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Neuro-hypnotism: Prospects for hypnosis and neuroscience

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ABSTRACT

The neurophysiological substrates of hypnosis have been subject to speculation since the phenomenon got its name. Until recently, much of this research has been geared toward understanding hypnosis itself, including the biological bases of individual differences in hypnotizability, state-dependent changes in cortical activity occurring with the induction of hypnosis, and the neural correlates of response to particular hypnotic suggestions (especially the clinically useful hypnotic analgesia). More recently, hypnosis has begun to be employed as a method for manipulating subjects' mental states, both cognitive and affective, to provide information about the neural substrates of experience, thought, and action. This instrumental use of hypnosis is particularly well-suited for identifying the neural correlates of conscious and unconscious perception and memory, and of voluntary and involuntary action.

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1. Introduction

Hypnosis is a social interaction in which one person, designated the subject, responds to suggestions offered by another person, designated the hypnotist, for imaginative experiences involving alterations in conscious perception and memory, and the voluntary control of action. In the classic instance, these experiences are accompanied by subjective conviction bordering on delusion, and feelings of involuntariness bordering on compulsion (Kihlstrom, 2008). Hypnosis provided the foundation for the development of both psychogenic theories of mental illness and insight forms of psychotherapy in the late 19th and early 20th centuries (Crabtree, 1993). More recently, hypnosis contributed to the "consciousness revolution" within psychology and cognitive

science (Hilgard, 1987), and to the revival of research interest in unconscious mental life (Kihlstrom, 1987, 2007). For comprehensive coverage of hypnosis research, see the volume edited by Nash and Barnier (2007).

Hypnosis has its historical roots in the techniques of "animal magnetism" practiced by Franz Anton Mesmer in the 18th century (Gauld, 1992), but the modern era of hypnosis research effectively began with the extensive program pursued by Hull (1933), leading to a "golden age" of hypnosis research facilitated by the development of behavioral scales for the measurement of hypnotizability (Hilgard, 1965). Most research in this area has focused on the behavioral effects of hypnotic suggestions, the cognitive and social processes which underlie these behaviors, and the correlates of individual differences in hypnotizability (for an overview, see

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Nash and Barnier, 2007). However, there has long been interest in the neural underpinnings of hypnosis. James Braid coined the term *hypnotism* to shed the excess baggage associated with animal magnetism and mesmerism, but – in an era where mind-body dualism was much more popular than it is now – initially added the prefix *neuro-* to make clear that hypnosis had a material basis in brain activity (Kihlstrom, 1992b; but see Gravitz and Gerton, 1984). Braid's own theory focused on a paralysis of nervous centers which presumably resulted from ocular fixation, and which induced a sleep-like state (Kravis, 1988). William James endorsed the view that hypnosis was a sleep-like state (Kihlstrom and McConkey, 1990), while Pavlov believed that the effects of hypnosis reflected a state of cortical inhibition (Edmonston, 1981).

In this paper, I provide an overview of the cognitive neuroscience of hypnosis, with emphasis on the most salient ideas. Most of this research focuses on three related questions: (1) the neural correlates of individual differences in hypnotizability; (2) alterations in neural activity accompanying the induction of hypnosis, especially in individuals who are highly hypnotizable to begin with; and (3) the neural correlates of response to individual hypnotic suggestions such as analgesia or motor paralysis. While most of these studies have been geared toward understanding hypnosis, a few investigators have used hypnosis as a tool for investigating the neural correlates of mental activity in general. Due to space considerations, this review is highly selective (for alternative coverage, see Barabasz and Barabasz, 2008; Oakley, 2008; Oakley and Halligan, 2009, 2010).

2. Hypnosis, hypnotizability, and suggestion

The single most important fact about hypnosis is that there are wide individual differences in hypnotizability, or the degree to which people respond to hypnotic procedures (Laurence et al., 2008). Unfortunately, these cannot be predicted with any accuracy from the usual sorts of paper-and-pencil questionnaires. Rather, they can only be measured by work-samples of actual hypnotic performance, collected under standardized conditions, with instruments such as the group-administered Harvard Group Scale of Hypnotic Susceptibility and the individually administered Stanford Hypnotic Susceptibility Scale, Form C (Woody and Barnier, 2008).

