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Belief, delusion, hypnosis, and the right dorsolateral prefrontal cortex: A transcranial magnetic stimulation study☆

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ABSTRACT

According to the Two-Factor theory of delusional belief (see e.g. Coltheart at al., 2011), there exists a cognitive system dedicated to the generation, evaluation, and acceptance or rejection of beliefs. Studies of the neuropsychology of delusion provide evidence that this system is neurally realized in right dorsolateral prefrontal cortex (rDLPFC).

Furthermore, we have shown that convincing analogues of many specific delusional beliefs can be created in nonclinical subjects by hypnotic suggestion and we think of hypnosis as having the effect of temporarily interfering with the operation of the belief system, which allows acceptance of the delusional suggestions. If the belief system does depend on rDLPFC, then disrupting the activity of that region of the brain by the application of repetitive transcranial magnetic stimulation (rTMS) will increase hypnotizability. Dienes and Hutton (2013) have reported such an experiment except that it was *left* DLPFC to which rTMS was applied. An effect on a subjective measure of hypnotizability was observed, but whether there was an effect on an objective measure could not be determined.

We report two experiments. The first was an exact replication of the Dienes and Hutton experiment; here we found no effect of rTMS to lDLPFC on any hypnotic measure. Our second experiment used rTMS applied to *right* rather then left DLPFC. This right-sided stimulation enhanced hypnotizability (when hypnotic response was measured objectively), as predicted by our hypothesis.

These results imply a role for rDLPFC in the cognitive process of belief evaluation, as is proposed in our two-factor theory of delusion. They are also consistent with a conception of the acceptance of a hypnotic suggestion as involving suspension of disbelief.

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1. Introduction

In this paper we are concerned with the explanation of belief formation – that is, how beliefs are generated, evaluated, and adopted or rejected – and in particular with the neuropsychology of these belief processes. We approach this topic from two angles. The first is the study of delusional beliefs in clinical patients. The second is the use of hypnotic procedures to manipulate belief formation in healthy subjects.

With respect to delusional belief, a distinction can be drawn between polythematic delusion and monothematic delusion (see e.g. Coltheart, 2013; Davies, Coltheart, Langdon, & Breen, 2001; Radden, 2011). A polythematic delusional condition is one in which the deluded person has a variety of different and unrelated delusional beliefs; a monothematic delusional condition is one where the deluded person has only a single delusional belief or at most a small set of delusional beliefs all related to a single theme. Our Two-Factor theory of delusion, described below, has been primarily concerned with monothematic delusions.

There are numerous distinct forms of monothematic delusion. They include Cotard delusion ("I am dead"), Capgras delusion ("My wife has been replaced by an impostor", Fregoli delusion ("People I know are following me around, but in disguise so that I can't recognize them"), somatoparaphrenia ("This is not my arm, it is my aunt's" – the patient here is referring to her own arm), erotomania aka de Clérambault's syndrome (" a famous person X is in love with me but keeps this a secret"), mirrored-self misidentification ("When I look into a mirror, the person I see is not me, but a stranger who looks like me"), alien control delusion ("other people can control the movements of my body against my will") and various others: for reviews of these monothematic delusions see Davies et al. (2001), Coltheart (2007) and Coltheart, Langdon, and McKay (2011).

With respect to the use of hypnotic procedures to influence belief formation in healthy subjects, we have over the past few years shown that features of some of these forms of monothematic delusional belief can be induced in high-hypnotizable subjects by appropriate hypnotic suggestions. We have demonstrated this for the mirrored-self misidentification delusion (Barnier et al., 2008), somatoparaphrenia (Rahmanovic, Barnier, Cox, Langdon, & Coltheart, 2012), erotomania (Attewell, Cox, Barnier, & Langdon, 2012), Fregoli delusion (Cox, Elliott, & Barnier, 2013) and alien control delusion (Cox & Barnier, 2010). We have argued (e.g. Connors, Barnier, Coltheart, Cox, & Langdon, 2012; Connors, Cox, Barnier, Langdon, & Coltheart, 2012, 2013; Cox & Barnier, 2010a, 2010b; for an overview of this work see; Connors, 2015) that in these studies of hypnotically-induced delusional beliefs, simply being in the hypnotic state by itself impairs belief evaluation, a view that is consistent with prior observations on hypnosis, such as that people tend to accept ideas during hypnosis that they would normally reject in an ordinary, everyday state of consciousness (Shor, 1959) and that a hypnotic induction reduces the ability of high-hypnotizable subjects to distinguish between suggested and real events (Bryant & Mallard, 2003; see also; Barnier et al., 2008).

1.1. *The two-factor theory of delusional belief*

What could give rise in clinical patients to the kinds of monothematic delusions we have described above – how might these be explained? A Two-Factor theory of monothematic delusion was proposed by Langdon and Coltheart (2000) and Davies et al. (2001), and subsequently elaborated by e.g. Coltheart (2007) and Coltheart et al. (2011). According to this theory, to account for any kind of monothematic delusion we just need to discover the answer to two questions. The first is: what brought the delusional thought to mind in the first place? The second is: why was this thought then adopted as a belief, rather than being dismissed from consideration as it should have been (because of its implausibility, and because of the strength of the evidence against it)?

The development of this Two-Factor theory was provoked by seminal work on the Capgras delusion by Ellis, Young, Quayle, and de Pauw (1997). It was known that when subjects are viewing photographs of faces, autonomic responses (as indicated by changes in skin conductance) are normally much larger when the faces are familiar than when they are unfamiliar. This difference was shown by Ellis and colleagues to be present also in nondelusional psychiatric patients but absent in patients with Capgras delusion, a finding confirmed by Hirstein and Ramachandran (1997) and Brighetti, Bonifacci, Borlimi, and Ottaviani (2007). Hence in Capgras delusion patients, the autonomic response to the face of a familiar person such as a spouse, is the response to be expected if that face were the face of a stranger: which, plausibly, prompts the idea that the person being looked at *is* a stranger.

But this disconnection between the face recognition system and the autonomic nervous system cannot be the complete explanation of the Capgras delusion, because it has been shown by Tranel, Damasio, and Damasio (1995) that patients with damage to ventromedial frontal cortex also do not show greater autonomic responsivity to familiar compared to unfamiliar faces: and yet these patients were not delusional. Proponents of the Two-Factor theory therefore argue that there must be some additional impairment in patients with Capgras delusion. A disconnection between the face recognition system and the autonomic nervous system is responsible for the content of the Capgras delusion; a second impairment is responsible for the maintenance of this content as a belief. That is, the normal processes of belief evaluation and belief acceptance or rejection are impaired in patients with Capgras delusion: that is the second factor.

