggestibility, Form C (WSGC; Bowers, 1993). As requested by the reviewers, later a second group of 14 participants were selected for a medium score on the SWASH (4 males, mean age = 23.4, *SD* = 5.2). The SWASH (Sussex Waterloo susceptibility to hypnosis scale) is a modified, ten item version of the WSGC:C, with age regression and dream suggestions removed to avoid participants becoming absorbed in negative experiences (Cardeña & Terhune, 2009). In addition to the objective ratings of the WSGC:C, the SWASH also includes a subjective experience rating for each suggestion. For example, the following is the subjective rating for item 2, "Moving hands together":

You were next told to hold your hands out in front of you about a foot apart and then told to imagine a force pulling your hands together. On a scale from 0 to 5, how strongly did you feel a force between your hands, where 0 means you felt no force at all and 5 means you felt a force so strong it was as if your hands were real magnets?

Participants were selected on the basis of their combined hypnotisability score (the simple mean of the objective and subjective scores, each scaled out of a maximum of 10), with a minimum cut-off of 5 (which was the top 11% of 266 screened) for the highly hypnotisable group. The medium hypnotisable group scored below 5 and above 2 on the SWASH. (15% of SWASH scores lie below 2).

To assess whether participants were able to maintain an experience of involuntariness for the duration of the task, verbal ratings of involuntariness on a scale between 0 (completely voluntary) and 5 (completely involuntary) were recorded after each block of trials. Seven participants from the highly hypnotisable group who reported full voluntariness (an involuntariness score of 0) after any block in the post-hypnotic involuntariness condition were excluded. Two of these participants did not complete all conditions, and therefore provided insufficient data for comparisons. As the aim was to determine an objective correlate (intentional binding) of reported feelings of involuntariness, only cases where there were feelings of involuntariness are relevant for the high hypnotisable group. Analyses of the results for all highly hypnotisable participants together (whether or not they were able to sustain the experience of involuntariness) are shown in Table S4 in the Supplemental Material available online. The combined hypnotisability scores of those unable to sustain the suggestion was lower 5.98 (*SD* = 1.11) than those who maintained involuntariness, 7.48 (*SD* = 1.24), $t(16) = 2.61$, $p = .019$, $B_{H[0,3.74]} = 3.16$. The medium hypnotisable group had a mean combined hypnotisability score of 3.19 (*SD* = 0.88). None of the participants in the medium hypnotisable group were able to sustain an experience of involuntariness throughout the experiment. One participant from the highly hypnotisable group was excluded based on prior criteria as fully specified also in Lush, Parkinson & Dienes (2016) (the standard deviation of their baseline action judgements was more than 3 times the group interquartile range in the passive (614.9 ms) and post-hypnotic (470.2 ms) conditions). Therefore, data from ten highly hypnotisable participants (1 male, mean age = 20, *SD* = 1.9) are reported.

Highly hypnotisable participants were recruited for the duration of two terms, until the participant pool was exhausted. Medium hypnotisable participants were recruited during the summer break, until there were no more responses. Bayesian analyses were used to assess sensitivity. Crucially, we used Bayesian analyses to indicate the strength of evidence for H1 versus H0; the measure of evidence is valid no matter what the stopping rule (Rouder, 2014; Schoenbrodt, Wagenmakers, Zehetleitner, & Perugini, in press).

No power analysis was conducted. We included Bayes factors so that there would be an assessment of the sensitivity of the data to distinguish H0 and H1. Once the data are in, power has no relevance to how sensitive the data are, because power is a property of decision rule in the long run; conversely Bayes factors indicate the sensitivity of the very data collected to distinguish H1 and H0.

Ethical approval was received from the University of Sussex ethics committee and informed consent was obtained. Participants received cash payment of £18 or course credits.

