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REVIEW/MISE AU POINT

Neurophysiology of hypnosis

Neurophysiologie de l'hypnose

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Summary We here review behavioral, neuroimaging and electrophysiological studies of hypnosis as a state, as well as hypnosis as a tool to modulate brain responses to painful stimulations. Studies have shown that hypnotic processes modify internal (self awareness) as well as external (environmental awareness) brain networks. Brain mechanisms underlying the modulation of pain perception under hypnotic conditions involve cortical as well as subcortical areas including anterior cingulate and prefrontal cortices, basal ganglia and thalami. Combined with local anesthesia and conscious sedation in patients undergoing surgery, hypnosis is associated with improved peri- and postoperative comfort of patients and surgeons. Finally, hypnosis can be considered as a useful analogue for simulating conversion and dissociation symptoms in healthy subjects, permitting better characterization of these challenging disorders by producing clinically similar experiences.

MOTS CLÉS
Hypnose ;
Réseau du mode par défaut ;
Réseau externe ;
Perception de la douleur ;
Hystérie ;
Symptômes de conversion

Résumé Nous proposons de discuter des études comportementales, électrophysiologiques et de neuroimagerie investiguant l'hypnose comme un processus de conscience ou comme un outil pour moduler les réponses cérébrales au repos ou lors de stimulations douloureuses. Différentes études ont mis en évidence une modification de l'activité cérébrale au niveau des réseaux interne (conscience de soi) et externe (conscience de l'environnement). Par ailleurs, les mécanismes cérébraux qui sous-tendent la modulation de la perception de la douleur sous-hypnose comprennent des régions telles les cortex cingulaire antérieur et frontal, les ganglions de la base et le thalamus. Combinée à une anesthésie locale et une sédation consciente chez les patients subissant une chirurgie, l'hypnose est également associée à une amélioration péri- et postopératoire du confort des patients et des chirurgiens. Enfin, l'hypnose peut être considérée comme un outil utile pour créer des symptômes de conversion et de dissociation chez des sujets sains, ce qui permet de mieux caractériser ces troubles en mimant des observations cliniques similaires.

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Numerous studies have highlighted the interest of hypnotic procedures in various clinical situations, such as pain management, treatment of phobia, depression, dissociative and psychotic disorders and so on. Some researchers believe that hypnosis is related to an altered state of consciousness, while others assume that these phenomena can be explained by psychological concepts such as clinician-patient expectations. Hypnosis can be defined as ''a procedure during which a health professional or researcher suggests that a patient or subject experience changes in sensations, perceptions, thoughts, or behavior'' [60]. Hypnosis is seen as a state of focused attention involving focal concentration, and inner absorption with a relative suspension of peripheral awareness and has three components [56]:

- absorption: tendency to become fully involved in a perceptual, imaginative, or ideational experience;
- dissociation: mental separation of components of experience that would ordinarily be processed together;
- suggestibility: responsiveness to social cues, leading to an enhanced tendency to comply with hypnotic instructions, representing a suspension of critical judgment.

We have shown that subjects in a hypnotic state reported a phenomenology of an altered state of consciousness: participants reported a higher degree of absorption and dissociation as compared to normal wakefulness and control conditions [12]. Other studies have also shown that hypnosis produces alterations in aspects of consciousness and is characterized by modulation of properties of the phenomenal self-consciousness such as mental ease (i.e. easy flow of thoughts), absorption, reduction in self-orientation and automaticity (i.e. responses are experienced as being produced without deliberation and/or effort) [47].

Measuring hypnosis in the brain

We here review neuroimaging and electrophysiological (EEG) studies of hypnosis as a state, as well as hypnosis as a tool to modulate brain responses to stimulation such as, for example, painful stimuli.

Hypnosis in the brain ''at rest''

fMRI and PET studies

In a first study, regional cerebral blood flow (rCBF) was shown to increase by 16% during hypnosis, with specific increase in occipital and right temporal regions [62]. Several years later, Maquet et al. [38] explored the brain mechanisms ''at rest'' underlying hypnosis in healthy volunteers and showed that hypnotic state was related to the metabolic activation of cortical areas involving left-sided occipital, parietal, precentral, premotor, and ventrolateral prefrontal cortices and right-sided occipital and anterior cingulate cortices, while a decrease of activity was observed in precuneus, bilateral temporal, medial prefrontal and right premotor cortices. In a functional magnetic resonance imaging (fMRI) study, we showed that self-related and external brain networks were modified under hypnosis [12]. The self-related network coincides with midline brain structures such as precuneus and mesio-frontal brain areas (also named default mode network — DMN) and is involved in self-related processes, while the external network encompasses lateral fronto-parietal regions routinely exhibiting activity increases during attention-demanding tasks and has been linked to cognitive processes of external sensory input [22]. In the normal awake state, we identified a negative correlation between external and internal awareness in healthy volunteers: explicit subjective reports for increased intensity of internal awareness were related to increased connectivity in the DMN, whereas increased external awareness scores were associated with increased connectivity in the external network [64]. Under hypnosis, the external network exhibited reduced functional connectivity, whereas the DMN showed reduced connectivity in its posterior midline and parahippocampal structures but increased connectivity in its lateral parietal and middle frontal areas [12], while other works showed opposite results with increased activity in posterior regions of the DMN as compared to decreased metabolic activity in anterior DMN areas [36,46]. Other fMRI studies have shown a hypnosis-related reduction in DMN connectivity [10,39], and increased activity in lateral prefrontal regions (involved in attentional/extrinsic systems) [10]. Subjects with high compared to low hypnotizability scores were shown to have greater functional connectivity between the left dorsolateral prefrontal cortex (involved in executive control processing) and the salience network (involved in detecting, integrating, and filtering relevant somatic and emotional information) [26]. The observed reduction in the DMN activity might reflect a decreased degree of continuous information being retrieved from the external world in terms of its relation to oneself [12]. The decreased connectivity observed by Demertzi et al. [12] in the extrinsic system might reflect a blockage of the sensory systems to receive stimuli as a result of hypnotic suggestion, while Deeley et al. [10] suggested that neural activity in DMN is inversely associated with attentional absorption and directly associated with spontaneous or stimulus-independent conceptual thought. Divergent finding obtained by these studies may be explained by distinct suggestion instructions used to induce hypnosis (e.g. pure/neutral hypnosis *vs*. experience of pleasant autobiographical memories) or the experimental fMRI designs used (e.g. block vs. continuous eyes-closed resting state design).

