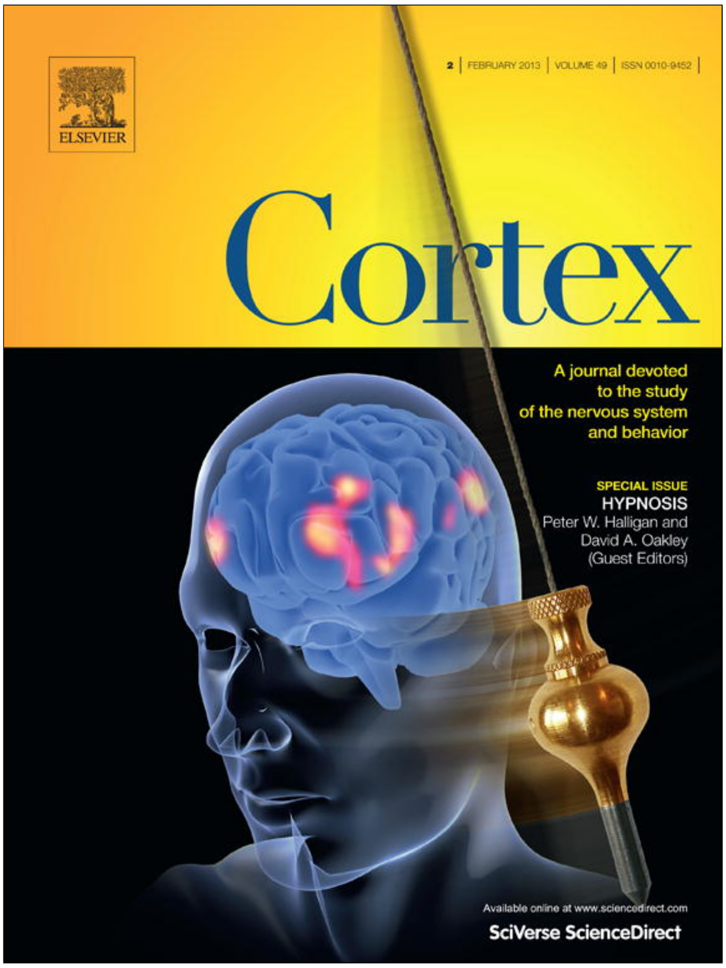
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Understanding hypnosis metacognitively: rTMS applied to left DLPFC increases hypnotic suggestibility

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ABSTRACT

Introduction: According to the cold control theory of hypnosis (Dienes and Perner, 2007), hypnotic response occurs because of inaccurate higher order thoughts of intending. The dorsolateral prefrontal cortex (DLPFC) is a region likely involved in constructing accurate higher order thoughts. Thus, disrupting DLPFC with low frequency repetitive transcranial magnetic stimulation (rTMS) should make it harder to be aware of intending to perform an action. That is, it should be easier to respond to a hypnotic suggestion.

Method: Twenty-four medium hypnotisable subjects received low frequency rTMS to the left DLPFC and to a control site, the vertex, in counterbalanced order. The hypnotist was blind to which site had been stimulated. Subjects rated how strongly they expected to respond to each suggestion, and gave ratings on a 0–5 scale of the extent to which they experienced the response, for four suggestions (magnetic hands, arm levitation, rigid arm and taste hallucination). The experimenter also rated behavioural response.

Results: Low frequency rTMS to the DLPFC rather than vertex increased the degree of combined behavioural and subjective response. Further, subjects did not differ in their expectancy that they would respond in the two conditions, so the rTMS had an effect on hypnotic response above and beyond expectancies.

Conclusions: The results support theories, including cold control theory, postulating a component of hypofrontality in hypnotic response.