Materials and methods

Visual stimuli were displayed at 100 Hz on a 21" CRT monitor and auditory stimuli were presented via Sennheiser headphones. For each trial, a clock face was presented, marked at thirty degree intervals and subtended a visual angle of five degrees. A static dot, subtending at 0.2 degrees, appeared at a pseudo-randomized position and began rotating around the clock 250 ms later (at 2560 ms per revolution). Participants were seated at a viewing distance of approximately 60 cm. A computer keyboard was used to record actions (button presses).

Each session began with a hypnotic induction adapted from the WSGC:C (included in the Supplemental Material available online). Following the hypnotic induction, participants were given the suggestion that their finger would move involuntarily onto the key for blocks of trials which followed a handclap from the experimenter. Participants were then ‘counted out’ of hypnosis before performing the experimental task. There were three counterbalanced conditions. In the voluntary condition, participants pressed the key when they wished. In the involuntary condition, the participant's index finger was pulled onto the key by the experimenter by a fabric loop, with the experimenter's action out of the participant's view. A single handclap was made in the post-hypnotic suggestion condition approximately 20 seconds before the start of each 35 trial block (except the solo tone condition). Participants were asked to rate the involuntariness of the action in each condition on a scale from 0 to 5 after each block in each condition and, additionally, after three trials of the first block of the post-hypnotic condition. No handclaps were delivered in the voluntary or involuntary conditions. Participants were informed during the hypnotic induction that the post-hypnotic suggestion would be removed when they left the room at the end of the session.

There were four trial types, presented in separate blocks. In contingent trials, pressing a key triggered a 1000 Hz, 100 ms duration tone after a 250 ms delay. Participants were asked to look at a fixation cross in the centre of the clock and to wait for at least one revolution before pressing the button at a time of their choosing. The trial was restarted if t0he action occurred before one full revolution or after six revolutions. Participants were asked not to plan ahead or to aim for a particular point on the clock and to report either the action or the tone (to give contingent action or contingent tone judgements). Baseline action trials were the same as contingent action trials except the button did not trigger a tone. In baseline tone trials, the tone was triggered pseudo-randomly between 2.5 s and 7 s following one revolution of the clock.

Following the tone (or action on baseline action trials), the dot continued moving for a pseudo-randomised period of time between 1200 ms and 2370 ms. The clock was then removed from the screen for a pseudorandomised time interval (500 ms to 1280 ms). When the clock reappeared, participants were able to control the position of the dot using a mouse and were asked to position the dot at the position at which it had been at the time of the judged event (action or tone) and to press the mouse button to record their judgement.

Each block consisted of 35 repetitions of one trial type except for baseline tone trials, for which 13 repetitions were taken in each condition and subsequently combined into a single block of 39 trials. The baseline tone trials were spread across the conditions in this way in order to minimise the experimental duration and reduce the possibility of participants becoming fatigued. As the baseline tone trials required no action to take place, the different experimental conditions should not influence these timing judgements. Blocks were separated by 30 s rest periods and presented in counterbalanced order. Before the session began, all participants were trained with four practice trials in the baseline tone condition and four in the baseline action condition. In order to reduce the effects of fatigue, the experimental task was split across two experimental sessions, with two conditions performed in the first session and one in the second. Participants were led through the hypnotic induction and count-out procedure at the start of each session. Sessions took place on separate days or following a gap of at least 2 hours. In total, the sessions took approximately 2 hours and 30 minutes, including training and debriefing. All Stimuli were generated with Matlab running Psychtoolbox v3.

Analysis

Mean judgement errors were calculated for each group on each trial type. Individual judgements more than 3.5 SD from the mean for each participant on each judgement type were then excluded before mean judgement errors were calculated for each participant, as also specified in Lush, Parkinson & Dienes (2016). Twenty judgements were excluded across all participants and trials (0.52% of judgements). Baseline action and tone judgement errors were subtracted from their respective contingent conditions to calculate action and outcome binding. Outcome binding was subtracted from action binding to produce a total binding measure.

Repeated measures ANOVAs were performed for action, outcome and total binding measures. Baseline action (M) judgements and within-participant SD of baseline action judgements were also compared. Where there was evidence for violation of sphericity, Greenhouse-Geisser corrected degrees of freedom were used. Significant Fs were followed up with Fisher's LSD post-hoc comparisons..