The various kinds of monothematic delusional beliefs differ from each other with respect to the content of the belief. It follows that Factor 1 must be different for each kind of monothematic delusional belief, since it is Factor 1 that is responsible for the content of the belief. For example, the specific content of the Capgras delusional belief is a consequence of the failure of autonomic response to familiar faces. It is therefore necessary for proponents of the Two-Factor theory to identify, for each type of monothematic delusion, what neuropsychological impairment is present that is plausibly connected to the specific content of that particular delusional belief; and we have made proposals regarding this for each of the well-studied monothematic delusional conditions (summarized in Coltheart et al., 2011).

But for a monothematic delusion to arise, Factor 2, an impairment of the system for belief evaluation and acceptance or rejection must also be present, regardless of the content of the delusional belief. Hence this theory predicts that this belief system impairment must be common to all cases of monothematic delusion. And since, in all the forms of monothematic delusion that have so far been well documented, the patients have clear neurological damage, the claim must be that there is a form of neurological damage common to all patients with monothematic delusions, a form of damage that impairs the belief evaluation system.

We have used this two-factor framework also to interpret our findings that various monothematic delusions can be created in healthy nonclinical high-hypnotizable subjects by appropriate hypnotic suggestions. As noted above, we consider that Factor 2 – impaired belief evaluation – is induced in subjects simply by their being in the hypnotic state. The specific hypnotic suggestion given to the subject is responsible for the specific content of the hypnotically-induced delusional belief i.e. it acts as Factor 1 of the Two-Factor theory.

1.2. Delusional belief and the right lateral prefrontal cortex (rLPFC)

Coltheart (2007) reviewed a variety of lines of evidence that support the conclusion that the cortical region at which damage impairs the normal processes of belief evaluation and belief acceptance or rejection is within the right frontal lobe. His reasons for suggesting this conclusion were as follows:

(a) Cold caloric stimulation of the left ear produces activation of a cortical network involving right prefrontal regions including the right dorsolateral PFC and areas adjacent to it such as the frontal operculum (pars opercularis) of the right inferior frontal gyrus (IFG) (Fasold et al., 2002). Such stimulation temporarily removed the delusion in two patients with somatoparaphrenia (Bisiach, Rusconi, & Vallar, 1991; Rode, Charles, Perenin, & Vighetto, 1992).

(b) In a patient with Capgras delusion and a right frontal parasagittal meningioma, the delusion disappeared when the tumour was removed (Fennig, Naisberg-Fennig, & Bromet, 1994).

(c) In a review of 22 cases of Capgras, reduplication or Fregoli delusions, 18 were reported to have had right frontal lesions, and a further two had diffuse bilateral brain damage (Burgess, Baxter, Rose, & Alderman et al., 1966, Table 4.1).

(d) Delusional Alzheimer's patients show reduced blood flow in right frontal regions compared to non-delusional Alzheimer's patients (Staff et al., 1999).

(e) The P300 ERP component is said to be the physiological correlate of (amongst other things) updating a cognitive hypothesis i.e. adopting a new belief. Papageorgiou, Ventouras, Lykouras, Uzunoglu, and Christodoulou (2003) studied this component in nine patients with Capgras or Fregoli delusion and eleven healthy controls. The delusional group showed a significant reduction in P300 amplitude, relative to the controls, in the right frontal region.

Other work has provided further evidence supporting these conclusions:

(f) Villarejo et al. (2011) reported a new case of the mirrored-self misidentification delusion subsequent to a small stroke; this stroke was in right dorsolateral PFC (rDLPFC).

(g) Thiel, Studte, Hildebrandt, Huster, and Weerda (2014) presented a new case of Capgras Delusion in whom (a) fMRI showed a lack of neural activity to the partner's face in left posterior cingulate cortex and left posterior superior temporal sulcus (part of the extended face processing system), which would correspond to Factor 1 in our account, and (b) structural MRI revealed a large right prefrontal lesion sparing the ventromedial and medial orbitofrontal cortex, which would correspond to Factor 2 in our account, since the patient's lesion included the rDLPFC.

(h) In an fMRI study, Corlett et al. (2007) used an associative-learning paradigm that we interpret as requiring the formation and evaluation of candidate beliefs for accurate performance (in their particular version of the paradigm, subjects had to form and evaluate beliefs about the particular allergy from which a hypothetical patient was suffering). This study reported that rLPFC is activated by violation of expectations. We interpret this activation as reflecting the belief formation and evaluation processes that are triggered by violation of expectations (i.e. prediction error) in this paradigm. Corlett and colleagues found that this activation was attenuated in patients with psychosis, and that the degree of attenuation of rLPFC activation was positively correlated with the level of delusion-like thought in the patients. In other work by this group (Turner et al., 2004), it has been suggested that the key right lateral prefrontal region is specifically right dorsolateral prefrontal cortex (rDLPFC).

(i) Radaelli et al. (2014) found reduced grey-matter volume in delusional compared to nondelusional subjects in right frontal sites, one of these in the right middle frontal gyrus and the other two in the right inferior frontal gyrus.

(j) Adequate insight into the presence of a pathological condition depends upon adequate ability to evaluate belief; and if the normal processes of belief evaluation and belief acceptance or rejection depend upon the integrity of rDLPFC, then there should be a relationship between insight and rDLPFC. This was shown by Shad, Muddasani, Prasad, Sweeney, and Keshavan (2004), who reported that first-episode schizophrenia patients with poor insight showed significantly smaller right DLPFC volumes as compared to those with preserved insight. Left DLPFC volume was not associated with degree of insight. These findings were confirmed in a subsequent study by Shad, Muddasani, and Keshavan (2006).

Thus the evidence seems clear that damage to right frontal cortex is associated with the presence of delusional belief, and even that the specific region of right frontal cortex that is critical here is rLPFC – and possibly an even more specific region, rDLPFC. Our claim is that the cognitive correlate of this right frontal damage is impairment of the belief evaluation system; and of course the Two-Factor theory asserts that this particular cognitive impairment is present in all forms of monothematic delusion.

Although the Two-Factor theory of delusional belief was developed specifically for the explanation of monothematic delusions, there are reasons to believe that this neuropsychological account of delusional belief might be more widely applicable – that is, might also be applicable to the more commonly occurring delusions i.e. polythematic delusions that manifest as delusions of reference or persecution. In the study of first-episode schizophrenia patients by Shad et al. (2006), who were not selected on the basis of the presence of monothematic delusion, not only was there a significant correlation between current awareness of symptoms and volume of right (but not left) DLPFC (the greater this volume, the more the awareness of symptoms); but there was also a significant correlation between current *attributions* (i.e. explanations) of symptoms and volume of right (but not left) medial orbitofrontal cortex (OFC) (the greater this volume, the higher the degree of misattribution).