1. Introduction

Hypnotic responding occurs when a person creates altered experiences of volition or reality in accord with situational requirements (Dienes, 2012; see Nash and Barnier, 2008; Oakley and Halligan, 2009, for recent reviews of the field). An example of creating an altered sense of volition is the 'magnetic hands' suggestion: the subject holds their arms outstretched, palms facing each other and imagines the hands are like magnets, attracting or repelling each other. If the subject feels a force moving the hands closer or further apart, they have successfully responded to the suggestion. The subject themselves moved their arms, but they experience the movement as involuntary. Suggested hallucinations provide an example of an altered sense of reality. For example, in the taste hallucination suggestion, it is suggested that there is honey or vinegar in the subject's mouth; if they can taste it, they have passed this suggestion. Magnetic hands is an

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example of a motor suggestion; hallucination of a cognitive suggestion.

While we do not know how it is that people are capable of producing altered experiences of volition and reality in ways sensitive to their goals, some recent approaches have emphasised either the role of metacognitive processes or the associated frontal cortex. For example, according to the cold control theory of hypnosis (Barnier et al., 2008; Dienes, 2012; Dienes and Perner, 2007), hypnotic response is constituted by intending to perform some motor or cognitive action, while remaining unaware of the intention – in fact, the hypnotised subject actively thinks she is not intending to perform the action. Construed in this way, hypnosis is a purely metacognitive phenomenon (i.e., to do with strictly cognition about cognition). It involves no changes in abilities that rely on mental states that are only about the world (which one might call 'first order' abilities). If one intends to lift one's arm it will rise; but if one is resolutely unaware of the intention, the arm will appear to lift by itself, producing the phenomenology of hypnosis. That is, hypnotic response is all due to the formation of inaccurate 'higher order thoughts' or HOTs (in the sense discussed by Rosenthal, 2005: the thought that one is in a certain mental state). Hypnotic response is constituted by intentional control without accurate HOTs: cold control.

Research has tried to identify brain regions involved in accurate HOTs, at least in vision. Lau and Passingham (2006) found two masking conditions where people could discriminate one of two shapes to an equal degree but the conditions differed in the extent to which people were aware of seeing the shapes rather than thinking they were just guessing. That is, first order abilities were equivalent, but accurate awareness of perception differed. fMRI indicated that a single cortical area distinguished the conditions, the left mid dorsolateral prefrontal cortex (DLPFC) (see also Fleming et al., 2010). Further, when Rounis et al. (2010) disrupted the area with theta burst transcranial magnetic stimulation (TMS), subject's awareness of seeing was disrupted even when first order perception (i.e., accuracy in classifying the external stimulus) was titrated to be the same with and without TMS. That is, the disruption Rounis et al. found was not in seeing but in having accurate HOTs about seeing. If the area is responsible for accurate HOTs in general[1] (and it may be, as the DLPFC is not specifically a visual area), disrupting the region with low frequency repetitive TMS (rTMS) should make it harder to be aware of intending to perform an action. That is, it should be easier to respond to a hypnotic suggestion, by cold control theory. This is the prediction we test.

Other theories have postulated that hypnosis involves hypofrontality (i.e., diminished frontal function), and thus would also make the same prediction (see Dietrich, 2003). For example, Gruzelier (1998, 2006) and Gruzelier and Warren (1993) argued that the better ability of highly hypnotisable subjects to focus attention allows them during an induction to exhaust their frontal abilities, and hence end up frontally impaired in a hypnotic state (cf Egner et al., 2005; Kallio et al., 2001). Woody and Sadler (2008) discuss different ways in which executive functioning may be impaired in order to produce hypnotic response in the context of dissociation theory (cf Farvolden and Woody, 2004). In these theories the disruptions need not be in forming accurate HOTs about intentions, but in implementing executive control in ways that can be different for different subjects (cf Terhune et al., 2011). Nonetheless, on these approaches, disruption of the frontal area by TMS should enhance hypnotic response.