Hypnotizability, so measured, yields a roughly normal (bell-shaped) distribution of scores: most people are at least moderately responsive to hypnosis, while relatively few “insusceptible” individuals are entirely unresponsive to hypnosis, and relatively few “virtuosos” respond positively to virtually every suggestion. Very young children appear to be relatively unresponsive to hypnosis. Hypnotizability assessed in college students remains relatively stable over the next 25 years, and then may decline somewhat in middle and old age. Hypnotizability is only one form of suggestibility, and is modestly correlated with “absorption”, a personality construct reflecting a disposition to enter states of narrowed or expanded attention and a blurring of boundaries between oneself and the object of perception. Absorption, in turn, is related to “openness to experience”, one of the “Big Five” dimensions of personality.

Individual differences in hypnotizability impose important constraints on hypnosis research: one can study hypnosis only in those who can experience it. For this reason, investigators cannot simply expose randomly selected subjects to a hypnotic induction. The canonical design for hypnosis research involves administering a standard hypnotic induction, or a control procedure, to subjects classified (on the basis of the standardized scales) as low, medium, or high in hypnotizability (Sheehan & Perry, 1976). Such a design permits assessments of both the correlates of hypnotizability (in the absence of hypnotic induction) and the effects of the induction procedure (independent of hypnotizability). Of particular interest, of course, is the interaction of these factors – i.e., how highly hypnotizable subjects behave following a hypnotic induction, compared to some control condition.

3. Studies of hypnosis and hypnotizability

A design like this is often favored by investigators who wish to search for the neural correlates of hypnosis – perhaps to address the question of whether hypnosis is, indeed, an altered state of consciousness (e.g., Kallio and Revensuo, 2003; Kallio and Revensuo, 2005; Kihlstrom, 2005, 2007; Lynn et al., 2007). However, physiological data are not decisive in this respect – not least because biological markers must be validated against subjective reports of an altered state of consciousness. Following the logic of converging operations, it seems best to infer alterations in consciousness from the convergence of four types of variables: an induction procedure, consequent alterations in subjective experience, associated changes in overt behavior, and physiological changes (Kihlstrom, 1984, 2005, 2007).

3.1. The EEG spectrum

Historically, the most popular approach to understanding the neural substrates of hypnosis has been to examine EEG correlates of hypnotizability and changes in the EEG spectrum which occur when hypnosis is induced (e.g., Lee et al., 2007; for a comprehensive listing of studies, see Hinterberger et al., 2011; Vaitl et al., 2005). Many of these studies were “fishing expeditions”, conducted in the hopes that they would yield interesting results, rather than tests of specific hypothesis about the nature or locus of electrocortical changes associated with hypnosis. Still, they were not always without some theoretical rationale, however weak. For example, in the late 1960s it was suggested that hypnotizability and hypnosis were associated with increased density of alpha activity in the EEG – a hypothesis which drew strength from early reports of increased alpha density in Zen and yoga meditation, as well as the meditation-like experiences once thought to be produced by EEG alpha biofeedback. Similar considerations, as well as speculations concerning the relevance of 40-Hz activity to focused arousal, perceptual binding, and consciousness itself, prompted investigation of the gamma band of the EEG (DePascalis, 1999, 2007). Finally, in a manner reminiscent of the 19th-century analogy between hypnosis and sleep, the association between theta activity and hypnagogic imagery

led some investigators to focus on this portion of the EEG spectrum (Sabourin et al., 1990; Williams and Gruzelier, 2001).

The most thorough of these studies was reported by Ray et al., who took advantage of advanced EEG technology to examine alpha, beta, and theta activity recorded separately from frontal, temporal, parietal, and occipital sites of both left and right hemispheres in hypnotizable and insusceptible male and female college students before and after a hypnotic induction (Graffin et al., 1995; Ray, 1997). As might be imagined, given the $3 \times 4 \times 2 \times 2 \times 2 \times 2$ design, the results of this experiment were quite complex. Analysis of baseline differences, before hypnotic induction, revealed higher theta power in hypnotizable compared to insusceptible subjects, especially in frontal and temporal areas. Hypnotizable subjects showed greater resting alpha activity only in the temporal area. The induction of hypnosis decreased theta activity in hypnotizable subjects, while increasing it among insusceptibles, particularly in parietal and occipital areas. Alpha activity generally increased across all sites in all subjects, consistent with enhanced relaxation and reduction of visual activity. Graffin et al. interpreted the changes in theta as indicative of heightened concentration among hypnotizable subjects, but the fact that theta activity decreased in hypnotizable subjects and increased in insusceptible subjects suggests that, following the induction of hypnosis, both groups of subjects were actually in very similar cortical states.