Bayes factors (*B*) were used to assess strength of evidence for one degree of freedom effects. A *B* of above 3 indicates substantial evidence for the alternative hypothesis and below 1/3 substantial evidence for the null. Thus, all Bayes factors, B, reported here represent the evidence for H1 relative to H0; to find the evidence for H0 relative to H1, take 1/*B*. *B*s between 3 and 1/3 indicate data insensitivity (see Dienes, 2014; cf Jeffreys, 1939). Here, $B_{\mathrm{H}(0,\, x)}$ refers to a Bayes factor in which the predictions of H1 were modeled as a half-normal distribution with an SD of *x* (see Dienes, 2014); the half-normal can be used when a theory makes a directional prediction where *x* scales the size of effect that could be expected (so x can be chosen from e.g. relevant past studies). $B_{\mathrm{N}(0,\, x)}$ indicates H1 was specified as a normal distribution with mean 0 and SD *x* (for non-directional predictions). Proposals that a shared mechanism underlies functional motor disorders (motor disorders with no known neurological cause) and hypnotic involuntariness have been made since the 19th century (for a recent review see Bell, Oakley, Halligan & Deeley (2010). Kranick et al (2013) provide an estimate of intentional binding effect size for the difference between functional motor disorder patients and healthy volunteers; the difference between groups in outcome binding was approximately half the effect found in control participants. Bayes factors for differences in each measure were therefore calculated using a half-normal distribution with SD based on half the mean in the voluntary condition. $B_{\mathrm{U}[0,\max]}$ refers to a Bayes factor in which the predictions of H1 were modeled as a Uniform distribution from 0 to max. We used this model for the rating of involuntariness which is on a scale from 0 to 5; thus the maximum that the population mean difference between conditions could be was 5. A Bayes factor for the regression of the difference in outcome binding between voluntary and post-hypnotic conditions on reported involuntariness in the post-hypnotic suggestion condition was calculated using a half-normal distribution with SD based on the quotient of the mean outcome binding in the medium group (as an independent estimate of the rough amount of binding that could exist in highs) and the range of the involuntariness rating scale (i.e. 120/6). Bayes factors for simple interactions between two conditions and group were calculated modeling H1 using half the mean binding in both groups for the relevant binding component.

Predictions

We tested highly hypnotisable and medium hypnotisable groups on an intentional binding task in voluntary action and in two involuntary conditions, in which the action was passive or was reported to be experienced as involuntary following a post-hypnotic suggestion (in which response occurs following hypnosis, Barnier & McConkey, 1998) of action involuntariness. As binding is sensitive to agency, binding should be strongest in the voluntary condition and weaker in passive action. If the experience of involuntariness reported in hypnotic responding by highly hypnotisable subjects reflects real changes in the experience of agency, intentional binding should also be weakened in post-hypnotically suggested involuntariness in highly hypnotisable subjects. In terms of the comparison of highly with medium hypnotisable subjects, highs compared to mediums should have a greater difference in binding between voluntary and post-hypnotic conditions, and between passive and post-hypnotic conditions; no prediction is made for highs being different from mediums in the difference between voluntary and passive conditions.