Other theoretical stances can be used to argue that reducing frontal function should reduce the capacity for hypnotic response. Both the normally opposing socio-cognitive position of Spanos (1986) and the neo-dissociation position of Hilgard (1977) emphasised the active strategic nature of hypnotic response. Spanos showed hypnotic response can actively overcome habit, i.e., it can involve inhibition and executive involvement (e.g., Bertrand and Spanos, 1985; Spanos et al., 1982). Based on dual task methodologies, Hilgard argued that hypnotic response required attentional capacity (see also Wyzenbeek and Bryant, 2011; Tobis and Kihlstron, 2010). Relatedly, Crawford et al. (1998) argued hypnotic analgesia was dependent on the effective functioning of the frontal supervisory attentional system. Sheehan and McConkey (1982) also demonstrated the active role that subjects can play in constructing a hypnotic response. Based on these considerations, reduction of frontal function by TMS could be expected to diminish capacity for hypnotic response.

We compared response to hypnotic suggestion after low frequency rTMS was applied to the left DLPFC or a control site, the vertex, on medium hypnotisable subjects. The left DLPFC was used because that was the specific site identified by Lau and Passingham (2006) for having accurate HOTs. Medium suggestible subjects were used to guard against floor and ceiling effects in degree of hypnotic response. The essence of hypnosis is the subjective response; that is, hypnosis is not intrinsically about whether people can move their hands together or not but rather whether the experience is as of magnets pulling them or not (cf Kirsch et al., 1998). Thus, for all subjects, after each suggestion we asked subjects to rate the extent of their subjective experience in responding to the suggestion. The experimenter also rated the degree of behavioural response.

We found low frequency rTMS to frontal regions rather than the vertex produced more discomfort to subjects (by sometimes causing contraction of facial muscles), which might cause a stronger expectancy for hypnotic response after frontal rather than vertex stimulation (cf Kirsch, 2009). As expectancy is a strong predictor of hypnotic response (Braffman and Kirsch, 1999), for the last half of the subjects we asked just before each suggestion how strongly the subject expected to respond. Theories, like cold control, that postulate some component of diminished frontal function in hypnotic response predict that site of TMS stimulation will have an effect on hypnotic response above and beyond any effect of expectancy.

[1] The evidence indicates the area is responsible for accurate HOTs, not simply for having HOTs at all (when defined as: thoughts about the mental states one is in). For example, in the Lau and Passingham (2006) study people in both conditions expressed the same number of HOTs in total (a thought that one is guessing or not seeing is still a HOT in this general sense) but activation in left DLPFC varied with the accuracy of those thoughts.

2. Method

2.1. Participants

Twenty-four participants were recruited from the University of Sussex, School of Psychology subject pool. Participants were paid £5 for their time.

The inclusion criteria for participants were as follows: 18–35 years of age; medically fit, healthy and not currently receiving psychoactive medication; able to provide informed consent; right handed and English as first language; medium susceptible participants – scores of between 4 and 8 of the 12 point Waterloo-Stanford Group Scale of Hypnotic Susceptibility, Form C (WSGC; Bowers, 1998). The gold standard measure of hypnotic suggestibility is sometimes regarded as the individually administered Stanford Hypnotic Susceptibility Scale: Form C (SHSS:C) (Woody and Barnier, 2008; see Moran et al., 2002 for an argument for the superiority of the SHSS:C), with which the WSGC correlates about .85 (Bowers, 1993), exactly the reliability of the SHSS:C (Hilgard, 1965, p. 237).

Exclusion criteria included: current or previous psychiatric or neurological illness; left-handedness; metal implants; cardiac pacemaker; history of epilepsy or fits; family history of epilepsy or fits; migraine; any history of brain damage (or surgery); neurological disorders; current treatment with any psychoactive medication; younger than 18 years of age; and pregnancy. Participants were screened according to a questionnaire taken from Keel et al. (2000) to ensure eligibility for receiving rTMS.

2.2. Design

The experiment had one main within-subjects factor, site of stimulation (left DLPFC *vs* vertex). Order of stimulation, DLPFC first or second, was a between-subjects counterbalancing factor.