3.2. The right hemisphere

In the late 1960s and 1970s, the recent discovery of hemispheric specialization led to the proposal that hypnosis is mediated by the right hemisphere (Bakan, 1969; Graham, 1977; Gur and Gur, 1974). Admittedly, this laterality hypothesis of hypnosis was based on a somewhat Romantic notion that the cerebral hemispheres (not to mention the people who possessed them!) could be divided into the creative, intuitive, holistic right and the logical, sequential, analytical left – a simplistic view which was later downplayed even by one its most ardent earlier proponents (Ornstein, 1997). Nevertheless, it provided a powerful stimulus for the study of the neural substrates of hypnosis.

By far the most popular approach to the laterality hypothesis employed self-report or behavioral measures that were presumed to correlate with lateralized cerebral function. For example, Bakan (1969) himself reported that hypnotizable subjects showed more reflective eye movements to the left than insusceptible subjects, presumably indicating greater right-hemisphere activation. On the other hand, these observations also proved difficult to confirm and extend (for a review, see Kihlstrom et al., in press, this issue).

Arguably the best approach to this question is direct, through studies employing psychophysiological, neuropsychological, and neuroimaging methods. Somewhat surprisingly, until recently no investigation compared the hypnotizability of neurological patients with lateralized brain damage. The first, and so far the only study of this kind found no differences in hypnotizability between groups of stroke patients with damage confined to the left or right hemispheres (Kihlstrom et al., in press, this issue).

Psychophysiological studies have produced conflicting results. Two early studies employing EEG alpha blocking as an index of hemispheric activity, found no evidence that hypnotizable subjects favored the right hemisphere, or that the induction of hypnosis induced a shift in preference from left to right (Morgan et al., 1971, 1974). However, some later investigators reported that subjects' EEG patterns showed a shift from left- to right-hemisphere activation when hypnotized (Edmonston and Moskovitz, 1990; MacLeod-Morgan and Lack, 1982), while Gruzelier et al. found lateral asymmetries in electrodermal responding (EDR) suggesting an inhibition of left-hemisphere activity (Gruzelier et al., 1984). Crawford et al., measuring regional cerebral blood flow (rCBF) with the 133-xenon inhalation method, found that hypnotizable (but not insusceptible) subjects showed a dramatic increase in blood flow in the right hemisphere following hypnotic induction, before subjects received a suggestion for analgesia (Crawford et al., 1983). However, the extensive study by Graffin et al. found no EEG evidence of lateralization differences related to hypnotizability, or shifts in lateralization related to the induction of hypnosis (Graffin et al., 1995; Ray, 1997).

Perhaps the most provocative EEG finding was by MacLeod-Morgan and Lack (1982), who found that hypnotizable subjects showed greater task-specific hemispheric activation than did their insusceptible counterparts. That is, hypnotizable subjects appeared more likely to activate the left hemisphere when performing a task designed to selectively activate the left hemisphere, and the right hemisphere when performing a right-hemisphere task. Although subsequent attempts to replicate have yielded somewhat mixed results, MacLeod-Morgan and Lack's findings led to the revised hypothesis that hypnotizable subjects possessed a flexible cognitive style which permitted them to shift easily between analytic (left hemisphere) and holistic (right hemisphere) modes of processing, as demanded by the task at hand: this flexibility is further enhanced by the induction of hypnosis (Crawford, 1989; Crawford and Gruzelier, 1992). In the final version of the flexibility hypothesis, Crawford (2001) and Gruzelier (1998) largely abandoned explicit reference to analytic and holistic tasks, and left and right hemispheres. Instead, they proposed that hypnosis selectively activates a variety of cortical and subcortical processes, depending on the task required of the subject. Thus, hypnotizable subjects are adept at tasks involving either analytic or holistic processing, and at tasks involving either sustained attention or disattention, especially when they are hypnotized. Put another way, the hypnotizable brain, even when hypnotized, is just like any other brain – only better.