Shad et al. (2006) suggested that increased right OFC activation resulted in an abnormal degree of perceived salience of experiences (since the OFC has direct connections with limbic-system structures). This salience abnormality could function as our Factor 1 in these patients i.e., as bringing thoughts of reference or persecution to mind as possible explanations of the abnormal salience. Such thoughts should not be accepted as beliefs because of the absence of any direct evidence of reference or persecution; the effect of the right DLPFC abnormality is to impair the normal processes of belief evaluation and hence to fail to prevent these thoughts from becoming beliefs.

If it is the case that rLPFC and perhaps even specifically rDLPFC is associated with the cognitive processes of belief formation and evaluation, then it should be possible to obtain evidence supporting this idea not only from studying people with delusions, but also from studying people in whom these belief processes are intact.

1.3. *The belief evaluation system and right lateral prefrontal cortex*

One example of such work is the study by McKay et al. (2013). They used an unrealistic-optimism paradigm: cognitively-intact people were asked to rate the likelihood that they would contract various diseases in the future, compared to their peers. A rating scale from −6 through 0 to +6 was used, a rating of zero indicating that the subject considered the probability of he or she contracting the illness to be the same as the probability of peers contracting it. Negative values (which are typically produced) indicated that the subject considers this likelihood to be lower than it was for their peers. In this paradigm, the ratings produce are typically negative, so people are unrealistically optimistic; that is, their evaluation of beliefs about their possible future ailments is defective.

McKay and colleagues investigated the effect of cold caloric stimulation of left or right ear on peoples' responses in the unrealistic-optimism paradigm. As noted above, Fasold et al. (2002) reported that irrigating the left ear with cold water produces activation of rLPFC regions including rDLPFC and rIFG. Since such irrigation in patients with the delusion of somatoparaphrenia temporarily dispels the delusion, one might take the view that this irrigation improves the operation of a belief formation and evaluation system located in rLPFC. So one might predict that such irrigation would improve the accuracy of people's beliefs about the likelihood of future illnesses. i.e., make them more realistic; and that is what McKay et al. (2013) found. In contrast irrigating the *right* ear with cold water had no effect on responses in this unrealistic-optimism task. Results consistent with those of McKay and colleagues were reported by Sharot, Korn, and Dolan (2011) who found that the degree to which healthy subjects made their unrealistically optimistic beliefs about future illnesses more realistic when provided with information about the true probabilities was positively correlated with degree of activation in right IFG. Sharot and colleagues concluded that unrealistic optimism is due to peoples' failure to revise beliefs adequately when presented with evidence conflicting with those unrealistic beliefs, and that the system responsible for carrying out such belief evaluation and revision is associated with rLPFC, specifically rIFG.

Another example of such work with cognitively intact subjects is the study by Gilbert, Zamenipoulos, Alexiou, and Johnson (2010). The task they used involved problem-solving with ill-structured problems (i.e., unstructured problems without a unique correct solution); solving these kinds of problems arguably involves hypothesis formation and evaluation. Subjects' brains were imaged using fMRI as they were solving these problems. Gilbert and colleagues interpreted their results as indicating "that a crucial area for dealing with ill-structured problems is right dorsolateral PFC (BA 9/46)" and "that this region is particularly involved in early stages of problem structuring and solution generation rather than solution execution".

In sum, then, we argue that the evidence from both healthy subjects and people with monothematic delusions points quite strongly towards the idea the belief system – the cognitive system we use to generate, evaluate and then accept or reject beliefs – is dependent upon right lateral prefrontal cortex, with particularly important regions of that cortex being rDLPFC and rIFG. Given that we also consider, as mentioned above, that in healthy high-hypnotizable subjects being in the hypnotized state impairs belief evaluation processes, we are led to investigate the role played by activation of rLPFC in hypnotic responding. Our reasoning is this: if in healthy subjects low frequency repetitive transcranial magnetic stimulation (rTMS) is applied to rLPFC so as to disrupt neural activity in that region, and if belief evaluation processes depend upon the activity of that region, then it would be expected that the strength with which these subjects respond to hypnotic suggestions should be increased by rTMS to rLPFC.

1.4. The study by Dienes and Hutton (2013)

We know of only one investigation of the effects of rTMS on hypnotic suggestibility, that of Dienes and Hutton (2013). Using healthy subjects who were of medium hypnotizability, they measured the response to hypnosis in two ways:

(a) "Objective ratings": by this term they referred to ratings by the experimenter (on a percentage scale) of the degree of objective response by the subject to each suggestion.
(b) "Subjective ratings": by this term they referred to subjects' post-suggestion ratings in response to, for example, the question "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?"

These measures were taken under two rTMS conditions: control (stimulation over the vertex) and experimental (stimulation over DLPFC). This is exactly the experiment we have in mind – except that in the Dienes–Hutton study the rTMS was applied to *left* DLPFC.

Above we provide much evidence that *right* DLPFC might be associated with degree of response to hypnotic suggestions. Why, then, did Dienes and Hutton instead select *left* DLPFC? They made this choice because of a result from a metacontrast masking study by Lau and Passingham (2006).[1] In that study, at certain target-mask intervals subjects reported being unaware that a target had been presented and yet were above chance at forced-choice identification of that target. In Dienes and Hutton's terminology, what happens on such occasions of unawareness is that subjects have inaccurate Higher-Order Thoughts (HOTs) about seeing. Low activation of left DLPFC was associated with these occasions of unawareness.

Dienes and Hutton characterize hypnosis as constituted by intentional control without HOTs pertaining to the intention. Hence if HOTs depend on left DLPFC, interfering with left DLPFC by rTMS should reduce the occurrence of HOTs and so amplify the response to hypnotic suggestion. The general idea that being in a hypnotized state is akin to having a frontal lobe disorder goes back to Woody and Bowers (1994; see the section in that chapter headed "The hypnotized subject as a frontal lobe patient").

Consider now the results of their study. As indicated in Table 1 of Dienes and Hutton (2013) mean subjective ratings on the 0–5 scale were .3 higher with left DLPFC stimulation than with vertex stimulation, a difference which was significant. As indicated in Table 2 of Dienes and Hutton (2013) mean objective ratings on a percentage scale were 5 percentage points higher with left DLPFC stimulation than with vertex stimulation, a difference that was not significant. Further analyses of the nonsignificant objective ratings effect led the authors to conclude (p. 389) that this result "is as consistent with there being a relevant effect as their being none" and "the results cannot be used decisively to count for or against the theory". So one cannot conclude anything here concerning the relationship between left DLPFC stimulation and objective response to hypnotic suggestion.

For reasons we have explained above, we think that *right* DLPFC rather than left DLPFC is more likely to be involved in response to hypnosis, and we will carry out a study investigating this (our Experiment 2). But first we will carry out an exact replication of the Dienes–Hutton study in order to determine whether we can replicate their findings of (a) no evidence supporting the theory that activity in left DLPFC is related to objective response to hypnotic suggestion and (b) an effect of rTMS to left DLPFC on subjective ratings. Having carried out that replication as our Experiment 1, we will carry out exactly the same experiment again with one difference: in our Experiment 2 the experimental condition will use rTMS to *right* rather than left DLPFC.