2.3. Suggestions

The four hypnotic suggestions used in the present study are as follows: one easy motor suggestion (magnetic hands: hands pulled together by a magnetic force, to which about 80% of people show some response, e.g., Carvalho et al., 2008); one difficult motor suggestion (arm levitation, arm so light that it raises in the air, to which about 35% of people respond, Fellows, 1979); a challenge suggestion (arm so rigid it cannot bend, to which about 70% of people respond, Carvalho et al., 2008); and a perceptual-cognitive suggestion (one of the easiest ones: sour taste hallucination, to which about 50% of people respond, Carvalho et al., 2008). Each suggestion was scripted so as to take 2 min to administer. The easy suggestion was for warm-up; the others, together with magnetic hands, to cover as briefly as possible the suggestion types of direct (magnetic hands, arm levitation, taste) and challenge (rigid arm); motor (magnetic hands, arm levitation, rigid arm) and perceptual-cognitive (taste): see Woody and Barnier (2008) for these distinctions.

2.4. Procedure

Intensity of TMS was determined individually for each participant by finding the level producing a visible twitch in the left hand following single pulse stimulation of the right motor cortex. Participants then received four sessions of 5 min of low frequency (1 Hz) rTMS, each session followed by a brief 1 min hypnotic induction and two hypnotic suggestions in the 5-min window of residual cortical disruption that followed. The initial induction reminded subjects of the last time they were hypnotised and informed them that they could enter that same state whenever they were told “now you are hypnotized”. The induction contained a few suggestions for relaxation and comfort (see e.g., Woody and Barnier, 2008, p. 260, for indications of the range of procedures that can be used as inductions). Suggestions were always given in the same order for a given site: magnetic hands, arm levitation, rigid arm, and finally taste hallucination. Thus, for the first site stimulated, in the first session, magnetic hands and then arm levitation was given; and in the second session, rigid arm and taste hallucination was given. The procedure was repeated for the second site. Sites were either the left DLPFC or the vertex (the sham site), which were ran in counterbalanced order. Sites were determined using an electrode cap marked according to the 10/20 system, using criteria based on previous studies that have used TMS to stimulate these areas (e.g., Wagner et al., 2006), i.e., F3 and F4 for the left DLPFC and Cz for the vertex (see Fig. 1). Note that as location was not determined by anatomical imaging, there would have been some variability in the brain region stimulated across subjects. The stimulation consisted of 5 min of 1 Hz rTMS with a stimulation intensity of 90% of the motor threshold (which is within the current guidelines; Wassermann, 1998). The induction coil was held in place with a fixed coil holder and participants' heads were stabilised with a chin rest. TMS stimulation was administered to participants with the hypnotist absent so that the hypnotist was blind to which brain region had been stimulated, so as to minimise experimenter effects.

Before each suggestion, the final 12 of the 24 subjects were informed of the nature of the hypnotic suggestion and asked to rate how strongly they expected to respond to each suggestion (on a 0–5 scale). For example: “If you were given a hypnotic suggestion that your arm will feel very rigid, so rigid you won't be able to bend it, how strongly do you expect to feel your arm becoming more rigid than normal? On a scale from 0 to 5, say 0 if you know you won't feel any change in its rigidity, 5 if you are completely certain you will feel a change in rigidity, and any number in between depending on how strongly you expect you would feel some rigidity.” The

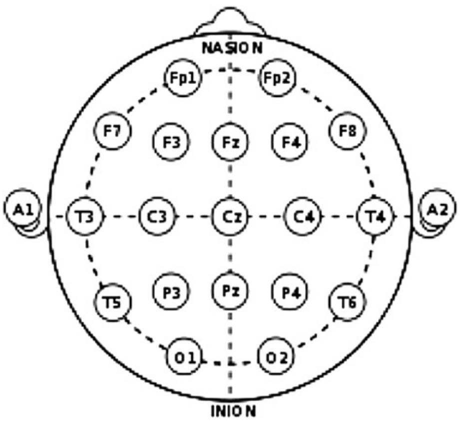

Fig. 1 – Standard EEG cap markers.

expectation ratings were taken after hypnotic induction and just before each suggestion, a timing which maximises sensitivity for predicting hypnotic response (Lynn et al., 2008).