In retrospect, the right-hemisphere hypothesis of hypnosis and hypnotizability was bound to fail. Hypnosis does have certain qualities stereotypically attributed to the right hemisphere, such as a nonanalytic mode of cognition which permits subjects to achieve the peaceful coexistence between illusion and reality required for a subject to answer questions emanating from a loudspeaker which is not there (Orne, 1959). On the other hand, there is plenty of evidence for left-hemisphere involvement in hypnosis (Jasiukaitis et al., 1996; Maquet et al., 1999) – as well there should be. After all, hypnosis is induced by means of verbal suggestion, and

therefore requires the language-processing capacities normally associated with the left hemisphere. Moreover, the hypnotist's suggestions must be interpreted before the subject can respond to them. This interpretive activity, and the generation of the corresponding response, will involve the integrated activity of every portion of the brain – just as is the case for other complex mental processes.

3.3. The frontal lobes

Of course, hypnotic suggestions experiences do have special phenomenal qualities, which may in turn entail special activity in certain brain areas. Of particular interest in this regard is the classic suggestion effect, in which the imaginative events suggested by the hypnotist seem to happen by themselves, instead of being actively generated by the subject. The experience of involuntariness, while ubiquitous in hypnosis, is subject to different interpretations (Hilgard, 1977; Kihlstrom, 1992a, 2007). From a social-psychological point of view, it may reflect the influence of the hypnotic context on the causal attributions that subjects make about their own behavior. From a cognitive point of view, it may reflect a division of consciousness which effectively prevents hypnotized subjects from being aware of their own role as active agents generating their responses to the hypnotist's suggestions.

Neither of these proposals have any particular neuropsychological implications. However, Woody et al. have suggested that experienced involuntariness reflects the freeing of subordinate cognitive modules from executive control associated with prefrontal cortex (Farvolden and Woody, 2004; Woody and Bowers, 1994; Woody and McConkey, 2003; Woody and Szechtman, 2003). This hypothesis, in turn, suggests that hypnosis involves an inhibition of frontal-lobe functioning, particularly affecting the prefrontal cortex. Gruzelier reported some evidence supporting this hypothesis from a study of event-related potentials (ERPs) using the “oddball” paradigm (Gruzelier, 1998), and a more recent study from this group found that hypnosis reduced conflict-related activity in the anterior cingulate cortex (ACC) during performance of a Stroop task (Egner et al., 2005). This pattern of results is consistent with increasing inhibition of frontal activity as hypnotizable subjects actually become hypnotized.

Early on, in fact, Crawford and Gruzelier had suggested that, compared to changes in laterality, “what may be more central to hypnosis is the inhibition of anterior frontal-lobe function” (Crawford and Gruzelier, 1992, p. 265; see also Crawford, 2001; Egner et al., 2005; Gruzelier, 1998, 2000; Vaitl et al., 2005). However, it should be noted that these three sets of investigators make rather different hypotheses about the involvement of the frontal lobes in hypnosis. Woody et al. go so far as to suggest that, in many ways, hypnotized subjects are similar to patients with lesions in the prefrontal cortex, while Gruzelier has cited support for associations between hypnosis and the activation of anterior fronto-limbic inhibitory processes – particularly in the left hemisphere. Crawford, in line with her emphasis on cognitive flexibility, suggested that highly hypnotizable subjects have more effective and flexible frontal systems for both attention and inhibition. Accordingly, we have three good reasons for thinking that investigations of the role of the frontal lobes in

hypnosis will be more productive than studies of the right hemisphere.

A further argument for the frontal lobes is supplied by recent studies of the “default mode network” (DMN) in the brain, involving cortical midline structures such as the medial prefrontal cortex, superior frontal cortex, and the anterior and posterior cingulate cortex (McGeown et al., 2009; Deeley et al., 2012). The DMN is so named because it is active when subjects are not engaged in a particular task-oriented activity. The DMN is deactivated when subjects engage in daydreaming and other task-unrelated mental activity, and these studies find that it is also deactivated during neutral hypnosis – a term referring to a subject's state following completion of a hypnotic induction procedure, before receiving any further suggestions (Cardena, 2005; Edmonston, 1981). In some respects, this is not surprising, because even “neutral” hypnosis is not all that neutral: after all, the subjects are still engaged in the activity of being hypnotized. Still, there now appear to be several different DMNs in the brain, and it remains to be seen whether the precise pattern of DMN deactivation in hypnosis differs from that observed in daydreaming and other such states.