Results

Involuntariness ratings. Table 1 shows mean involuntariness ratings for each group in each condition. The effects of hypnotisability on reported involuntariness were analysed using hypnotisability (high vs medium) as a between-subjects factor and condition (voluntary action vs post-hypnotically suggested involuntariness vs passive action) as a within-subject factor. Importantly, there was a significant interaction between condition and group on reported involuntariness, F (1, 22) = 50.85, p < .001, η^2p = .698. The interaction was decomposed into the simple effect of condition for each hypnotisability group. For the highly hypnotisable group, there was a significant effect of agency condition on involuntariness, F(2, 18) = 135.2, p <.001, η^2p = .94. Compared to voluntary action, participants reported more involuntariness in the passive action, p <.001, $B_{U[0,5]}$ = 3.84 x 10^{28}, 95% CI [-4.98, -3.62], dz = 5.53, and post-hypnotic conditions, p <.001, $B_{U[0,5]}$ = 3.53 x 10^{11}, 95% CI [-3.62, -2.23], dz = 3.01. However, passive actions were reported to be more involuntary than actions performed following a post-hypnotic suggestion of involuntariness, p <.001, $B_{U[0,5]}$ = 2.15 x 10^{8}, 95% CI [.99, 1.76], dz = 2.53. For the medium hypnotisable group, there was a significant effect of agency condition on involuntariness, F(2, 26) = 413.08, p <.001, η^2p = .97. Compared to passive action, participants reported less involuntariness in the voluntary action condition, p <.001, $B_{U[0,5]}$ = 6.95 x 10^{125}, 95% CI [-5.00-, -4.28], dz = 7.33. There was evidence for no difference between voluntariness ratings in the voluntary and post-hypnotic conditions, p >.250, $B_{U[0,5]}$ = .10, 95% CI [-.53, .24], dz = .22. Passive actions were rated as more involuntary than actions performed following a post-hypnotic suggestion of involuntariness, p <.001, $B_{U[0,5]}$ = 2.43 x 10^{84}, 95% CI [4.06, 4.94], dz = 5.92.

Total binding. Analyses of the total binding measure are reported in the online supplemental material

Outcome binding. Table 2 shows the binding measures in each condition for both groups and Table 3 shows *p* values, Bayes factors, 95% confidence intervals and effect size for post-hoc comparisons for each main effect. The effects of hypnotisability on outcome binding were analysed using hypnotisability (high or medium) as a between-subjects factor and condition (voluntary action, post-hypnotically suggested involuntariness or passive action) as a within-subject factor. There was a significant main effect of condition on outcome binding, $F_{corrected}(1.42, 31.30) = 10.30$, $p = .001$, $\eta^2p = .319$, but no significant main effect of hypnotisability on this measure, $F(1, 22) = .929$, $p > .250$, $\eta^2p = .041$. There was a marginally significant interaction between condition and group on outcome binding, $F_{corrected}(1.42, 31.30) = 2.81$, $p = .091$, $\eta^2p = .11$. The theory that hypnotic response is experienced as passive predicts two key partial interactions. Specifically, there was, as predicted, an interaction between group and voluntary vs post-hypnotic conditions on outcome binding, $F(1,22) = 9.18$, $p = .006$, $B_{H(0, 62.5)} = 39.01$, $\eta^2p = .29$. There was no evidence one way or the other for a predicted interaction between passive and post-hypnotic conditions, $F(1,22) = .222$, $p > .250$, $B_{H(0, 62.5)} = .67$, $\eta^2p = .01$. Finally there was no sensitive evidence for an interaction between group and voluntary vs passive conditions on outcome binding, $F(1,22) = 3.52$, $p = .074$, $B_{N(0, 62.5)} = 1.63$, $\eta^2p = .14$. The planned simple effect of condition for the highly hypnotisability group revealed a significant effect of agency on outcome binding, $F_{corrected}(1.15, 10.37) = 5.50$, $p = .037$, $\eta^2p = .38$. Compared to voluntary action, outcome binding was lower for both the passive action and post-hypnotic conditions. For the medium hypnotisable group, there was also a significant effect of agency on outcome binding, $F(2, 24) = 5.52$, $p = .010$, $\eta^2p = .30$. Compared to passive action, outcome binding was higher for voluntary and post-hypnotic action. There was sensitive evidence for no difference in outcome binding between the voluntary and post-hypnotic conditions.

