Functional Neuroimaging Studies of Hypnosis and Meditation: A Comparative Perspective

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Over the last few decades, an increasing number of functional neuroimaging studies have been performed with respect to hypnosis and meditation. The objective of this article is to review a number of these studies to compare the neural substrates related to different components of hypnosis and meditation. We examine neuroimaging studies conducted to explore the impact of hypnosis on the brain regions and systems involved in color perception, hand paralysis, pain, and the default-mode network (DMN). We also review neuroimaging investigations carried out to examine the neural correlates of various meditation techniques, as well as the effects of meditation on the brain mechanisms related to emotion, pain, and the DMN. Given the discrepancy existing between the findings from neuroimaging studies of hypnosis and meditation carried out in regard to pain and the DMN, we conclude that it is premature to claim that hypnosis and meditation are mediated by similar brain systems and neural mechanisms.

1. Introduction

Over the last few decades, *an increasing* number of functional neuroimaging studies have been performed in regard to hypnosis and meditation. The objective of this article is to review the main areas of the literature on both subjects in order to compare the neural substrates related to different components of hypnosis and meditation. In the introductory section, we provide working definitions of these two constructs and outline the framework under which they will be examined. In the next section, we present a series of functional brain imaging studies that have been conducted to investigate the impact of hypnosis on the brain regions and systems involved in colour perception, hand paralysis, pain, and the default-mode network (DMN). In the third section, we review neuroimaging investigations carried out to examine the neural correlates of various meditation techniques, as well as the effects of meditation on the brain mechanisms related to emotion, pain, and the DMN. In the fourth and final section, we compare findings from neuroimaging studies of hypnosis and meditation reviewed in this article (particularly related to pain and the DMN), and offer a few concluding remarks.

1.1 Hypnosis

While the word 'Hypnosis' is a term derived from the Greek word 'hypnos' which means sleep, it has been shown that these two states have little in common when it comes to brain activity (Halsband, Mueller, Hinterberger, & Strickner, 2009). Hypnosis is seen as either an altered state of consciousness or a cooperative interaction in which one person, the subject, becomes highly focused and receptive to verbal suggestions given by another person, the hypnotist. The subject is guided by the hypnotist to respond to suggestions for specific changes in subjective experience, sensation, perception, thought, emotion, or behavior. But hypnosis does not necessarily have to involve another person. Hypnotic suggestions can also be self-administered: a hypnotic state that is self-created is called *autohypnosis* (or self-hypnosis) (Rainville & Price, 2003). However there are, to our knowledge, no fMRI studies investigating self-hypnosis to date. Hence this review will focus on means of hypnotic induction that include a hypnotist or a recording.

In order to get a clear picture of the workings of hypnosis in the brain, two components must be differentiated. The first aspect is the basic putative change of state following a hypnotic induction procedure without further targeted suggestions (i.e., neutral hypnosis). The second aspect regards the influence of specific suggestions provided during a hypnosis session. Two main types of hypnotic induction are recognized in the literature—relaxation and active/alert inductions—though most neuroscientific studies have concentrated on the former. The changes in subjective experience that follow relaxation-based hypnotic inductions typically include mental relaxation (i.e, becoming at

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ease, letting go of tensions) and mental absorption (i.e., a shift from an effortful and ever changing focus of attention to the full concentration on a particular object, whether it be internal or external). Such alterations lead to a decrease in the sense of time (Kroger & Yapco, 2007). Hypnosis can also be characterized by a reduced sense of self-monitoring and self-agency. This reduction is manifested by feelings of automaticity associated with thoughts or actions (Rainville & Price, 2003; Grant & Rainville, 2005; Price, 1996).

1.2 MEDITATION

The term 'meditation' comes from the Latin 'meditatio' which originally meant "to think, contemplate ". Meditation usually refers to a very wide range of mental techniques associated with Hindu, Buddhist, Jewish, Christian, and Islamic traditions (Halsband et al., 2009). A popular distinction between two components present in meditation has been made by Lutz et al. (2008). These components are open monitoring (OM) and focused attention (FA). OM techniques involve allowing any sensations, thoughts, or feelings to arise and pass away from moment-to-moment, while maintaining awareness as an attentive and non-attached observer without judgment or analysis. These techniques cultivate meta-awareness and observation of experience. FA techniques involve focusing attention on specific objects (e.g., mantra, religious pictures, scriptural passage), body sensations (e.g., breath), or other types of mental events (e.g., imagined images). A third subdivision in types of meditation, automatic transcendental meditation, has also been suggested by Travis & Shear (2010). The purpose of these techniques involves going beyond the usual realm of sensations and experiences to "transcend their own activity".

These broad classifications intend to foster a sense of coherence and help draw more general conclusions about the effects and workings of meditation. This would be achieved by separating clearly different entities present in the realm of meditation. The authors of both the original classification (Lutz et al. 2008) and its revision (Travis & Shear, 2010) mentioned the fact that the different categories are neither exclusive from each other nor constant during a meditation session, between types of session, or even across practitioners. Such intricacies have yet to be explored by research and should be brought forward in future efforts to better characterize the phenomenology of meditation.

1.3 COMPARISON

Some nuances must be mentioned in order to understand the subtleties that differentiate hypnosis and meditation and to avoid a black and white portrait of similarities and discrepancies. These nuances must be kept in mind throughout the present review in order to maintain a critical eye on the reviewed literature, as the studies themselves do not always take these factors into consideration.