4. Studies of hypnotic suggestions

Although the concept of “neutral” hypnosis, is attractive (Kihlstrom and Edmonston, 1971), it should be understood that any alteration in consciousness that occurs in hypnosis is instigated by specific suggestions made by the hypnotist, as interpreted by the subject in the context of the experiment. These suggestions – to feel one's arm too heavy to keep extended, or too stiff to bend; not to feel touch or pain; to hear a voice asking questions; to be unable to see or identify an object; to have the urge to touch one's ankle in response to a cue; not to remember what has been happening – constitute the domain of hypnosis (Hilgard, 1973; Kihlstrom, 2008). Whatever neural signature hypnosis may emerge only when hypnotizable subjects are actually hypnotized, and responding to these sorts of suggestions.

4.1. Hypnotic analgesia

One implication of the complexity of hypnosis is that whatever neural changes occur, will depend on what the subject is doing at the time the observations are made. While comparisons between before and after the induction of hypnosis, or among various stages in the induction procedure, are potentially interesting, the fact remains that the real action in hypnosis occurs when the subject responds positively to specific suggestions for motor responses, hallucinations, age regression, amnesia, and the like. So what is the brain doing at these times?

Before brain-imaging methods such as fMRI became widely available (and relatively inexpensive), most research in this area relied on EEG ERPs – and, in particular, on the late components that relate to cognitive and emotional processing of inputs (e.g., Ray and DePascalis, 2003). In some of these studies, ERPs were used as an unobtrusive measure of response to hypnotic suggestion (e.g., Allen et al., 1995). In other cases, however, the

location of changes in particular ERP components served as a pathway to understanding the neural underpinnings of particular hypnotic suggestions.

For example, Crawford *et al.* included ERPs in their psychophysiological studies of hypnotic analgesia, one of the most dramatic (and clinically useful) phenomena of hypnosis (Crawford *et al.*, 1998). One experiment, involving punctate electrical stimulation, showed enhanced N140 and N250 components during analgesia, especially over frontal regions, compared to a control condition in which subjects were instructed to attend to the pain stimulus (Crawford *et al.*, 1998; see also Kropotov *et al.*, 1997). Crawford *et al.* concluded that hypnotic analgesia involves active inhibitory processes involving the allocation of attention and disattention, associated with frontal areas of the brain.

Congruent findings, especially the suppression of late “cognitive” components of the ERP, were obtained in a series of studies by DePascalis and his associates (e.g., DePascalis *et al.*, 2004). Ray and DePascalis (2003) suggested that hypnotic analgesia inhibits the processes by which cognitive and emotional evaluation is linked to sensory processes. However, the precise localization of this inhibition may differ, depending on how the analgesia is achieved: through focused or divided attention, mental imagery, relaxation, or absorption.

4.2. Framing the suggestion

The importance of the wording of suggestions is underscored by a controversy over ERP correlates of hypnotic effects on perception. One study obtained increased P3 components in response to olfactory stimulation during suggested anosmia (Barabasz and Lonsdale, 1983), while another reported that P3 decreased in response to a suggestion that an imaginary cardboard box was blocking the subject’s view of a visual stimulus (Spiegel *et al.*, 1985). In both cases, the subjects failed to perceive the target stimuli; but the two studies revealed opposite effects on the ERP. However, as Spiegel and Barabasz (1988) subsequently noted, the suggestions employed in these two studies were actually quite different. The suggestion in the Barabasz study was for an olfactory anesthesia – a reduction in sensitivity affecting an entire sensory modality. By contrast, the suggestion in the Spiegel study was for a positive visual hallucination of a cardboard box, which ostensibly occluded the subject’s view of the target visual stimulus. The implications of the Spiegel and Barabasz analysis were put to a direct test by Barabasz *et al.* (1999), who showed that suggestions to see “nothing at all” enhanced P300 response to a visual stimulus among highly hypnotizable subjects, while suggestions to “imagine a cardboard box blocking the computer screen” diminished this component. Insusceptible subjects showed no ERP changes in either experimental condition. The same pattern of results was observed in conditions involving suggested deafness and obstructive auditory hallucinations.

A word on terminology may be in order here. Barabasz *et al.* referred to their blindness and deafness conditions as involving negative visual and auditory hallucinations. However, negative hallucinations typically involve the inability to perceive a specific object, class, or region of space – e.g., one of three boxes placed in view of the subject.