Action binding. The effects of hypnotisability on action binding were analysed using hypnotisability (high or medium) as a between-subjects factor and condition (voluntary action, post-hypnotically suggested involuntariness or passive action) as a within-subject factor. There was no significant main effect of condition on action binding, $F(2, 44) = .579$, $p > .250$, $\eta^2p = .026$, nor was there a significant effect of group, $F(1, 22) = 1.165$, $p > .250$, $\eta^2p = .050$. The interaction between condition and group on action binding was also not significant, F (2, 44) = .579, $p > .250$, $\eta^2p = .03$. The more precise partial interactions were all non-evidential; no conclusions follow. Specifically, there was only insensitive evidence for the interaction between group and voluntary vs post-hypnotic conditions on action binding, $F(1,22) = .859$, $p > .250$, $B_{H(0, 19)} = 1.19$, $\eta^2p = .038$; the same for the interaction between group and voluntary and passive conditions on action binding, $F(1,22) = .013$, $p > .250$, , $B_{N(0, 19)} = .68$, $\eta^2p = .001$; and for the interaction between group and passive vs post-hypnotic conditions, $F(1,22) = .623$, $p > .250$, $B_{H(0, 19)} = 1.22$, $\eta^2p = .03$. The planned simple effect of condition for the highly hypnotisability group was not significant, $F(1.30, 11.72) = .032$, $p > .250$, $\eta^2p = .004$. While the action binding shifts in the voluntary condition for highly hypnotisable participants are comparable to other reported results (e.g., 20 ms reported in Haggard, Clark & Kalogeras, 2002), we found no sensitive evidence for a difference in action binding between conditions to parallel the shift in outcome binding. However, as can be seen in Table 2, neither is there is substantial evidence for no difference between any two conditions; the data are simply insensitive and provide support for neither the experimental or null hypothesis. We can therefore draw no conclusions about action binding based on the results of this study. The insensitivity is not surprising; as we found, outcome binding is typically a bigger effect than action binding (e.g. Desantis, Roussel & Waszak, 2011; Kranick et al, 2013; Lush, Parkinson & Dienes, 2016). Given that action binding is characterised by a smaller shift than tone binding, a larger sample might be required to reveal differences in this measure.

Figure 1 shows the derived interval between the action and tone events in each condition. As outcome binding was reduced but not eliminated in passive actions, these results are broadly consistent with evidence that intentional binding is a special case of a general causal binding (Buehner, 2012). As passive actions were reported to be more involuntary than post-hypnotically induced involuntariness for highly hypnotisable subjects, we should expect a difference in magnitude of binding between these two conditions. Table 2 shows that the mean values follow this expected pattern. However, as the comparisons between these two conditions are insensitive, we can draw no firm conclusions about this pattern of results (table 3).

To investigate the relationship between the experience of involuntariness and binding, regression analysis of the difference in outcome binding between voluntary and post-hypnotic suggestion conditions over reported involuntariness in the post-hypnotic condition was conducted. All medium and highly hypnotisable participants (including those excluded from other analyses because they were unable to maintain involuntariness) were included in this analysis.

Reported involuntariness predicted the difference in outcome binding between voluntary and post-hypnotic conditions, the raw slope being 19 ms/rating unit, $t(27) = 2.37$, $p = .025$, $B_{H(0, 20)} = 6.48$. Therefore, outcome binding was reduced in the post-hypnotic condition compared to the voluntary condition as reported involuntariness increased, supporting the hypothesis that binding difference is related to subjective experience.

*Figure 1: Derived time intervals between action and tone events in the highly hypnotisable group: ** = 3 <B <10, *** = B >10*