Both hypnosis and meditation experiencers feel qualitative changes in mental functioning such that their consciousness is distinct from the way it usually operates (Tart, 1972). Other elements common to both neutral hypnosis and meditation include relaxation, attentional focus, concentration, and absorption (Holroyd, 2003; Otani, 2003). In addition, both hypnosis and meditation are associated with alterations in self-awareness, time sense, and perception (Ott, 2007). An interesting parallel to draw between both states is the importance of the capacity to immerse one's phenomenological experience in a particular object. Regarding hypnosis, absorption capacity has been strongly correlated to hypnotisability numerous times and is thought by some researchers to be a core component of hypnosis (Cardena, 1991; Nadon et al. 1991; Green & Lynn 2010). Absorption also seems to be linked to meditation (Davidson et al. 1976).

Both hypnosis and meditation can be either self- or externally- induced. In the case of hypnosis, the traditional way is to be brought into hypnosis by a hypnotist but it is possible for someone to learn to hypnotize themselves or to follow a recording instead of an actual human being. As for meditation, while typically this activity is self-initiated and self-monitored, it also often involves a teacher that will guide the practitioner's mental activity before or during meditation. Halsband et al. (2009) argued that social interactions were a differentiating point between both states but the preceding facts (self-hypnosis, guided meditation, etc.) cast doubt on this clear cut distinction.

Traditionally, hypnosis has been seen in the terms of enhanced response to suggestions, yet it is also possible to undergo "neutral hypnosis" without specific suggestions. Both components—neutral hypnosis and targeted suggestions—often fail to be distinguished within the studies discussed further, but it will be mentioned throughout the review if the original authors addressed such nuances. The specific role of suggestion in meditation is far from being as clearly determined in the scientific literature (for in-depth discussions on

this topic, see Lynn et al., this issue; Farb et al., this issue). Indeed it might be argued that meditators use a form of self-suggestion to attain and/or maintain a meditative state, or that the words of a meditation teacher constitute suggestions (let alone the question of how similar these suggestions might be to those used in hypnosis).

2. FUNCTIONAL NEUROIMAGING STUDIES OF HYPNOSIS

2.1. VISUAL PERCEPTION AND CONVERSION PARALYSIS

In a seminal study, Kosslyn et al. (Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel, 2000) sought to determine whether hypnotic suggestion could influence the brain mechanisms underlying visual perception. While being scanned using positron emission tomography (PET), highly hypnotizable participants viewed two visual patterns and were instructed to perceive them in the four following ways: a colour pattern in colour, an identical colour pattern as gray-scale, a gray-scale pattern as gray-scale, and an identical gray-scale pattern as brightly coloured. Following a hypnotic induction and suggestion (when compared to normal wakefulness), areas in both hemispheres associated with colour processing (in the fusiform/lingual region) were activated when subjects were instructed to perceive colour, regardless of whether they were in fact shown the colour or the gray-scale stimulus. Activation of these colour-associated areas was diminished when subjects were asked to see gray scale, whether they were actually presented with colour or gray-scale stimuli.

McGeown et al. (2012) conducted a follow-up study to see if the effects obtained by Kosslyn et al. (2000) were attributable to response to suggestion regardless of the induction procedure. To do so, they presented both high and low suggestibles with identical suggestions in and out of hypnosis. Following the subjective reports of colour perception, responses to suggestion in normal wakefulness were indistinguishable from responses to an identical suggestion following hypnotic induction. Compared to low suggestibles, highly suggestible individuals showed stronger responses to suggestions both in and out of hypnosis. Behaviourally, only suggestibility influenced the response to the suggestion, despite the presence or absence of hypnotic induction. However, when looking at the fMRI data within the highly suggestible participants, different activations (namely in the left inferior occipital gyrus,

both middle occipital gyri and various other regions at the voxel level, several of which were in the DMN*) were present following suggestion in hypnosis compared to suggestion in normal waking consciousness. This evidence highlights the difficulty of dissociating the added contribution of hypnotic induction to altered color perception but eloquently replicates the power of suggestion in modulating perception.

Other researchers have attempted to measure the neural correlates of hypnosis-induced paralysis. In one study, Pyka and co-workers (Pyka, Burgmer, Lenzen, Pioch, Dannlowski, Pfleiderer, Ewert et al., 2011) scanned highly suggestible subjects with fMRI to investigate brain activity mediating hypnotic left-hand paralysis. Hypnotic induction began with suggestions such as "the left hand feels weak, heavy." These suggestions were followed by direct suggestions such as "the left hand is paralyzed, you cannot move the hand anymore." Subjects under hypnotic suggestion reported feeling that they were not able to move their left hands. Interestingly, the left-hand paralysis induced by hypnosis was not associated with activation of brain areas involved in the inhibition of movement. Indeed, functional connectivity analyses revealed enhanced connectivity of the precuneus with the right dorsolateral prefrontal cortex (DLPFC), a cortical area known to be involved in cognitive control (Frith, 2000). Pyka et al. (2011) argued that the increased coupling of the precuneus supports the view that hypnotic paralysis may be related to an altered representation of the self which affects motor abilities. These researchers further proposed that the increased coupling of the right DLPFC with the precuneus may support the idea that hypnotic paralysis of the left hand was maintained by cognitive control processes implemented by the contralateral DLPFC. Similar results were obtained by Cojan and collaborators (Cojan et al. 2011) using a go/no-go task. In half of the blocks, a hypnotic induction was followed by suggestion of paralysis of the left hand. A control group was also asked to feign hand paralysis to account for willful withholding of the movement (though when reading the instructions that were given, it could be argued that a suggestion had been made). Even when under induced paralysis, preparatory motor activity was still found but activity from M1 was decoupled from the activity in the premotor areas and functional connectivity was increased in the precuneus. These findings support the notion that modifications in self-monitoring are at play when eliciting suggested rather than willed behaviour.