Hypnotic suggestions are normally scored as either 'pass' or 'fail'. To increase sensitivity all subjects rated the degree of their subjective response on a continuous (0–5) scale, after the suggestion was complete. For example: "On a scale from 0 to 5 how stiff did your arm feel, where 0 means no more stiffness than normal and 5 means you could feel a stiffness so compelling no amount of effort would overcome it?" The experimenter also rated the degree of objective response to each suggestion on a percentage scale (percentage of maximum possible movement for motor suggestions, reverse coded for rigid arm, and percentage of maximum possible facial expression for taste hallucination).

3. Results

There were no effects of order of site stimulated, and this variable will not be considered further.

Table 1 shows the mean subjective ratings on a 0–5 scale according to site (left DLPFC *vs* vertex) and suggestion. A 2 × 4 ANOVA indicated a significant effect of suggestion $F(3, 69) = 21.95$, $p < .0005$, partial $\eta^2 = .488$, indicating suggestions varied in difficulty. Most importantly, there was an effect of site, $F(1, 23) = 11.86$, $p = .002$, partial $\eta^2 = .340$, indicating a greater response when the DLPFC ($M = 2.9$, standard deviation – SD = .9) was stimulated rather than the vertex ($M = 2.6$, SD = .8), a difference of .3 points. The interaction was not significant, $F(3, 69) = 1.85$, $p = .15$, partial $\eta^2 = .074$.

Table 2 shows the mean objective ratings on a percentage scale. It can be seen from the size of the SDs compared to the end points of the scale that the data are markedly non-normal; nonetheless, if we average over suggestions for each site to obtain a main effect of site the distributions are reasonable. The difference between the DLPFC ($M = 43\%$, SD = 18%) and vertex ($M = 38\%$, SD = 17%) was not significant, $t(23) = 1.54$, $p = .14$, $dz = .32$, 95% confidence interval – CI [−2, 10]. In order to interpret this non-significant result, an expected effect size is needed. On a 0–5 scale the subjective ratings showed a .3 point difference; thus, on a 0–100 scale one might expect roughly a raw effect of .3*(100/5) = 6% difference. Notice the 95% CI includes a 6% difference, so in fact nothing follows from the non-significant result: It is as consistent with there being a relevant effect as with there being none.[2]

[2] Non-significant results can also usefully be interpreted with Bayes Factors (Dienes, 2008, 2011). A Bayes Factor can compare the theory (that stimulating the DLPFC rather than the vertex will lead to better responding) to the null hypothesis. A Bayes Factor greater than 3 indicates strong evidence for the theory over the null; of less than a 1/3, strong evidence for the null over the theory; and anything in between indicates the data are insensitive and do not strongly support either the null or the theory over the other. Predictions of the theory were represented as a half-normal scaled with an SD of 6%, where the 6% was derived in the text (see Dienes, 2011 Appendix and associated free online software). The Bayes Factor was 2.06 – the evidence actually supports the theory more than the null, but only weakly, and the results cannot be used decisively to count either for or against the theory.

Table 1 – Mean subjective ratings on a 0–5 scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. N = 24.