2. Experiment 1[2]

2.1. Methods[3]

2.1.1. Subjects

Subjects [3M 9F, mean age 19.8 years (sd 2.55)] were recruited from the subject pool of the Departments of Psychology and of Cognitive Science at Macquarie University. They were paid $15 for their time.

The inclusion criteria for subjects 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 subjects with scores of between 4 and 8 on the 12-point Waterloo-Stanford Group Scale of Hypnotic Susceptibility, Form C (WSGC; Bowers, 1998). The gold standard measure of hypnotizability is sometimes regarded as the individually administered Stanford Hypnotic Susceptibility Scale: Form C (SHSS: C) (Woody & Barnier, 2008; see Moran, Kurtz, & Strube, 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).

The mean WSGC hypnotizability score was 5.50 for this group of subjects.

Exclusion criteria were: current or previous psychiatric or neurological illness; 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. Subjects were screened according to a questionnaire taken from Keel, Smith, and Wassermann (2000) to ensure eligibility for receiving rTMS.

[1] See also subsequent relevant papers by Hesselmann et al. (2011), Jannati and Di Lollo (2012) and Fleming and Dolan (2012).

[2] The raw data from this experiment and from Experiment 2 are publicly available at https://osf.io/6nr29/files/.

[3] The text of our Section 2.1, **Methods** is reproduced approximately verbatim from the Methods section of Dienes and Hutton (2013) since our experiment 1 is intended as a replication of their experiment.

2.1.2. *Design*

The experiment has one within-subjects factor, site of stimulation (left DLPFC *vs*. vertex), the order of which was counterbalanced across subjects.

2.1.3. *Suggestions*

The four hypnotic suggestions used in this study were as follows: one easy motor suggestion (magnetic hands: hands pulled together by a magnetic force, to which about 80% of people show some response (Carvalho, Kirsch, Mazzoni, & Leal, 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. These suggestions 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.

Appendix A gives the exact scripts for each suggestion.

2.1.4. *Procedure*

The TMS stimulator we used was a Magstim Rapid 2 with a 70 mm figure-of-8 coil (Double 70 mm Alpha Coil). Intensity of TMS delivered to the PFC was based on motor threshold determined in the same hemisphere. We used the visual observation of muscle twitch (OM-MT) method described in Varnava, Stokes, and Chambers (2011) who confirmed its reliability for both left and right motor cortex. Briefly, in each subject we found the minimum level of stimulator output that produces a visible twitch in the first dorsal interosseus (FDI) of either the left or right hand (depending on group) following single pulse stimulation of the respective contralateral motor cortex during minimal motor activation. Subjects were instructed to relax their arm, and rest it on their lap, palm upwards, whilst gently squeezing their thumb and forefinger together – as if squeezing a pea, whilst simultaneously keeping their other fingers relaxed. We then monitored for 3/5 visible twitches in the FDI in response to TMS. Subjects were occasionally asked to shake their arm to relax everything and then to resume holding their hand as before.[4]

With respect to coil orientation, we followed Dienes and Hutton's procedure (Sam Hutton, personal communication) in that the coil was always angled such that the edges of both wings were equidistant from the skull. The aim was to keep the arm of the coil parallel with the anterior–posterior midline, and horizontal, or as close to horizontal as possible. If this arrangement caused twitches that seemed to be uncomfortable for the subject the angle would have been changed slightly; but this did not happen for any of our subjects.

Subjects 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 the residual cortical disruption that followed. The initial induction reminded subjects of the last time they were hypnotized 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 & 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, the magnetic hands and then arm levitation suggestions were given; and in the second session, rigid arm and taste hallucination suggestions were given. The procedure was repeated for the second site.

Sites were either the left DLPFC or the vertex (the control site), which were run in counterbalanced order: that is, all four suggestions were administered with one of the sites, and then administered with the other site. Sites were determined using an electrode cap marked according to the 10/20 system, as was done by Dienes and Hutton: a 10–20 net was used to locate F3/F7, and we generally aimed to stimulate close to F3. Due to individual differences in cranial nerve layout, sometimes this point can result in uncomfortable face/eye twitching, in which case the position and angle of the coil would have been moved slightly (within the F3/F7 area) until some comfortable position was reached[5] However, this was not needed for any of our subjects. Site Cz was used for the vertex.

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 was 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 subjects' heads were stabilised with a chin rest. TMS stimulation was administered to subjects with the hypnotist absent so that the hypnotist was blind to which brain region had been stimulated, so as to minimise experimenter effects.

We are confident that the particular rTMS method we used had the desired effect of reducing cortical excitability in the targeted cortical regions, because there have already been numerous rTMS studies using exactly the same paradigm used that have shown that this paradigm does result in reduced cortical excitability (see for example Chen et al., 1997; Maeda, Keenan, Tormos, Topka, & Pascual-Leone, 2000; Muellbacher, Ziemann, Boroojerdi, & Hallett, 2000; Touge, Gerschlager, Brown, & Rothwell, 2001).

Before each suggestion, each subject was 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

[4] We thank Sam Hutton for providing these details of the motor threshold determination procedure used in the Dienes–Hutton paper.

[5] We thank Sam Hutton for providing these details. Note that there was a typographical error on page 388 of Dienes and Hutton (2013): "F3 and F4" should have read "F3 and F7".

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 expectation ratings were taken after hypnotic induction and just before each suggestion, a timing that maximizes sensitivity for predicting hypnotic response (Lynn, Kirsch, & Hallquist, 2008). Hypnotic suggestions are normally scored as either 'pass' or 'fail'. To increase sensitivity of the measure, all subjects rated the degree of their subjective response on a continuous (0–5) scale, after the suggestion has been completed. 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).

2.1.5. *Analysis*

In order to deal with issues concerning power, the experiment was conducted using a Bayes Factor stopping rule approach applied to the subjective ratings data (since this was the variable that yielded a significant effect of TMS site in the study by Dienes & Hutton, 2013). We specified H1 (the alternative hypothesis that left DLPFC stimulation will produce stronger effects than vertex (control) stimulation) using a half-normal distribution with .3 rating units as the standard deviation of that half-normal (i.e. the roughly expected subjective-rating effect size; we chose a value of .3 because this was the mean effect on ratings observed by Dienes and Hutton (2013), averaged over all their suggestions). After every subject (but see next paragraph), we calculated the Bayes Factor (B), the odds in favour of the alternative hypothesis H1 relative to the null hypothesis H0. . We continued to run subjects until either $B > 3$ (allowing us to conclude in favour of H1) or else $B < 1/3$ (allowing us to conclude in favour of H0). These choices for B followed the recommendations of Jeffreys (1961), which are currently widely adopted: a value B in the range 3–10 may be considered as moderate evidence in favour of the alternative hypothesis H1 whereas a B in the range .1–.3 may be considered as moderate evidence in favour of the null hypothesis H0. We calculated B using the on-line calculator at http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/bayes_factor.swf.