* See McGeown et al. (2012) for an extensive list of these regions

2.2. Pain

Pain is a multi-dimensional experience that includes sensory-discriminative, cognitive, emotional, and behavioural components (Price, 1996; Peyron et al., 2000; Knudsen et al., 2011). These various components are mediated by neural circuits commonly referred to as the "pain matrix" (Peyron, Laurent, & Garcia-Larrea, 2000). This functional brain network involves the brainstem, thalamus, insula, anterior cingulate cortex (ACC), primary (S1) and secondary (S2) somatosensory cortices. Neuroimaging findings support the contention that two distinct neural circuits are implicated in pain perception. On this view, the somatosensory thalamus (lateral thalamic nuclei) and its projections to the primary and secondary somatosensory cortices are involved in the sensory component of pain, whereas the emotional component implicate the medial thalamic nuclei and its projections to the ACC and prefrontal cortices (Hofbauer, Rainville, Duncan, & Bushnell, 2001). As for the insula, this cerebral structure acts as an intermediary between the sensory and emotional components of pain (Augustine, 1996).

Rainville et al. (Rainville, Duncan, Price, Carrier, & Bushnell, 1997) used PET and hypnosis to investigate the cerebral structures involved in the emotional aspect of pain. Hypnotic suggestions were given to healthy subjects to change the unpleasantness of noxious stimuli ("painfully hot" water) without altering the perceived intensity. The levels of activation within the ACC were consistent with the perceived unpleasantness of these noxious stimuli, whereas primary somatosensory cortex activation was unaffected. Rainville and colleagues (Rainville, Hofbauer, Paus, Duncan, Bushnell, & Price, 1999) utilized PET also to explore the neural mechanisms underlying hypnotic states and responses to hypnotic suggestions. Regional cerebral blood flow was measured during rest (Baseline), hypnotic relaxation alone (Hypnosis), and hypnotic relaxation with suggestions (Hypnosis-with-Suggestion) for altered pain unpleasantness. Subjects had their left hand immersed in neutral or hot water—in the Baseline and Hypnosis conditions—and in painfully hot water in the Hypnosis-with-Suggestion condition. In this condition, suggestions for High or Low pain unpleasantness were given to the subjects. Results revealed that hypnosis was accompanied by both rCBF increases (in occipital areas, inferior frontal gyri, right anterior cingulate sulcus, right anterior superior temporal gyrus, and left insula) and rCBF decreases (in the right inferior parietal lobule, medial precuneus, left posterior cingulate gyrus, left medial superior frontal gyrus, and left posterior middle temporal areas). Likewise, hypnosis-with-suggestions (for

both High and Low pain unpleasantness) resulted in widespread increases (in medial superior and left dorsolateral areas of the frontal lobes, right dorsolateral frontal areas, left medial posterior parietal areas, and left nucleus accumbens) and decreases (in the right uncus, bilateral posterior orbitofrontal areas, and left lateral cerebellum) in rCBF. Rainville et al (1999) proposed that the occipital increases in rCBF seen in the Hypnosis condition reflect an altered state of consciousness associated with possible facilitation of visual imagery. These researchers also speculated that the frontal increases in rCBF associated with suggestions for altered pain perception might be related to the verbal mediation of the suggestions, working memory, and top–down processes implicated in the reinterpretation of the perceptual experience of pain. This conclusion is in line with the results of a recent fMRI study (Raij, Numminen, Närvänen, Hiltunen, & Hari, 2009), which sought to examine the neural correlates of hypnotic-suggestion-induced pain (during laser-induced pain). The level of activation, measured by blood-oxygen-level-dependent (BOLD) signal, in the right DLPFC during initiation of suggestion for pain was found to be positively correlated with the subjective intensity of the subsequent suggestion-induced pain. In this case, hypnotic suggestions modulated reactions on an emotional level rather than on a perceptual level, confirming the importance of reappraisal in response to these suggestions.

Some investigators have combined experiential measures (e.g., self-rating of subjective experience; Varela & Shear, 1999) and functional brain imaging to address the neurophenomenology of hypnotic states. For example, Rainville and co-workers (Rainville, Hofbauer, Bushnell, Duncan, & Price, 2002) used PET to scan healthy volunteers before and after the induction of hypnosis. In these two conditions, subjects rated their perceived level of "mental relaxation" and "mental absorption," two of the crucial aspects characterizing the experience of being hypnotized. The subject's left hand was submerged in either warm or painfully hot water. In the hypnotic state, rCBF increases were noted in the left insula, occipital lobes, superior frontal and orbitofrontal areas, and ACC (middle, rostral, perigenual), whereas decreases in rCBF were observed in the right inferior parietal lobule and precuneus. Increases in mental relaxation were correlated with rCBF increases in the middle and perigenual ACC and rCBF decreases in the mesencephalic tegmentum of the brainstem and the thalamus. Rainville et al. (2002) speculated that the negative correlations in the mesencephalic brainstem and thalamus may reflect the involvement of these cerebral

structures in the regulation of wakefulness and cortical arousal. In other respects, increases in mental absorption during hypnosis were associated with rCBF increases in a distributed network of cortical (e.g., rostral ACC, right inferior frontal gyrus) and subcortical (e.g., thalamus, upper pons) structures critically involved in the brain's attentional system. Overall, these findings indicate that, in the context of pain modulation, the basic alterations in subjective experience produced by hypnotic induction (without overt suggestion for pain reduction) are mediated, at least in part, by modulation of activity within brain regions playing a pivotal role in self-monitoring and the control of conscious states (Rainville et al., 2002).