Because the “negative” suggestions in Barabasz *et al.* (1999) study entailed a complete or partial loss of visual and auditory acuity, they are probably better considered variants on sensory anesthesia. Moreover, their comparable suggestions of obstructive visual or auditory hallucinations really involve positive hallucinations – i.e., suggestions to see or hear something that is not actually present in the stimulus environment, interposed between the observer and the some other object that actually is present.

All of which simply illustrates how diverse hypnotic suggestions can be, for: (1) reduced sensory acuity in some modality, whether visual, auditory, or tactile; (2) positive hallucinations (e.g., seeing something that is not there); and (3) negative hallucinations (e.g., failing to see something that is there) affecting the perception of some object or region of space. The fourth logical possibility, for enhanced sensory acuity (hyperesthesia), seems not to occur. Although there have been occasional reports of enhanced visual acuity in hypnosis (e.g., Graham and Leibowitz, 1972), the story of the hypnotic enhancement of human performance provides a cautionary tale: it is one thing to believe that one’s strength, or visual acuity, or learning ability and memory have been enhanced, and another for one’s performance to actually improve over baseline (Dinges *et al.*, 1992; Evans and Orne, 1965).

4.3. Localization of effects

The scalp topography of ERPs can provide coarse-grained information about the source location of specific neural responses to particular events (such as the presentation of a surprising or incongruous stimulus). Better spatial resolution is permitted by advanced brain-imaging techniques such as PET and fMRI – if perhaps at the expense of temporal resolution. The first such study, by Crawford *et al.* employing the 133-xenon, found that hypnotizable subjects experiencing hypnotic analgesia showed increased bilateral activation in anterior frontal and somatosensory areas of cerebral cortex (Crawford *et al.*, 1993). While the frontal activity is consistent with increased inhibitory processing, the parietal activity may reflect the fact that the subjects were attending to those body parts receiving the pain stimulus, even if they were experiencing decreased levels of pain.

Another early study employed PET to study positive auditory hallucinations, in which the subject hears sounds in the absence of corresponding auditory stimulation (Szechtman *et al.*, 1998). Positive hallucinations are of particular interest because they are mental images which, despite being self-generated, are experienced as external stimuli. Subjects were tested in four experimental conditions: baseline, hearing, imagining, and hallucinating; a comparison group, who were incapable of experiencing suggested hallucinations despite high hypnotizability, was also tested. Both hearing and hallucinating activated widespread regions in temporal cortex, as might be expected, although hearing was associated with much more extensive activation than hallucination. Activation in the right ACC (Brodmann’s area 32) was greater in hearing and hallucinating than in imagining or baseline. Interestingly, as these investigators noted, roughly the same area has been identified in schizophrenic patients who experience auditory hallucinations.

Similarly, Kosslyn, Spiegel, *et al.* employed hypnotic suggestions in a study of the neural correlates of color perception (Kosslyn *et al.*, 2000). Perception of a colored stimulus as colored activated a “color area” in the fusiform gyrus, compared to perception of a greyscale stimulus as gray. Moreover, suggestions to drain color from a colored stimulus reduced fusiform activity, particularly in the left hemisphere, while suggestions to add color increased activity in that same region. Interestingly, nonhypnotic color imagery activated the right, but not the left, fusiform region, supporting the notion that hypnosis is not just a special case of mental imagery.

Investigators who wish to use advanced brain-imaging methods to identify the neural correlates of hypnosis and suggestion face a dilemma. On grounds of temporal and spatial resolution, fMRI is preferable to PET for brain-imaging investigations of hypnosis. But the fMRI environment is exceptionally noisy, and – at least at first glance – not particularly conducive to hypnosis. Fortunately, a recent study indicates that concerns about the noise levels and physical restrictions associated with fMRI have probably been overstated (Oakley *et al.*, 2007). And it has even been suggested that hypnosis can make the MRI process more tolerant for medical patients (Simon, 1999).

As the expense associated with brain-imaging diminishes, we may expect to see a surge of studies employing fMRI to identify the neural correlates of hypnotic suggestions. However, researchers should not abandon “older” techniques, such as EEG and MEG, which offer fine-grained temporal resolution that may be particularly useful for studying the temporal dynamics of hypnosis, as individual suggestions are made, acted upon, and canceled. Of particular interest in this respect is the frequent observation that hypnotic responses may be initiated as voluntary actions, but end up experienced as involuntary behaviors (and vice-versa). MEG may be particularly useful in identifying the neural mechanisms of these changes in experienced voluntariness.