Our experience has been that B values are somewhat unstable when only a few subjects have been run (see also Dienes, 2016, for an illustration of this). To avoid this difficulty and to allow preliminary checking of distributional assumption, we decided in advance not to begin to apply this stopping rule until after 12 subjects had been run.

2.2. *Results*

When we calculated B after the twelfth subject, using the abovementioned on-line calculator, the value of B was .29; since that is <.33, data collection then ceased and data analysis was carried out. B was also calculated using the software package JASP (https://jasp-stats.org/) using a scaling parameter of .703 because that was the Cohen's dz effect size on subjective ratings reported by Dienes and Hutton (2013). This calculation yielded $B = .275$ The two calculators produce nonidentical values of B because the Dienes calculator assumes the normal distribution for H1 and the JASP calculator assumes the Cauchy distribution, which has slightly heavier tails than the normal, and also because the JASP calculator requires a standardized effect size, whereas we used a raw effect size for the Dienes calculator.

Table 1 shows the mean subjective ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of $-.32$ ($sd = .75$) i.e. subjective rating of strength of response was numerically *lower* in the experimental (Left DLPFC) than the control (Vertex) condition. Given that $B < .33$, we accepted the null H0 and concluded that TMS to left DLPFC does not enhance subjective strength of the hypnotic response. As reported in Table 1, we also calculated the Bayes Factors for each of the four individual suggestions using the effects for each suggestion reported by Dienes and Hutton (2013).

Table 2 shows the mean objective ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of -5.44 ($sd = 9.50$) i.e. subjective rating of strength of response was numerically *lower* in the experimental (Left DLPFC) than the control (Vertex) condition. For the Dienes calculator we used a value of 4.25 as the standard deviation of the half-normal (i.e. the expected objective-rating effect size under H1) because this was the mean effect on objective ratings observed by Dienes and Hutton (2013), averaged over all their suggestions). With JASP we used a scaling parameter of .32 because that was the Cohen's dz effect size on objective ratings reported by Dienes and Hutton (2013). The Dienes Calculator yielded a value of .21 for B; the JASP value was .228. Given that $B < .33$, we accepted the null H0 and concluded that site of TMS had no effect on objective ratings of the strength of the hypnotic response. As reported in Table 2, we also calculated the Bayes Factors for each of the four individual suggestions using the effects for each suggestion reported by Dienes and Hutton (2013).

Table 3 shows the mean expectancy ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of .02 ($sd = .53$). Since no predictions were made as to the direction of this difference we used two-tailed tests here. For the Dienes calculator we used a value of .10 as the standard deviation of the half-normal (i.e. the expected expectancy-rating effect size under H1) because this was the mean effect on expectancy ratings observed by Dienes and Hutton (2013), averaged over all their suggestions. With JASP we used a scaling parameter of .076 because that was the Cohen dz effect size on expectancy ratings reported by Dienes and Hutton (2013). The Dienes Calculator yielded a value of .89 for B; the JASP value was .856. Given that B was not greater than 3.0 nor less than .33, we cannot conclude anything with confidence about whether there was any effect of site on expectancy. However, given that the difference in mean expectation as a function of site was so tiny (.02) we do not think this is important. As reported in Table 3, we also calculated the Bayes

Table 1 – Mean subjective 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	Mean
Left DLPFC	2.83 (1.03)	1.50 (1.09)	2.29 (1.54)	1.46 (1.20)	2.02 (.82)
Vertex	3.08 (1.62)	1.88 (1.54)	2.75 (1.71)	1.67 (1.56)	2.34 (1.18)
Difference	−.25 (.97)	−.38 (1.19)	−.46 (1.12)	−.21 (.84)	−.32 (.75)
Cohen's dz	−.26	−.32	−.41	−.25	−.43
SEM	.28	.34	.32	.24	.22
D&H effect	.3	.6	0	.3	.3
B (Dienes)	.44	.29	–	.39	.29

Table 2 – Mean objective ratings on a percentage scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. N = 12.

	Magnetic hands	Levitation	Rigid arm	Taste	Mean
Left DLPFC	30.92 (37.68)	5.75 (8.04)	67.00 (40.08)	9.17 (13.62)	28.21 (14.81)
Vertex	46.67 (41.47)	6.25 (8.82)	77.50 (31.30)	4.17 (5.30)	33.65 (16.96)
Difference	−15.75 (36.77)	−.50 (7.13)	−10.50 (31.59)	5.00 (10.30)	−5.44 (9.50)
Cohen's dz	−.43	−.07	−.33	−.49	−.57
SEM	10.61	2.06	9.12	2.97	2.74
D&H effect	6	0	7	4	4.25
B (Dienes)	.53	–	.49	2.71	.21

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	Mean
Left DLPFC	2.75 (1.14)	2.00 (1.35)	2.17 (1.19)	1.17 (1.12)	2.02 (.88)
Vertex	2.58 (1.44)	1.75 (1.22)	2.42 (1.31)	1.25 (1.28)	2.00 (.92)
Difference	.17 (1.59)	.25 (1.54)	−.25 (1.29)	−.08 (1.00)	.02 (.53)
Cohen's dz	.11	.16	−.19	−.08	.04
SEM	.46	.44	.37	.29	.15
D&H effect	−.1	−.1	.5	.1	.1
B (Dienes)	.92	.89	.40	.88	.89

Factors for each of the four individual suggestions using the effects for each suggestion reported by Dienes and Hutton (2013).

We assessed the reliability of the subjective and objective ratings techniques by examining the intercorrelations between the different sets of averaged ratings.[6] These are shown in Table 4. All correlation coefficients are positive and significant (p values ranging from .027 to < .001) which could not have been so if any of the rating techniques were seriously unreliable.

Table 4 – Intercorrelations of the four sets of averaged ratings.

	Vertex objective	Vertex subjective	DLPFC objective	DLPFC subjective
Vertex objective		.677	.830	.897
Vertex subjective			.633	.830
DLPFC objective				.854

3. Experiment 2

3.1. Methods

3.1.1. *Subjects, design, suggestions and procedure*

Subjects (7M 32F, mean age 21.6 years (sd 5.13)) were recruited from the subject pool of the Departments of Psychology and of Cognitive Science at Macquarie University. They were paid $15 for their time.

This experiment was identical in every way to Experiment 1 except that a different set of subjects was recruited and that, rather than left DLPFC, ***right*** DLPFC was the target of the experimental rTMS condition. As with Experiment 1, sites were determined using an electrode cap marked according to the 10/20 system, but this time to locate F4/F8, and we generally aimed to stimulate as close to F4 as was comfortable for the subject.