Other research teams have sought to identify the neural mechanisms responsible for hypnotic analgesia. For instance, Schulz-Stubner et al. (Schulz-Stübner, Krings, Meister, Rex, Thron, & Rossaint, 2004) used fMRI to measure BOLD signal changes induced by thermal pain in hypnotized subjects. Healthy volunteers had a heating device put on their skin to determine the temperature at which each of them felt a comparable degree of pain (8 out of 10 on a 0 to 10 subjective pain scale). Next, the subjects were hypnotized and scanned during repeated painful heat stimulation. Brain activity was recorded also when subjects were not hypnotized during painful heat stimulation. Under hypnosis, all subjects experienced a significant pain reduction (down to less than 3 on the self-reported pain scale) in response to the painful heat. These subjective reductions were accompanied by decreased activations in regions of the pain network including S1 and the middle cingulate gyrus. Increased activation was seen in the left ACC. No activation was detected within the brainstem and thalamus. These observations suggest that hypnosis, even without the presence of overt analgesic suggestion (but with mental imagery), may prevent pain signals from reaching higher cortical structures implicated in the conscious perception of painful stimulation (Schulz-Stubner et al., 2004). These findings are in good agreement with those of another fMRI study carried out on healthy volunteers (Vanhaudenhuyse, Boly, Balteau, Schnakers, Moonen, Luxen, Lamy et al., 2009). In this investigation, painful stimuli (induced by a laser) activated the brainstem, thalamus, ACC, striatum, insula, DLPFC, and contralateral S1. In the hypnotic state, and without overt analgesic suggestions, the painful stimuli failed to produce significant activation in these regions. Thus, the combined evidence indicates that hypnotic induction seems sufficient to exert a reappraisal effect on the emotional component of pain.

2.3. DEFAULT MODE NETWORK

Recent work by Oakley and colleagues suggests that modulations of the default mode network (DMN; a network of brain regions that show more activity at rest, i.e. in absence of goal-directed behaviour or external stimulation (Buckner, Andrews-Hanna, & Schacter, 2008)) might be a promising avenue to explore for scientists who wish to elucidate neural markers of a putative hypnotic state (Oakley, 2008; Oakley & Halligan, 2009). Since then, a few studies have explored hypnosis in relation to activity in the DMN.

McGeown and colleagues (McGeown, Mazzoni, Venneri, & Kirsch, 2009) pointed out that the experimental design adopted in a number of neuroimaging studies of hypnosis does not allow for discrimination between changes in brain activity resulting from the hypnotic induction procedure and changes arising from task-related suggestions. These researchers proposed an alternative approach to attenuate the confounding effect of task demand characteristics and performance expectations: to scan subjects during rest periods following the hypnotic induction procedure (that is, while they are not performing any specific task). Using such an approach, McGeown et al. measured the patterns of brain activation and deactivation of high and low suggestible individuals, while resting in a MRI scanner, both in and out of hypnosis. When hypnotized, highly suggestible subjects showed a reduction of brain activity in the anterior parts of the DMN (ACC, medial and superior frontal gyri, left inferior and middle frontal gyri). No detectable changes in DMN areas were noted when low suggestible subjects underwent the same hypnosis-inducing procedure. In contrast to the default mode, which has been associated with mind-wandering and internally-directed attention (Buckner et al., 2008; Mason et al., 2007), hypnosis has been described as a state of readiness to respond to whatever suggestions are made by the hypnotist (Kirsch & Lynn, 1997; Tellegen, 1981). In this context, McGeown et al (2009) postulated that diminished levels of anterior default mode activity during resting periods following hypnotic induction indicate that high suggestible individuals may be able to suspend spontaneous, non-goal-directed cognitive activity.

Demertzi and co-workers (Demertzi, Soddu, Faymonville, Bahri, Gosseries, Vanhaudenhuyse et al., 2011) have used independent component analysis (ICA) on resting state fMRI acquisitions to assess functional connectivity between DMN regions during neutral hypnosis. As compared with a control condition of autobiographical mental imagery, hypnosis produced enhanced

connectivity in angular and middle frontal gyri, and reduced connectivity in posterior midline and parahippocampal structures. Demertzi et al (2011) posited that these functional connectivity changes between DMN regions reflected an altered "self" awareness and posthypnotic amnesia. This is partly supported by the fact that subjective reports of the occurrence of external thoughts were significantly decreased in the hypnosis condition. But an absence of direct evidence towards "self" awareness and amnesia in the present study mitigates their conclusions.

Lipari and collaborators (Lipari et al. 2011) investigated the extent of DMN involvement under pure or neutral hypnosis in a particularly highly hypnotizable, or virtuoso, subject using both EEG and fMRI in order to assess how specific or attributable that involvement was to hypnosis. Resting state activity was assessed in a normal wakeful state before hypnotic induction and again under hypnosis without other suggestions (other than those used during the induction, including "let your mind go" and "your mind must not know.") Posterior DMN (in areas including the precuneus, the posterior cingulate gyrus, the retrosplenial cortex, the IPL and PH) BOLD signal was increased under hypnosis while anterior DMN (in areas including the medial prefrontal cortex, the middle frontal gyrus and the ACC) BOLD signal was diminished during hypnosis. Activity outside of the DMN (in motor and visual areas) was also observed during hypnosis despite the lack of suggestions that could elicit such activity. This could be attributed to singularities of the virtuoso and is coherent with the exhaustion she felt following the hypnotic session. But these results complicate the hypothesis that neutral hypnosis can be best described as a modulation of the DMN. Another interesting point is the fact that the decreased activity in anterior areas, also related to the sense of self and self-monitoring (Rainville et al., 1999) are consistent with the phrases "let your mind go" and "your mind doesn't know" used during the hypnotic induction phase.

Taken together, these results appear consistent with the initial report of McGeown et al. (2009) and suggest that the DMN is involved in a distinct manner during neutral hypnosis. A consistent anterior DMN involvement seem to emerge from the findings, even if it two of the three studies reviewed show decreased activation (McGeown et al., 2012; Lipari et al., 2011; see also recent evidence from Deeley et al. 2012) while the other reported increased connectivity (Demertzi et al. 2011). The role of the posterior DMN might be an interesting avenue to explore but has only been witnessed in one virtuoso subject (Lipari et al. 2011). Importantly, it is difficult to say if the changes in DMN are related to a special hypnotic state or rather to specific suggestions employed during the induction procedure.