	Magnetic hands	Levitation	Rigid arm	Taste
Left DLPFC	3.6 (1.2)	2.7 (1.5)	3.4 (1.2)	1.8 (1.2)
Vertex	3.3 (1.2)	2.1 (1.2)	3.4 (1.1)	1.5 (1.0)

Objective and subjective scores correlated $r = .51$ over subjects, $p = .015$. A new variable was created by transforming the subjective ratings to be on the same scale as the objective scores (by multiplying the subjective scores by 20 so that they lay on a 0–100 scale). A combined hypnotic response variable was created by averaging the subjective and objective scores. The difference in hypnotic response between vertex and left DLPFC stimulation (4.81, SD = 8.01), was significant, $t(23) = 2.94$, $p = .007$, $d = .60$.

Table 3 shows the mean expectancy ratings on a 0–5 scale according to site (left DLPFC *vs* vertex) and suggestion. A 2 × 4 ANOVA indicated no significant effects. In particular the effect of site was non-significant, $F(1, 11) = .14$, $p = .72$, partial $\eta^2 = .01$, with a similar expectancy when the DLPFC was stimulated ($M = 2.2$, SD = 1.0) as when the vertex was ($M = 2.1$, SD = .9), 95% CI on the difference [−.5, .7]. Although a non-significant result is consistent with the stimulation producing effects above and beyond expectancy, a non-significant result has to be interpreted carefully (especially as the CI contains .3, the same difference found for subjective ratings).[3] To see if expectancy can account for the effect of site on subjective ratings, for each subject a multiple regression was run with site and expectancy predicting

[3] The sensitivity of the result can be more optimally determined by a Bayes Factor. For expectation to mediate the effect of site on hypnotic response, the *standardised* effect of site on expectation must be as least as large as the standardised effect of site on hypnotic response. The standardised effect of site on hypnotic response can be expressed as an *r* [see Dienes, 2011 Appendix, i.e., $r^2 = t^2/(t^2 + df)$]. The *r* for effect of site on hypnotic response is .58. This can be transformed to a normally distributed variable using Fisher's z (Fisher's z = .5 loge[(1 + r)/(1 − r)]), giving a z of .66. The theory that expectation mediated the effect requires the effect of site on expectation to be at least this large. To be conservative, the predicted effect of site on expectation was represented as a normal centred on .66 (with SD = .33, i.e., half as large as the mean, a default suggested by Dienes, 2011). This representation makes it harder to get evidence in favour of the null, because ideally the representation should give more plausibility to values above .66 rather than below – but the representation is simple and if we obtain evidence for the null, we have done so despite our representation being symmetric when it should be asymmetric. The standardised effect of site on expectation was $r = .08$ and thus $z = .08$. The standard error of z is 1/sqrt(N − 3) = .22. Putting this in the Bayes Factor calculator gives B = .22, less than .33 and thus strong evidence for the null hypothesis over the theory that expectation changed enough to mediate the effect of site on hypnotic response. That is, we reject the mediation hypothesis. (This paragraph describes a novel procedure for dealing with mediation – standard procedures rely on asserting the null hypothesis after a null result, which is problematic.)

Table 2 – Mean objective ratings on percentage scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. N = 24.

	Magnetic hands	Levitation	Rigid arm	Taste
Left DLPFC	74 (30)	21 (20)	66 (38)	10 (13)
Vertex	68 (30)	21 (22)	59 (38)	6 (11)

subjective response. The mean raw regression weight for expectancy was .58, significantly above chance, $t(11) = 3.99$, $p = .004$, $d = 1.15$, indicating expectancy was a strong predictor of subjective response. Nonetheless, even with expectancy controlled, the raw regression weight for site was .39 (no smaller than the effect of .3 found above when expectancy was not controlled), $t(11) = 1.77$, $p = .05$, one-tailed, $d = .51$.

4. Discussion

Application of low frequency rTMS to the left DLPFC rather than the vertex enhanced subjective response, by .3 units on a 0–5 scale. While expectancy strongly predicted performance, the effect of site on subjective response was not mediated by expectancy. The results support theories postulating that diminished function in the frontal cortex is related to hypnotic response, such as the cold control theory (e.g., Dienes, 2012), some types of dissociation theory (e.g., Woody and Sadler, 2008) and related neurophysiological approaches (Gruzelier, 2006).