The mean WSGC hypnotizability score for this group of subjects was 5.69. The subjects in the two experiments did not differ significantly in hypnotizability ($t(49) = .452$, $p = .653$).

[6] These correlational analyses were not part of the analyses prespecified in this paper's Registered Report, but were carried out in response to a subsequent suggestion by a reviewer. This applies also to the correlation reported in Table 8.

3.2. *Results*

Experiment 2 was conducted in the same way as Experiment 1. i.e. using a Bayesian stopping rule. After 12 subjects had been run, the value of B for the subjective-rating data according to the Dienes calculator was 2.25; according to the JASP calculator with the same scaling factor as in the Experiment 1 analyses it was 1.664. Given that in both cases 3.0 > B > .33, we continued to run subjects.

Fig. 1 shows the values of the Dienes-calculated and JASP-calculated Bs for the subjective-rating data after each subject was run.

We have three points to make concerning this Figure.

The first point is that after Subject 13 the Dienes B exceeded 3.0. Why did we not stop collecting data then? The reason was that because of a miscommunication from the first author to the research assistant who was doing the B calculations, what was being calculated by the latter was JASP B rather than Dienes B, and after subject 13 the JASP B was 2.188. Since this value was within the range .33–3.00, data collection continued; which was just as well, given what is shown in Fig. 1.

The second point is that this Figure illustrates the instability of B values when sample size is small, which we mentioned earlier. For both methods of calculating B, the B values stopped fluctuating only from Subject 14 onwards.

The key point, though, is the third: that from subject 21 onwards the B values seem to have stabilised at a very low value which nevertheless never reached the critical value of .33. From subject 21 to subject 39, the minimum B value for the Dienes B was .40 and the maximum was .66. For JASP B these values were .35 and .59. Although the critical value of .33 was not reached, we decided at this point that it was not a worthwhile use of our resources to continue running subjects because Fig. 1 suggests that a very large number of additional subjects would be needed to yield a BF outside the range [.33; 3.0].

Table 5 shows the mean subjective ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of .08 (sd = .77). The values of B after 39 subjects were .66 (Dienes) and .59 (JASP). Since both values are within the range [.33; 3.0] our data are inconclusive concerning the question of whether TMS to rDLPFC affects subjectively-measured hypnotic susceptibility.

Table 6 shows the mean objective ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of 4.04 (sd = 11.00). For the Dienes calculator as with Experiment 1 we used a value of 4.25 as the standard deviation of the half-normal (i.e. the expected subjective-rating effect size under H1). The Dienes Calculator yielded a value of 7.13 for B; the

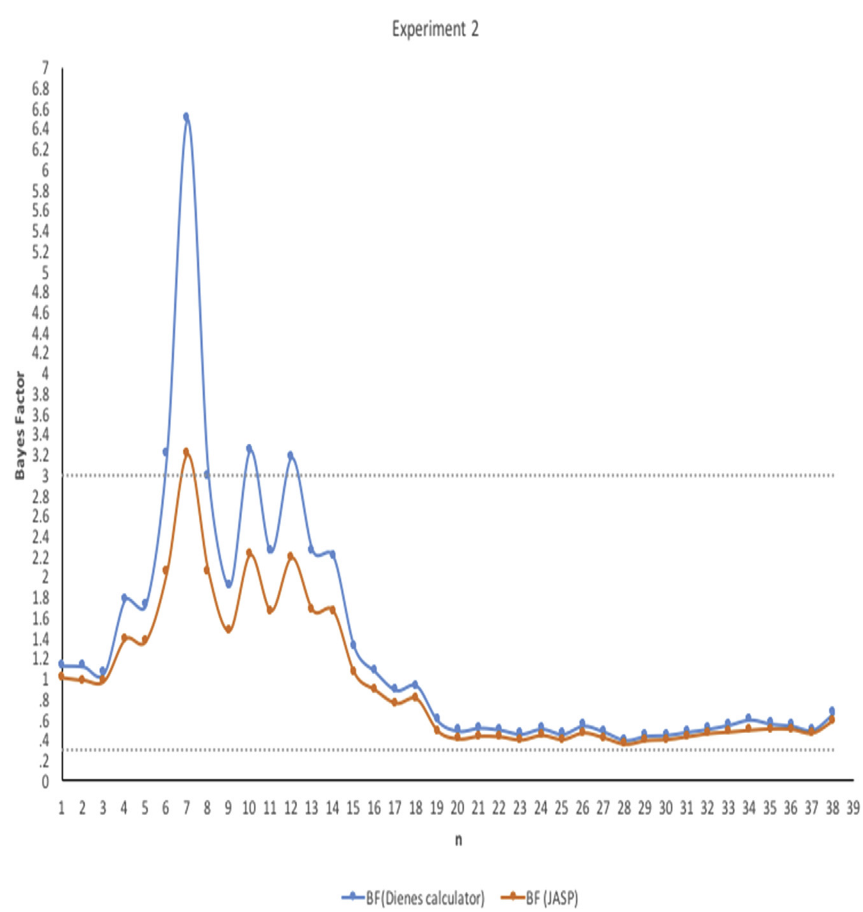

Fig. 1 – Values of Dienes and JASP B for the subjective-rating data after each subject in Experiment 2. Upper horizontal line: BF = 3.0. Lower horizontal line: BF = .33.

Table 5 – Mean subjective ratings on a 0–5 scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. $N = 39$.

	Magnetic hands	Levitation	Rigid arm	Taste	Mean
Right DLPFC	3.27 (1.47)	2.60 (1.79)	3.26 (1.68)	2.05 (1.56)	2.80 (1.28)
Vertex	3.27 (1.39)	2.27 (1.47)	3.21 (1.64)	2.12 (1.57)	2.72 (1.07)
Difference	.00 (1.13)	.33 (1.51)	.05 (.89)	−.07 (1.05)	.08 (.77)
Cohen's dz	0	.22	.06	−.07	.10
SEM	.18	.24	.14	.17	.12
D&H effect	.3	.6	0	.3	.3
B (Dienes)	.52	1.51	–	.38	.66

Table 6 – Mean objective ratings on a percentage scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. $N = 39$.

	Magnetic hands	Levitation	Rigid arm	Taste	Mean
Right DLPFC	63.46 (35.67)	20.38 (25.99)	76.67 (36.10)	16.79 (19.00)	44.33 (20.79)
Vertex	61.15 (32.66)	16.79 (23.10)	69.74 (38.16)	13.46 (19.61)	40.29 (18.13)
Difference	2.31 (20.93)	3.59 (11.92)	6.93 (27.06)	3.33 (12.89)	4.04 (11.00)
Cohen's dz	.11	.30	.26	.26	.37
SEM	3.35	1.91	4.34	2.07	1.76
D&H effect	6	0	7	4	4.25
B (Dienes)	.85	–	2.41	2.35	7.13

JASP value with the same scaling factor as in the Experiment 1 analyses was 4.617. So there is clear evidence that objectively measured response to hypnotic suggestion was enhanced by TMS to rDLPFC.