2.4. SUMMARY

Findings from functional neuroimaging studies demonstrate that hypnotic suggestions can modulate the neural activity supporting colour perception and the experience of painful stimuli. There is also some evidence indicating that suggestions of hypnotic analgesia can result in a reduction of activity in certain areas of the pain matrix. The situation is more complicated with regard to the neural correlates of the putative hypnotic state. Indeed, while some findings indicate that there is a reduction of activity in various regions of the PFC following hypnotic induction (McGeown et al., 2009), other findings indicate that hypnosis (without suggestions) may be mediated by increased activity in distinct prefrontal cortical areas (Rainville et al., 1999). Nonetheless it seems that neutral hypnosis is associated with a distinct anterior alteration of the DMN.

3. FUNCTIONAL NEUROIMAGING STUDIES OF MEDITATION

3.1. BASIC NEURAL SUBSTRATES

In recent years, many functional imaging studies have explored the neural correlates of different types of meditation, including OM, FA, transcendental, or even mixed meditative practices. In a pilot investigation, Newberg et al. (Newberg, Alavi, Baime, Pourdehnad, Santanna, & d'Aquili, 2001) scanned eight experienced Tibetan Buddhist meditators with single photon emission computed tomography (SPECT) while they focused their attention on a mental image. They were scanned twice, once during meditation and once during normal resting wakefulness. Experientially, the meditators reported "becoming one with" the visualized image during the meditative state. The baseline activation patterns revealed a difference in the thalamic laterality index in which meditators displayed a greater rightward dominance of thalamic rCBF compared to controls. Increased rCBF was measured in the cingulate gyrus, inferior and orbital frontal cortex, DLPFC, midbrain, and thalamus during meditation relative to baseline. In addition, decreased rCBF activity in the left posterior superior parietal lobe was negatively correlated with the activity increase noted in left DLPFC. Newberg and colleagues suggested that the increased frontal rCBF may reflect focused concentration while thalamic increases may be correlated with increased cortical activity during

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meditation. These researchers also proposed that midbrain activation may be related to alterations in autonomic activity during meditation, and that the negative correlation between the left posterior superior parietal lobe and the left DLPFC may reflect an altered sense of space experienced during meditation. Other interpretations of these results include the notion of an internal vs external focus of attention.

In another study of concentrative meditation, Brefczynski-Lewis and colleagues (Brefczynski-Lewis, Lutz,, Schaefer, Levinson, & Davidson, 2007) used fMRI to examine the neural correlates of "one-pointed concentration"—a form of FA meditation that is practiced to increase attentional focus and reach a peaceful state in which preoccupation with thoughts and emotions is progressively diminished. The researchers compared a group of Tibetan Buddhist monks with extensive meditation experience to a group of age-matched novice meditators. Subjects were instructed to focus on a small fixation dot presented on a screen. Results showed that activation in brain regions normally implicated in visual sustained attention (e.g., FEF, both interparietal sulci, middle cingulate cortex, anterior insula, thalamus and lateral occipital) was generally more robust for the expert meditators compared to novices. However, whereas the monks with an average of 19,000 hours of practice (intermediate) exhibited greater activation in these regions than the novices, the monks with an average of 44,000 practice hours (advanced) showed less activation*. This pattern of results fits well with traditional descriptions which present concentration meditation as initially requiring higher levels of effortful concentration but eventually becoming less effortful, such that later phases of this meditative practice necessitate minor effort (Brefczynski-Lewis et al., 2007). Given this finding it becomes even more difficult to compare the neural correlates found in the different studies due to the inherent differences at various points of the learning process of the meditator.

FMRI has also been utilized to investigate brain changes associated with open monitoring (OM), or mindfulness, meditation. For instance, Ives-Deliperi et al. (Ives-Deliperi, Solms, & Meintjes, 2011) scanned healthy volunteers who had practiced daily mindfulness meditation for a minimum of four years. Subjects were scanned while performing a control task (random generation of numbers) and mindfulness meditation. In the mindful condition, subjects were asked to be aware of present-moment bodily sensations, thoughts and emotions without judging or reacting to these physical and mental events.

Significant BOLD signal decreases were recorded during mindfulness meditation relative to the control condition in midline cortical structures associated with interoception, including the precuneus, right medial PFC, and left ventral ACC, and also the anterior insula. According to Ives-Deliperi and colleagues (2011), these findings indicate that mindfulness has an overall "quieting" effect on brain regions associated with the subjective and cognitive aspects of emotions. Yet, the task can be seen as an externally directed task, while meditation is internally directed, and thus, the absence of a neutral resting state control limits their findings. These researchers also proposed, as a possible explanation of their results, that mindfulness may promote emotional well-being through a process of disidentification. Such a process would allow mindfulness practitioners to realize that thoughts and feelings are transient mental events that do not define a substantial self (Martin, 1997).

The previously reviewed studies all presented different meditation techniques. Given that the instructions or tasks performed during the meditation conditions are quite different, one can rightfully argue that the inconsistent findings are due to that very fact. In a recent fMRI investigation, Manna and co-workers (Manna, Raffone, Perrucci, Nardo, Ferretti, Tartaro et al., 2010) contrasted the neural correlates of concentrative and mindfulness meditation techniques within the same experiment. Theravada Buddhist monks, expert in both Samatha (concentrative, FA) and Vipassana (mindfulness, OM) practices (range of experience with meditation: 25–53 years), participated in the study. In the concentrative meditation condition, subjects were asked to "observe and recognize any experiential or mental content as it arises from moment to moment, without restrictions and judgement, including breath and body sensations, percepts of external stimuli, arising thoughts and feelings" (p. 47). In the mindfulness meditation condition, subjects were instructed to focus their attention on breath sensations.