Nonetheless, there remain arguments for why impairing frontal function should impair hypnotic response: hypnotic response appears active (Spanos, 1986), constructive (Sheehan and McConkey, 1982), and capacity demanding (Wyzenbeek and Bryant, 2011). Indeed, on cold control theory, the behavioural or cognitive response itself (e.g., the movement of lifting the arm) is produced by the executive system intending the response. From the point of view of cold control theory, so long as the executive system is still capable of readily producing the response – of moving the arms, of tensing muscles, of imagining a taste –any small lack of fluency in performing these actions is not relevant (contrast the discrepancy-attribution theory discussed in Barnier et al., 2008, which claims the feeling of involuntariness arises because the action is slightly easier than average to perform). What is most important is that the frontal system is targeted so that there is diminished capacity to form accurate HOTs (as shown by Rounis et al., 2010, for the manipulation we used), enabling inaccurate thoughts of not intending to occur. On the other hand, if the frontal system were to be impaired so that the intentional and voluntary performance of an activity sometimes failed (e.g., consider frontally demanding tasks, such as a hypnotic suggestion for inhibiting the recall of words in particular categories, Bertrand and Spanos, 1985), then the hypnotic performance of the same activity would be impaired to the same degree (as predicted by Dienes and Perner, 2007). Note this latter prediction contrasts with a version of dissociated control theory (Woody and Sadler, 2008), which postulates that hypnotic response is not controlled by the executive system. Future research could also distinguish dissociated control theory and cold control by taking measures of HOT accuracy independent of hypnotic response: According to cold but not dissociated control theory, impairment of frontal function will only facilitate hypnotic response to the degree HOT accuracy has been impaired. In future, manipulations that may affect frontal function (e.g., Whalley and Brooks, 2009) could include measures of effects on HOTs.[4]

Cold control can be regarded as isolating a common component of various approaches to explaining hypnotic response (e.g., the socio-cognitive approach of Spanos, 1986, and the ‘dissociated experience’ version of dissociation theory, Hilgard, 1977): hypnotic response is essentially a form of self-deception. According to cold control theory, hypnosis involves only a metacognitive change: hypnotic response is mediated by a lack of awareness of the intentions that initiate and control the cognitive or motor action. For example, the feeling of stiffness in a rigid arm suggestion could be produced by intentionally contracting the antagonistic muscles but being unaware of that intention. A hallucination is produced by imagining the to-be-hallucinated content, and not being aware of the intention to imagine. Future research could usefully investigate the phenomenology in more detail: the sense of reality or externality of a hallucinated image should be directly related to the lack of awareness of intending it.

While the prediction of cold control that disruption of the DLPFC would enhance hypnotic response was confirmed, TMS stimulation would have affected a large area of prefrontal cortex subserving numerous functions, not just that of forming accurate HOTs. Thus the results do not provide specific support for cold control compared to theories such as those of Woody and Sadler (2008). However, the situation is not one of stalemate. Cold control in principle specifies which areas are the important ones for future work, as technology allows more specific areas of the cortex to be targeted, namely those regions that mediate accurate HOTs.

Table 3 – Mean expectancy ratings on a 0–5 scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. N = 12.

	Magnetic hands	Levitation	Rigid arm	Taste
Left DLPFC	2.3 (1.4)	2.2 (1.3)	2.8 (1.4)	1.6 (1.8)
Vertex	2.4 (1.3)	2.3 (1.1)	2.3 (1.2)	1.5 (1.4)

[4] Conversely, if frontal function is not impaired, hypnotic response may still be facilitated by, for example, improving motivation and rapport so that subjects engage with the metacognitive strategies needed for hypnotic response more effectively (Bryant et al., 2012). Cold control is situated in a tradition of seeing hypnosis as “goal directed striving” (White, 1942) in which motivation is important.

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