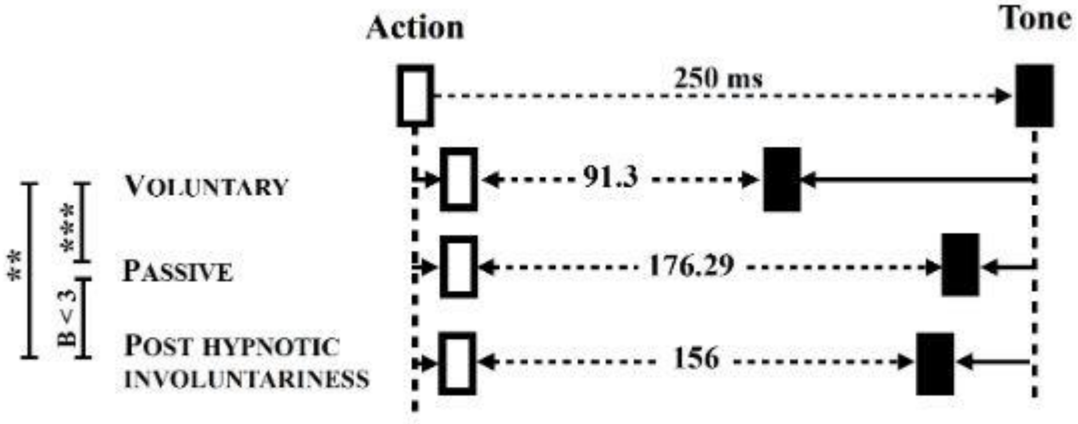
Action
Tone
250 ms
**
***
B < 3
VOLUNTARY
91.3
PASSIVE
176.29
POST HYPNOTIC
INVOLUNTARINESS
156

Table 1: Mean (SE) involuntariness ratings in each group. 0 = completely voluntary, 5 = completely involuntary.

Group (hypnotisability)		Condition		
		Voluntary	Post-hypnotic involuntariness	Passive
High				
	Involuntariness rating	.7 (.30)	3.3 (.17)	5 (0)
Medium				
	Involuntariness rating	.3 (.16)	.4 (.20)	4.9 (.07)

Table 2: Mean binding for the high and medium hypnotisable groups in the three experimental conditions

Group (hypnotisability)		Condition		
		Voluntary	Post-hypnotic involuntariness	Passive
High				
	Action binding	28.0 (25.0)	24.6 (56.7)	23.2 (53.7)
	Outcome binding	-130.7 (45.4)	-69.4 (56.0)	-50.51 (89.1)
Medium				
	Action binding	9.9 (28.2)	25.6 (38.4)	3.1 (42.9)
	Outcome binding	-120.2 (66.3)	-117.9 (67.9)	-83.5 (79.7)

Mean times are given in ms (SD).

Table 3: Post-hoc comparisons between each condition in the high and medium hypnotisable groups.

Group (hypnotisability)		Comparison: Voluntary action vs passive action	Comparison: Voluntary action vs Post-hypnotic suggestion	Comparison: Passive action vs post-hypnotic suggestion
High				
	Action binding	$p > .250$ $B_{H(0, 14)} = .91$ 95% CI [-29.3, 38.8] $dz = 0.10$	$p > .250$ $B_{H(0, 14)} = .89$ 95% CI [-32.9, 39.7] $dz = 0.07$	$p > .250$ $B_{H(0, 14)} = .93$ 95% CI [-59.4, 56.8] $dz = 0.02$
	Outcome binding	$p = .003$* $B_{H(0, 65)} = 79.51$** 95% CI [-124.4, -35.9] $dz = 1.08$	$p = .009$* $B_{H(0, 65)} = 14.70$** 95% CI [-103.4, -19.2] $dz = 0.93$	$p > .250$ $B_{H\ 0, 65)} = .76$ 95% CI [-59.0, 96.8] $dz = 0.17$
Medium				
	Action binding	$p > .250$ $B_{H(0, 5)} = 1.08$ 95% CI [-16.8, 30.5] $dz = .17$	$p > .250$ $B_{H(0, 5)} = .77$ 95% CI [-44.3, 12.8] $dz = .31$	$p = .121$ $B_{H(0, 5)} = 1.33$ 95% CI [-52.0, -6.9] $dz = .43$
	Outcome binding	$p = .019$* $B_{H(0, 60)} = 7.07$** 95% CI [-66.4, -7.0] $dz = .67$	$p > .250$ $B_{H(0, 60)} = .22$** 95% CI [-23.5, 18.8] $dz = .063$	$p = .022$* $B_{H\ 0, 60)} = 6.11$** 95% CI [-62.8, -5.9] $dz = .65$

** Significant at the .05 level. ** Sensitive B (> 3 or < 1/3).*

Discussion

Replicating previous studies, causal binding in voluntary action was stronger than in passive action (Haggard, Clark & Kalogeras, 2002; Buehner, 2015). Crucially, binding was also reduced in high hypnotisables after a post-hypnotic suggestion of involuntariness, providing evidence for hypnotically induced changes in sense of agency.