Compared to a resting state, the concentrative meditation condition revealed a widespread pattern of deactivation in the left hemisphere (lateral anterior PFC, anterior and posterior insula, and precuneus) and right hemisphere (inferior frontal gyrus, superior temporal gyrus). Additionally, activity was observed in the dorsal ACC and right medial anterior PFC. As for the mindfulness meditation condition (relative to rest), activations were noted in the left hemisphere, medial anterior PFC, superior temporal gyrus, and superior parietal lobule.

* It is important to specify that an extensive and long-term commitement to meditation is necessary to attain a certain mastery of the discipline. It is the main reason why a separation can be drawn between practitionners who all seem to have plenty of experience in the eye of the layperson.

While no significant differences were found when comparing mindfulness and concentrative meditation among beginners, advanced meditators showed more activity during mindfulness in the left DLPFC, bilateral anterior prefrontal cortices, left medial frontal gyrus, left precuneus, left superior parietal lobule, left anterior insula, right infero-frontal gyrus and transverse temporal gyrus. A greater BOLD activation was found during concentrative meditation in the right dorsal ACC and right medial anterior prefrontal cortex. These results indicate that expert meditators cognitively engage in conscious processing of sensations, thoughts, and emotions via self-regulation of frontal, parietal, and insular areas in a meditation state-dependent manner. Moreover, these results suggest that the ACC and the DLPFC play antagonistic roles in the executive control of attention during meditative states (Manna et al., 2010).

Due to methodological specificities, it is still impossible to pinpoint with certainty the neural correlates of meditation. Generally speaking, the studies reviewed above show a distinct modulation of the attentional networks but the nature and the extent of this modulation may fluctuate with experience and tradition. Attentional networks seem to be recruited differently at various stages in the experience of the meditator and, once one has sufficient practice, mindfulness and concentrative meditation appear to differentially engage these circuits.

3.2. Emotion processing

To investigate the neural mechanisms through which mindfulness modulates emotional responses, Taylor et al. (2011) carried out an fMRI study that sought to explore the effects of a mindful state on the neural responses to emotionally laden stimuli (Taylor, Grant, Daneault, Scavone, Breton, Roffe-Vidal et al., 2011). Another goal of this study was to examine the impact of the extent of mindfulness training on the brain mechanisms supporting the processing of emotional stimuli. Experienced and beginner meditators were scanned as they viewed negative, positive, and neutral pictures in a mindful state and a nonmindful state of awareness. Mindfulness attenuated emotional intensity perceived from pictures. Brain imaging data suggested that this effect was achieved through distinct neural mechanisms for each group of subjects. For experienced meditators, compared with beginners, mindfulness induced a deactivation of DMN areas (medial prefrontal and posterior cingulate cortices) across all valence categories, and did not influence responses in structures involved in emotional reactivity during emotional processing. On the other hand, for beginners relative to experienced meditators,

mindfulness induced a down-regulation of the left amygdala during emotional processing. These findings suggest that the long-term practice of mindfulness leads to emotional stability by promoting acceptance of emotional states and enhancing present-moment awareness, rather than by eliciting control over low-level affective cerebral systems from higher-order cortical brain regions (Taylor et al., 2011).

3.3. Pain

Similarly to hypnosis, meditation has been shown to be highly effective is in its ability to reduce the intensity and emotional perception of pain. With respect to this issue, Grant and colleagues (Grant, Courtemanche, & Rainville, 2011) used fMRI to examine the brains of Zen meditators during painful stimulation. To induce pain, thermal stimuli were applied to the inner surface of the left calf. During pain induction, meditators showed greater activation of primary pain processing regions (ACC, thalamus, insula), compared to controls. In addition, in meditators relative to controls, decreased activity was found in appraisal and emotion areas (e.g., lateral and medial PFC, amygdala and posterior cingulate cortex) during the administration of the painful stimuli. Furthermore, reductions in functional connectivity between executive and pain-related cortices strongly predicted lower pain sensitivity in meditators. Grant et al. (2011) hypothesized that the disengagement of anterior brain systems in meditators may reflect a functional decoupling of the cognitive-evaluative and sensory-discriminative components of pain. Such a phenomenon would allow Zen meditators to perceive painful stimuli in a mindful manner, that is, more neutrally from an emotional perspective.

In one investigation conducted by Gard et al. (Gard, Hölzel, Sack, Hempel, Lazar, Vaitl, & Ott, 2011), mindfulness practitioners and controls were given unpleasant electric shocks in the fMRI scanner during a mindful state and a control condition. Mindfulness practitioners, but not controls, were able to decrease pain unpleasantness by 22% during the mindful state. This decrease was accompanied by reduced activation in the lateral PFC and enhanced activation in the right posterior insula during painful stimulation. These findings suggest that mindfulness increases sensory processing and diminishes cognitive control, confirming the role of meditation in the reduction of cognitive-evaluative aspects of pain (Grant et al, 2011). In another investigation (Zeidan, Martucci, Kraft, Gordon, McHaffie, & Coghill, 2011), arterial spin labelling fMRI was used to investigate the neural mechanisms by which mindfulness modulates pain in healthy

individuals. The experiment was performed after 4 days of mindfulness meditation training. Noxious (thermal) stimuli were administered to subjects during a restful state and a mindful state. Mindfulness significantly diminished pain unpleasantness (by 57%) and pain intensity ratings (by 40%) relative to the rest condition. Neurally, mindfulness meditation decreased pain-related activation of the contralateral S1. Mindfulness-induced decreases in pain intensity ratings were correlated with enhanced activity in the ACC and anterior insula—cerebral structures implicated in the cognitive regulation of pain processing. Furthermore, decreases in pain unpleasantness ratings were correlated with an activation of the orbitofrontal cortex—an area involved in the re-appraisal of the contextual evaluation of sensory events. Reductions in pain unpleasantness ratings were also associated with a deactivation of the thalamus. Zeidan and co-workers (2011) postulated that this thalamic deactivation may support a gating mechanism implicated in altering interactions between afferent input and executive-order brain regions.