Table 7 shows the mean expectancy ratings for all four suggestions and averaged over all four suggestions. For the mean ratings there was a mean difference between the two sites of .20 (sd = .73). Since no predictions were made as to the direction of this difference we used two-tailed tests in the Dienes calculator here and also used as with Experiment 1 a value of .10 as the expected subjective-rating effect size under H1 because this was the mean effect on expectancy ratings observed by Dienes and Hutton (2013), averaged over all their suggestions. The Dienes Calculator yielded a value of 1.36 for B; the JASP value with the same scaling factor as in Experiment 1 was 1.89. As with Experiment 1, given that 3.0 > B > .33, we cannot conclude anything with confidence about whether there was any effect of site on expectancy.

Because this Bayesian analysis of whether site of TMS affected the subjects' expectations of how strongly they would respond to an upcoming hypnotic suggestion yielded inconclusive results, we cannot dismiss the possibility that the relationship we observed between TMS site and strength of objective response was mediated by expectation. We explored this in two ways.

Firstly, we calculated the correlations between subjects' expectancy ratings and the strength of their subsequent objective response to hypnosis. As in previous research (for a review of this research see Benham, Woody, Wilson, and Nash (2006)) there were strong positive correlations between these two variables. What's important here, though, is whether the size of this correlation differed as a function of TMS site. If rDLPFC TMS has a specific effect on expectation, this correlation would be higher with DLPFC TMS than with Vertex TMS. However, the difference between these two correlations was negligible (DLPFC +.690; Vertex +.610), suggesting that there was no specific effect of rDLPFC TMS on subjects' expectations.

Secondly, we used Bayesian multilevel analysis (Vuorre & Bolger, 2017) to test the mediational model of expectation as a mediator of the relationship between TMS site and objective response to suggestions. In this analysis, mediation is indicated if the 95% Credible Interval (representing the range of 95% of the most plausible values) for the indirect effect does not include 0. Results based on 4000 Markov Chain Monte Carlo (MCMC) iterations indicated that the mean value of the posterior distribution for the indirect effect of TMS site on objective response was 2.73 ($SD = 1.62$), with 95% of the most plausible values falling in the range of −.33 to 6.13. This result does not support the hypothesis of mediation.

Table 7 – Mean expectancy ratings on a 0–5 scale according to suggestion and site of rTMS stimulation. SDs appear in parentheses. $N = 39$.

	Magnetic hands	Levitation	Rigid arm	Taste	Mean
Right DLPFC	3.10 (1.45)	2.51 (1.25)	2.90 (1.48)	2.10 (1.25)	2.65 (1.09)
Vertex	2.85 (1.25)	2.36 (1.18)	2.68 (1.38)	1.95 (1.34)	2.46 (1.01)
Difference	.25 (1.09)	.15 (1.14)	.22 (1.02)	.15 (1.09)	.20 (.73)
Cohen's dz	.23	.13	.22	.14	.27
SEM	.17	.18	.16	.17	.12
D&H effect	−.1	−.1	.5	.1	.1
B (Dienes)	1.14	.95	.72	.95	1.36

Neither analysis, of course, turned out to provide strong evidence in favour of the null hypothesis that an indirect effect of expectation makes no contribution to the relationship between TMS site and strength of objective response to hypnosis.

We assessed the reliability of the subjective and objective ratings techniques by examining the intercorrelations between the different sets of averaged ratings. These are shown in Table 8. All correlation coefficients are positive and significant (p values all <.001) which could not have been so if any of the rating techniques were seriously unreliable.

Given that our basic hypothesis was that right-sided PFC stimulation will have a larger effect than left-sided PFC stimulation, we next pooled the results of the two experiments so as to do an analysis with the factors Site (Vertex *vs* DLPFC) and Experiment (left *vs* right stimulation). Our hypothesis predicts that an interaction between these two factors would be observed: the (DPLFC-Vertex) ratings difference should be larger for Experiment 2 than for Experiment 1. We tested this with Bayesian analyses.

When the dependent variable in this Experiment analysis was mean subjective rating, the test of the hypothesis that this (DPLFC-Vertex) rating difference would be larger for experiment 2 (rDLPFC) than for Experiment 1 (lDLPFC) (using a half-normal with an SD of .3 derived as before from the Dienes and Hutton data) was inconclusive: the BF was 2.41, with Cohen's $d = .53$.

When the dependent variable in this Experiment analysis was mean objective rating, the hypothesis that this (DPLFC-Vertex) rating difference would be larger for experiment 2 (rDLPFC) than for Experiment 1 (lDLPFC) (using a half-normal with an SD of 4.25 derived as before from the Dienes and Hutton data) was supported: the BF was 10.77, with Cohen's $d = .92$.

Further support for this hypothesis is provided by the results of the separate Bayes Factor analyses of the objective ratings for the two experiments. In Experiment 1, with left-sided stimulation, the Site BF for the mean objective ratings was <.33 for both the Dienes and JASP calculations, which is evidence that left-sided TMS has no effect on hypnotizability; this effect was in any case numerically in the opposite direction to that predicted by the hypothesis. In Experiment 2, with right-sided stimulation, the effect numerically was in the direction predicted by the hypothesis and the Site BF for the mean objective ratings was >3.0 for both the Dienes and JASP calculators, providing evidence that right-sided TMS to rDLPFC increases hypnotizability.

A convenient way of quantifying the effects of DLPFC stimulation is to calculate the percentage increase in hypnotizability ratings in the DLPFC condition relative to the vertex condition. This percentage is reported for each suggestion in Table 9. The overall effect was an increase of 14.95%, with the effects being numerically larger for the Levitation and Taste suggestions than for the other two suggestions.

In sum, our data support the hypothesis for objectively-measured effects of hypnotic suggestions, while not supporting the hypothesis for subjectively-measured effects of such suggestions. That is, we have obtained evidence that TMS to right DLPFC specifically increases hypnotizability when this is measured in terms of magnitude of objective response to the hypnotic suggestion.

4. Discussion

Our Experiment 1 was a replication of the experiment reported by Dienes and Hutton (2013). Our results differed from theirs: they found that TMS to left DLPFC increased subjective (but not objective) ratings of hypnotizability, whereas we found no effect of such stimulation on either type of measure of hypnotizability. We have nothing to suggest about why these two experiments yielded different results; further work is needed here.