We only found evidence for changes in outcome binding. The prediction of the sensory outcome of an action may provide cues for sense of agency by comparing a predicted sensory outcome to the actual outcome and hypnotic suggestion may disrupt this mechanism by preventing motor intentions from activating sensorimotor predictions (Blakemore, Oakley & Frith, 2003). Therefore, reduced outcome binding may arise from disruption to a comparator preventing sensorimotor pre-representation of an action outcome.

An alternative account proposes that, by analogy with cross-modal cue combination (Ernst & Banks, 2002; Körding et al, 2007), the timing judgements of intentional actions and their outcomes may be a weighted average of the action and outcome cues (Kawabe, Roseboom & Nishida, 2013), with the weighting dependent on the estimated precision with which each is individually timed. The decreased outcome judgement shift reported here may therefore arise from the increased weighting of the outcome cue over the action cue in estimating the time of the outcome event when motor intention information is discounted and the estimated precision of the action cue consequently decreases (consistently, in the supplemental material we report lower within-participant SD in the voluntary than in the post-hypnotic condition for high hypnotisables and sensitive evidence of no difference in medium hypnotisables). This would occur in passive action because motor intention information is absent, and in post-hypnotic involuntariness because hypnotist induced beliefs reduce the relative weighting of motor intentions in generating sense of agency. A cue combination mechanism is predictive of an increase in action binding when motor intention information is reduced, as lower precision of action should result in a relatively higher weighting of the outcome cue in outcome timing judgements and consequently a greater shift of the weighted average of the two events toward the action cue. This might run contrary to our prediction of reduction in overall binding, as the two opposing shifts would, to at least some degree, cancel each other out. However, as we report no sensitive evidence for differences in action binding, the results of the current study do not bear on this prediction either way.

While the current study is the first to show the relevance of beliefs about intentions to binding, outcome binding is also reduced when participants incorrectly believe that an outcome is triggered by another's action (Desantis, Roussel & Waszak, 2011). This may reflect a reduced contribution of motor intentions to outcome timing judgements when, according to beliefs, such information is not relevant to event timing. Binding has also been shown to be reduced when participants are instructed to press a particular key at a particular time (Caspar et al 2016). By contrast, in the current study, participants were free to press the button when they wished and were merely instructed that they would not feel that they had intended the action.

It might be argued that hypnotic responding occurs in the absence of intentions (e.g. Woody & Bowers, 1994). However, given hypnotic actions are performed in appropriate and flexible ways, intentions appear undisrupted in hypnotic responding, and it is the metacognition of intentions that is disrupted (e.g. see Woody &Sadler, 2008). Thus, the difference between hypnotic and non-hypnotic action may lie in the awareness of intentions (Dienes, 2012; Lush, Naish & Dienes, 2016). If so, an intention being conscious may increase its availability to other processes (Cleeremans & Jiménez, 2002), and thus to the process of timing its associated action. Consistently, mindfulness meditators, who may have more accurate metacognition of motor intentions (Dreyfus, 2011), show stronger outcome binding (Lush, Parkinson & Dienes, 2016). It should be noted that highly hypnotisable people are a highly selected group, and these results may not generalise to the general population.

We report that hypnotically suggested actions behave more like genuinely involuntary than voluntary actions in an implicit measure sensitive to agency, providing objective evidence for hypnotically suggested changes in agentic experience and demonstrating that beliefs about whether an action is intended influence binding.

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Data available at: https://osf.io/abq5f/