One generally robust finding from the findings reviewed above is that mediation can help reduce pain, even if the mechanisms supporting this process appear to vary according to the extent of the experience of the meditator. Indeed, participants in the study by Zeidan et al (2011) were novices and showed distinct neural mechanisms of pain modulation compared to the long-term practitioners investigated in other reports (Grant et al., 2011; Gard et al., 2011). Specifically, whereas novices appeared to modulate pain by decreasing activity in sensory processing regions and increasing activity in areas associated with cognitive control (Zeidan et al., 2011), experienced practitioners achieved similar effects in a seemingly converse manner: enhancing sensory processing and down-regulating control mechanisms (Grant et al., 2011; Gard et al., 2011). Because the studies reviewed in the previous sections showed differences attributable to the level of experience of meditators, one can reasonably expect that this relationship would hold true in the case of pain modulation. Even if this claim is presently speculative, these issues could easily be investigated by comparing in a single study the processes at work during painful stimulation between novice and expert meditators.

3.4. Default mode network

A handful of fMRI studies have examined functional connectivity between DMN areas during various types of meditation. In one of these studies, Josipovic et al. (Josipovic, Dinstein, Weber, & Heeger, 2011) recorded the brain activity of experienced meditators from the Tibetan-Buddhist tradition, while they fixated without meditation (fixation) or engaged in either non-dual awareness (NDA or transcendental) or FA meditation. The anti-correlation between intrinsic (or DMN) and extrinsic networks seemed to be stronger in FA than in rest, and lower in NDA meditation when compared to rest. On the other hand, correlation between areas within the DMN did not change during NDA meditation and FA meditation, relative to fixation without meditation. In another investigation, Brewer and colleagues (Brewer, Worhunsky, Gray, Tang, Weber, & Kober, 2011) measured brain activity in experienced meditators and matched meditation-naïve controls as they performed three distinct meditations [Concentration (FA), Loving-Kindness (practiced through directed well-wishing;) Choiceless Awareness (OM or attention to whatever arises in one's conscious field of awareness at any moment)] (Gunaratana, 2002). Across all meditation types, experienced meditators showed deactivation in core regions of the DMN (medial prefrontal and posterior cingulate cortices). Moreover, a greater coupling in experienced meditators was found between cortical areas of the DMN thought to be involved in self-monitoring and cognitive control (posterior cingulate, dorsal ACC, and DLPFC), both at baseline (restful state) and during meditation. This account also reported a relative absence of involvement of the extrinsic network, which is coherent with the supposed absence of stimulus-independent thoughts achieved in meditation. In addition, the consistency of connectivity patterns within DMN areas across meditation and baseline periods indicates that meditation practice may alter the resting-state experience such that it is similar to a meditative state (Brewer et al., 2011). The increased connectivity within the DMN, yet lowered activity, seems to point towards a more efficient recruitment of this network.

Aiming to confirm the notion that meditation alters the efficiency of DMN recruitment, Jang and co-workers (Jang, Jung, Kang, Byun, Kwon, Choi, & Kwon, 2011) employed fMRI to investigate functional connectivity within the DMN during a resting state (fixation on a foveal crosshair). Healthy controls and "brain-wave vibration meditation" practitioners were recruited. Brain-wave vibration meditation is believed to help quiet the mind and release negative emotions through focusing on bodily sensations while performing natural rhythmic movements. Thus, this form of meditation likely reflects a combination of both FA and OM practice. At rest, meditation practitioners showed greater functional coupling within the DMN in the medial prefrontal cortex

area than did the control subjects. This suggests that the long-term practice of meditation may lead to functional alterations in DMN activity, even when meditation is not being practiced. Such a conclusion is consistent with the findings of a fMRI study recently conducted Taylor, Daneault et al. (2012). In this investigation, resting-state data were collected from experienced mindfulness meditators and beginner meditators (trained for one week before the study). Relative to beginners, experienced meditators had weaker functional connectivity between DMN regions involved in self-referential processing and emotional appraisal. Moreover, experienced meditators had increased connectivity between certain other DMN regions (e.g., posterior cingulate cortex/precuneus and right inferior parietal lobule), compared to beginner meditators. These findings suggest that meditation training leads to functional connectivity changes between core DMN regions, possibly reflecting strengthened present-moment awareness, accompanied by a reduction in self-referential thoughts during rest. These findings also reinforce the idea that mindfulness training leads to changes in the functional dynamics of the DMN that extend beyond a state of meditation per se. Overall, therefore, meditation seems to influence the DMN both during and after practice, but it might have distinct impacts on regions related to self-referential and emotional appraisal, depending on the type of meditation practiced.

3.5. Brain structure

Many long-term outcomes have been associated with meditation and, in accordance with recent findings in neuroplasticity, it is logical to hypothesise that meditation might have a tangible impact on brain structure. Several studies in recent years have shown plastic gray matter changes in brain regions previously associated with meditation; namely in the brainstem (Vestergaard-Poulsen et al., 2009), in the hippocampus and frontal lobes (Luders et al., 2009), and in the left inferior temporal gyrus and right hippocampus (Hölzel et al., 2008). Furthermore, age-related decreases in gray matter usually observed in normal adults seems to be slowed or reversed in advanced meditators, which is to say that meditation might have a protective effect on the brain (Lazar et al., 2005; Ott et al., 2011). Finally, studies employing diffusor tension imaging and fractional anisotropy also report increased cortical thickness and thicker callosal regions, confirming the long term impact of meditation on the brain (Kang et al., 2012; Luders et al., 2012).