As described above, we intended in our Experiment 2 to continue testing subjects until Bayes Factor analysis of the subjective ratings data yielded a BF greater then 3 or less than 1/3 (the values conventionally associated with acceptance of the null or of the alternative hypotheses), but abandoned that intention when after 39 subjects had been run it did not seem to us that this BF result would be achieved with a practicable number of subjects. Our decision was a legitimate one within the Bayesian approach: “The likelihood principle emphasized in Bayesian statistics implies, among other things, that the rules governing when data collection stops are irrelevant to data interpretation. It is entirely appropriate to collect data until a point has been proven or disproven, or until the data collector runs out of time, money, or patience” (Edwards, Lindman, & Savage, 1963, p. 193; for an elaboration of this point see pp. 238–239 of the paper).

This decision had the consequence that we were not able to reach any firm conclusions about the effect of rDLPFC disruption on the subjective response to hypnosis. However, this does not in any way compromise the main conclusion we wish to draw from that experiment, which is that rDLPFC disruption does enhance the objective response to hypnosis. We next discuss the theoretical implications of that finding.

Two important aspects of the response to hypnosis are the experiential and the behavioural: hypnosis makes people feel in certain ways and also behave in certain ways. For example, the suggestion that there is a fly in the room can evoke an auditory experience of a buzzing sound, a tactile experience of something crawling on one's skin, or even a visual experience

Table 8 – Intercorrelations of the four sets of averaged ratings.

	Vertex objective	Vertex subjective	DLPFC objective	DLPFC subjective
Vertex objective		.719	.849	.644
Vertex subjective			.654	.799
DLPFC objective				.781

Table 9 – Percent change in hypnotizability ratings with rDLPFC stimulation relative to vertex stimulation.

	Magnetic hands	Levitation	Rigid arm	Taste	Mean increase
Percent change	+3.78	+21.38	+9.93	+24.74	+14.95

of a small object moving around in the air. Such a suggestion can also evoke a behavioural response: swatting, for example.

Dienes and Hutton (2013) sought to measure both of these types of response. For example, they measured the response to the suggestion "Your arm is so stiff that you can't bend it" by both asking subjects to rate, after the suggestion, how stiff their arm felt, and also by having the experimenter rate the degree to which the subject was actually able to bend the arm when asked to.

We used both types of measure also, and found that experiential ("subjective" in our terminology) and behavioural ("objective" in our terminology) ratings were highly positively correlated, a finding also reported by Kirsch, Milling, and Burgess (1998). These high ratings might be taken as indicating that the two types of measure are measuring the same variable. If that were so, however, the two measures would not be dissociable: any factor affecting one measure should also affect the other. This is not the case; as Kirsch et al. (1998) point out, for example, the Carleton Skills Training program increases an objective measure of hypnotic response while no evidence of an effect on a subjective measure could be obtained (Bates & Brigham, 1990), and, conversely, testing context significantly affects the relationship between absorption and a subjective measure of hypnotic response while no evidence of an effect on the relationship between absorption and an objective measure of hypnotic response (Council, Kirsch, & Hafner, 1986; Spanos, Arango, & de Groot, 1993). Hence Kirsch et al. (1998, p. 275) concluded that "behavioural and experiential scoring systems measure overlapping but distinct constructs... some of the variance in the behavioral and experiential scales appears to be unshared".

Our results suggest yet another way in which these two types of hypnotic measure are dissociable: TMS to rDLPFC increases an objective measure of hypnotizability but has no detectable effect on a subjective measure (though the evidence that there is no effect here was not substantial), suggesting that there might be some component of the response to hypnosis that affects objective responding but not subjective responding (this component would be part of the non-overlap between the two constructs, in the terms of Kirsch et al., 1998). We speculate that this component that is confined to objective responding has to do with what the subject *believes*. That there can be dissociations between belief and experience is a rather speculative idea; but not without support from the literature on psychopathology. Many patients who experience audiovisual hallucinations ("hearing voices") do not believe that the voices are genuine. They correctly believe that these experiences are delusional, so here we have experience without belief. In the condition known as flatness of affect, a person can believe extremely threatening things but remains emotionally unperturbed by them: here we have belief without experience.

Each of the four suggestions used by Dienes and Hutton (2013) and by us invited subjects to believe a proposition that was false:

"Your extended hands are coming together without your will"; "Your left hand is growing heavier and your right hand has an irresistible desire to move upwards"; "You cannot bend your right arm at its elbow"; "There's a sour taste in your mouth that is getting more and more sour". Our proposal is that hypnosis involves suspension of disbelief: "the hypnotized subject develops a transient belief that the state of affairs is as conveyed by the communications of the hypnotist rather than by the information that comes from objective reality... the development of a false belief on the part of the hypnotized subject can be said to be a central feature of hypnosis" (McConkey, 1991, p. 545 and p. 546). The degree to which subjects adopt these false beliefs is what controls the degree to which they will behave in accordance with the hypnotic suggestion, while not affecting subjective experience.[7] If belief evaluation depends upon the rDLPFC (and in the Introduction we referred to various lines of evidence supporting this view), then beliefs which ought to be rejected will be less likely to be rejected if the activity of the rDLPFC is disrupted. We suggest that the failure to reject the false beliefs embodied in hypnotic suggestions that is consequent upon such disruption is what produces behaviours that are consistent with these false beliefs, behaviours that are reflected in objective ratings of the response to hypnosis.

5. Conclusions

In the Introduction to this paper, we reviewed literature which provides support for the following four premises:

(a) In cases of various kinds of monothematic delusion, damage to right frontal cortex, and particular right dorsolateral prefrontal cortex, is commonly observed;
(b) There are reasons to believe that in monothematic delusion the role played by such right frontal damage is that it impairs the operation of a cognitive system – the Belief System – responsible for the generation, evaluation, and adoption or rejection of beliefs;
(c) Various studies of nondelusional populations, including nonclinical populations, also provide evidence that there is a Belief System responsible for the generation, evaluation, and adoption or rejection of beliefs that is neurally realised in right dorsolateral prefrontal cortex;
(d) These various kinds of monothematic delusions can be induced by hypnotic suggestion in high-hypnotisable nonclinical subjects. The acceptance of a hypnotic suggestion can be conceptualised as hypnosis having the effect of temporarily interfering with the operation of the Belief System, which is what facilitates acceptance of a hypnotic suggestion.

If all of these four premises hold, it follows that hypnotizability will be increased by any manipulation that impairs the functioning of right dorsolateral prefrontal cortex. The manipulation we chose was the application of repetitive transcranial magnetic stimulation to right dorsolateral prefrontal cortex. As predicted, we found that the objective magnitude of the response to hypnotic suggestions was

[7] It might be thought that this increase in objective ratings reflects "compliance" – but why is "compliance" specifically increased by rDLPFC stimulation? If this is because "compliance" is mediated by alterations in belief, then that is what we are arguing.

increased by such stimulation. This prediction would not follow if any one of the four premises were false, and so we take our finding as providing further support for all four of these premises.

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Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.cortex.2018.01.001.

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