5. Hypnosis as an experimental medium

Whether it employs psychophysiological, neuropsychological, or brain-imaging methods, most neuroscientific research has been geared toward understanding the nature of hypnosis. Reyher (1962) distinguished between such “intrinsic” research and “instrumental” research, in which hypnosis is used to investigate the neural substrates of other phenomena (see also Cox and Bryant, 2008; Oakley and Halligan, 2009). Instrumental research has a long history in hypnosis: Charcot, Janet, and Freud considered hypnosis to be a laboratory model for the study of hysteria and dissociative psychopathology (Kihlstrom, 1979; Bell *et al.*, 2011). Luria (1932) and others have employed hypnotically suggested paramnesias in the study of delusions and psychodynamic conflict (Blum, 1979; Kihlstrom and Hoyt, 1988; Cox and Barnier, 2010; Reyher, 1967). The search for correlates of hypnotizability led to the identification of “openness to experience” as a major dimension of personality (Glisky and Kihlstrom, 1993; Tellegen and Atkinson, 1974). In the wake of the cognitive revolution in psychology, hypnosis helped stimulate an interest in both consciousness and unconscious mental life (Hilgard, 1977; Kihlstrom, 1987).

The discovery of priming effects in posthypnotic amnesia bolstered the case for the episodic-semantic and implicit-explicit distinctions in memory (Kihlstrom, 2007). Hypnosis was also employed to manipulate emotional state in early studies that fomented the “affective counterrevolution” in psychology (Bower, 1981). Hypnosis has also offered critical insights into the relations between the cognitive and affective components of attitudes (Rosenberg, 1960), as well as the differential role of cognition and emotion in moral judgment (Wheatley and Haidt, 2005).

It seems likely that hypnosis can play a similar role in neuroscience (Oakley and Halligan, 2009). In this respect, Kosslyn and Spiegel’s PET study of color vision was something of a hybrid (Kosslyn *et al.*, 2000). Its conclusions were framed in terms of the “state-nonstate” debate concerning hypnosis: hypnotically induced changes in color vision were correlated with activity in the “color” center of visual cortex; therefore the changes reported by the subjects were genuine. But the paper could just as easily serve as a demonstration of the neural correlates of color vision, revealing which parts of visual cortex change activation levels when the subject’s experience of color changes.

The same description applies to another study, which employed PET to dissociate the cognitive and affective components of the pain experience (Rainville *et al.*, 1997). On the one hand, it demonstrated, to those who might doubt, it that hypnotized subjects really do experience analgesia. On the other hand, the same study can be considered as a contribution to our understanding of the neural correlates of pain. It was already known, from behavioral studies, that the experience of pain has two components, sensory pain and suffering; and that hypnosis can dissociate these components. Rainville, *et al.* then employed hypnotic suggestion to show that somatosensory sites process the sensory aspects of pain, while frontal regions, including the ACC, process the emotional aspects.

Similarly, hypnosis has played a role in uncovering the function of the ACC. It has long been known that suggestions for hypnotic color-blindness do not affect Stroop color naming, but recent studies indicate that suggestions for hypnotic agnosia – i.e., for color names to be meaningless gibberish – can reduce or even eliminate Stroop interference (e.g., Raz *et al.*, 2002; see also Kihlstrom, 2011). A subsequent fMRI study (Raz *et al.*, 2005) showed that this reduction in cognitive conflict was correlated with decreased activation in the ACC, which strengthens the conclusion that this brain module is important for conflict monitoring.

Finally, the phenotypic similarities between the phenomena of hypnosis and the symptoms of “hysteria” suggest that brain-imaging studies hypnosis can help elucidate the neural substrates of the conversion and dissociative disorders traditionally grouped under the rubric of “hysteria” (Bell *et al.*, 2011; Kihlstrom, 1979). For example, Halligan *et al.* (2000) found that attempted movement during hypnotically suggested paralysis of the left leg led to increased activation in the same regions (right ACC and orbitofrontal cortex) activated in “hysterical” paralysis. Similarly, Mendelsohn *et al.* (2008) found decreased activation in the occipital and temporal cortex during posthypnotic amnesia, consistent with a failure of visual memory, as well as increased activation in the prefrontal cortex – changes paralleling those that occur during

attempted retrieval in psychogenic amnesia. Such findings strengthen the hypnosis–hysteria analogy, and underscore once again the involvement of the frontal cortex. Given that both hypnosis and hysteria involve alterations in the monitoring and controlling functions of consciousness (Kihlstrom, 1987), it seems likely that brain structures critical for executive functions will be involved, regardless of the specific content of the suggestion or symptom.