3.6. Summary

Globally, the findings from functional neuroimaging investigations indicate that concentrative meditation techniques are accompanied by enhanced activity in cortical areas known to be involved in sustained attention. With respect to the neural correlates of mindfulness, however, brain imaging studies present conflicting results. Effectively, whereas some investigations suggest that mindfulness is mediated by an overall decrease in brain activity (e.g., Ives-Deliperi et al., 2011), the results of other investigations indicate instead that this form of meditation is correlated with enhanced activity in various prefrontal, parietal, and temporal regions (e.g., Manna et al., 2010). Findings from other studies suggest that meditation can influence neural activity supporting the processing of emotional (Taylor et al., 2011) and painful (Grant et al., 2011; Gard et al., 2011; Zeidan et al., 2011) stimuli. Still, there are consistent effects of meditation on processes involving the DMN and compelling evidence that meditation leads to enduring changes in brain structure.

4. Concluding remarks and future directions

In this article, we have reviewed a number of functional neuroimaging studies that have investigated the neural mechanisms underlying the effects of hypnosis and hypnotic suggestion on colour perception, hand paralysis, pain, and the DMN. We also examined neuroimaging investigations conducted to identify the neural correlates of different meditation techniques, as well as the impact of meditation on the brain mechanisms supporting emotion, pain, and the DMN.

Despite some experiential similarities between hypnotic and meditative states (e.g., mental relaxation, attentional focus, concentration, mental absorption, letting go of thoughts) (Holroyd, 2003; Otani, 2003; Halsband et al., 2009), the results of the neuroimaging studies reviewed in this paper do not allow us to posit that hypnosis and meditation are mediated by similar brain systems and neural mechanisms (in contrast to the position held by Grant & Rainville, 2005). The comparison between the neuroimaging investigations of hypnosis and meditation performed in regard to pain processing and the DMN will illustrate why we reach such a conclusion. In the case of pain processing, it has been demonstrated that suggestions of hypnotic analgesia can produce a decrease of activity in regions of the pain matrix (e.g., S1, middle cingulate gyrus) (Schulz-Stübner

et al., 2004). In contrast, mindfulness meditation has been shown to be associated with increased activity in certain pain matrix areas (e.g., ACC, insula), depending on the level of training (Grant et al., 2011; Gard et al., 2011; Zeidan et al., 2011). As for the DMN, a decrease of activity in diverse prefrontal cortical areas has been reported during a restful state following hypnotic induction (McGeown et al., 2009). In addition, increased connectivity in angular and middle frontal gyri, and decreased connectivity in posterior midline and parahippocampal structures, has been found during this putative hypnotic state (Demertzi et al., 2011). With respect to meditation, Taylor et al. (2012) have reported a weaker functional connectivity between DMN regions involved in self-referential processing and emotional appraisal (dorsomedial PFC, ventromedial PFC, inferior parietal lobule) in experienced mindfulness meditators (compared to beginner meditators). Furthermore, Taylor et al. (2012) have shown enhanced connectivity between other DMN areas (posterior cingulate cortex/precuneus and right inferior parietal lobule) in experienced meditators. The processes through which these outcomes are reached likely vary depending on the type of meditation and the experience of the meditators.

It is important to point out that considerable discrepancy exists among results of neuroimaging studies even within the individual domains of hypnosis and meditation. A number of factors might account for such inconsistencies. It should come as no surprise that the use of different hypnotic suggestions targeting distinct sensory/perceptual systems leads to different patterns of neural activity (Rainville et al., 1999). Moreover, since distinct kinds of mental events/processes are associated with different brain patterns, the control condition is critical when interpreting the results from neuroimaging studies of hypnosis (Demertzi et al., 2011). In other respects, differing control tasks, meditative techniques, and experimental designs most certainly contribute to the discrepant findings found in the neuroimaging literature on meditation (Ives-Deliperi et al., 2011). The level of expertise of the subjects in meditative practices

and the sample size constitute other potentially confounding variables (for a discussion of such factors, see Grant, this issue).

Direct comparisons accounting for a wider range of variables would be required in order for neuroscience to really determine and compare the processes at work in hypnosis and meditation. Such variables could include comparison of both states in the same subjects, whether by hypnotising advanced meditators or by asking highly hypnotisable non-meditators to practice meditation. The impact of suggestion while under hypnosis and while meditating could also be assessed in order to see if meditation also facilitates the suggestion effect and if this effect is mediated by similar neural mechanisms. In the case of hypnosis, a comparison of the variables of interest should be done both under neutral hypnosis and following suggestions in order to determine the precise contribution and the differential workings of both. In the case of meditation, when possible, two styles (or two variants of the same style) could be compared in the same meditator. Another possibility would be to take into account a phenomenological report of the content of the meditation or hypnosis session in order to control for the semantic content in terms of beliefs, goals, and expectations.

This review aimed to outline and compare the neural correlates and processes involved in hypnosis and meditation. We reviewed a wide range of findings, highlighted significant caveats and drew conclusions as to where research should head in order to attain a clearer understanding of hypnosis and meditation, as well as of their similarities and differences. Even if the experimental control of the critical variables we discuss (e.g., attitudes and beliefs, experience of the practitioner, and validity of the control task) might disnature the practices from their usual settings, such assays would be necessary to determine if hypnosis and meditation differ only because of these particular contexts and come together when stripped from them, or are truly different in their fundamental workings.

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