The proposal to use hypnosis instrumentally in neuroscientific research raises the specter of studying one unknown with another. This is particularly the case with hypnosis researchers, who since the time of Braid has labored under the suspicion that subjects were faking. Indeed, as noted earlier, much of the neuroscientific literature on hypnosis has been motivated by the desire to demonstrate that hypnotic subjects are not faking – that hypnosis is *real*. At the same time, it should be pointed out that nobody ever questioned whether neuropsychological patients, such as the amnesic H.M., were faking. There is something of a paradox here, in that it sometimes seems as if the only self-reports that psychologists are prepared to believe come from persons who are brain-damaged! Still, at this point, hypnosis is hardly unknown. Almost a century has passed since the pioneering experimental studies of Young and Hull, and we now know a great deal about hypnosis – who can experience it and who cannot, what it can do and what it cannot; and what its mechanisms are at the psychological level of analysis. These days, even those who doubt that hypnosis represents a "special state of consciousness" do not doubt that the experiences reported by highly hypnotizable subjects are genuine (e.g., Lynn et al., 2007).

6. Prospects

More than 150 years after Braid coined the term *hypnosis* and articulated the first neurophysiological theory of the phenomenon, the study of the neural correlates of hypnosis, and the instrumental use of hypnosis to study the neural correlates of other aspects of mind and behavior, are both still in their infancy. But then again, the same could be said about many other complex psychological phenomena, including perception and memory. Still, three important trends are already visible. First, investigators are beginning to adopt modern sophisticated brain-imaging techniques, especially fMRI, which can provide more fine-grained analyses of both the location and timecourse of brain activity involved in hypnotic experience. Second, and more important, theory in this area has evolved from a rather simplistic and Romantic focus on alpha activity, or the right hemisphere, to positions that recognize the complexity of the experience of hypnosis. Hypnosis research and theory has tracked developments in cognitive neuroscience more broadly, and is now poised to embrace the most sophisticated techniques to map the complex neural underpinnings of the multifaceted experience of hypnosis. Third, hypnosis is increasingly being employed by researchers whose primary interests lie outside the domain of hypnosis. For more than a century, psychologists have viewed hypnosis as intrinsically interesting, a challenge for psychological theory to explain; now hypnosis is also viewed

as interesting for what it can tell us about other things – like consciousness. Q3

Future developments in this area, however, will require more than machine time, computational power, and a tame hypnotist. They will require increasingly sophisticated experimental designs, geared to answer the kinds of questions that are particularly addressable by hypnosis – questions that pertain to the monitoring and controlling functions of consciousness. Two features that are prominent in hypnosis are divisions of awareness and the experience of involuntariness. In hypnotic analgesia or posthypnotic amnesia, the subject is unaware of current or past events that would normally be accessible to conscious awareness; in the sensory anesthetics, the subject is unaware of stimuli in some sensory modality; negative hallucinations, the subject is unaware of a specific stimulus present in his or her sensory field. In the ideomotor responses and positive hallucinations, subjects experience the suggested state of affairs, but do not perceive themselves as actively generating the corresponding mental imagery.

More than a decade ago, Frith, Perry and Lumer argued that studies of the neural correlates of conscious experience should contrast conditions where the same physical stimulus elicits the same behavioral response, *with* and *without* accompanying conscious awareness (Frith et al., 1999). A similar strategy might well be revealing with respect to hypnotic alterations in the monitoring and controlling functions of consciousness. For example, it is known that post-hypnotic amnesia impairs explicit memory, but spares priming and other expressions of implicit memory (Kihlstrom, 2007). Accordingly, a brain-imaging strategy which compares both explicit and implicit memory for studied items during amnesia and after the amnesia suggestion has been canceled might well reveal neural activity specifically associated with both conscious remembering and unconscious expressions of memory. The neuroimaging tools are now available, and a century of behavioral research on hypnosis has laid the empirical and conceptual foundations for their proper use. All that remains is to begin the work in earnest.

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