Finally, in a structural MRI study, Horton et al. [28] reported differences in brain structure size between low and highly hypnotizable subjects: highly hypnotizable subjects demonstrated a larger (32%) rostrum of the corpus callosum than subjects with low hypnotizability. This area is known to be involved in the allocation of attention and transfer of information between prefrontal cortices. The authors suggested that these results provide support for the neuropsychophysiological model that highly hypnotizable subjects have more effective frontal attentional systems implementing control, monitoring performance and inhibiting unwanted stimuli from conscious awareness (Table 1).

Electroencephalography

Highly hypnotizable subjects (as compared to medium and low) have been shown to demonstrate different EEG phase synchronization rhythms: high subjects demonstrated less phase synchronization in frontal brain areas [4]. In

Table 1 Results of PET and fMRI studies on neural correlates of hypnosis.

Reference	Technique	Number of subjects and degree of hypnotizability	Paradigm	Results
Maquet et al. [38]	PET	9 high	Listening to autobiographical event Revivification of autobiographical event under hypnosis Hypnosis with color hallucination	Hypnosis > normal state: increased activity in bilateral occipital cortex, L inferior parietal, precentral and prefrontal cortices, R ACC, R cerebellum Decreased activity in bilateral temporal, prefrontal and R premotor cortices, precuneus, R cerebellum
McGeown et al. [39]	fMRI	10 high/7 low	Resting state Resting state under hypnosis	Hypnosis > normal alertness in: scoring high: decreased activity in ACC, medial superior frontal gyri, L inferior and middle frontal gyri scoring low: decreased activity in PCC, thalamus, caudate nucleus, insula bilaterally; L inferior frontal gyrus, claustrum, lentiform nucleus, R subthalamic nucleus High > low: lower level of activity in L inferior, middle, superior and medial frontal gyri
Demertzi et al. [12]	fMRI	12 high	Resting state Revivification of pleasant autobiographical event under hypnosis Mental imagery of autobiographical memories	Hypnosis > mental imagery: DMN (intrinsic system): increased connectivity in middle frontal and bilateral angular gyri and decreased connectivity in PCC and bilateral parahippocampal areas Extrinsic system: decreased connectivity in the R supramarginal and L superior temporal areas
Deleey et al. [10]	fMRI	8 medium to high	Passive visual fixation in pre-hypnotic state Hypnosis state Post-hypnosis state	Hypnosis: decreased activation in DMN regions: L medial frontal, R ACC, bilateral posterior cingulate, and bilateral parahippocampal gyri and Increased activation in R middle frontal, inferior frontal and bilateral precentral gyri
Lipari et al. [36]	fMRI	1 high	Resting state Resting state under hypnosis	Hypnosis > normal alertness: increased activity in posteromedial cortex, bilateral occipital areas, superior and inferior parietal lobule, bilateral angular gyri, frontal areas, ACC, R parahippocampal Decreased activity in medial and middle prefrontal cortex
Hoeft et al. [26]	fMRI	12 high/12 low	Resting state Resting state under hypnosis	High > low: increased functional connectivity between ACC and L dorsolateral prefrontal cortex

fMRI: functional magnetic resonance imaging; DMN: default mode network; R: right; L: left; ACC: anterior cingulate cortex; PCC: posterior cingulate cortex.

addition, studies suggested a predominance of alpha activity specifically in the left hemisphere [43] and over anterior regions of cortex [69] in highly hypnotizable subjects. It seems that hypnotizability rather than being in a hypnotic state was more associated with the generated alpha activity [56]. Recently, highly hypnotizable subjects were shown to display lower fronto-parietal alpha synchronization during hypnosis as compared to low subjects, suggesting that high subjects have more labile fronto-parietal networks and are thereby more responsive to hypnotic induction [58]. Other studies found that the most relevant EEG changes in highly hypnotizable subjects consisted in a decrease of alpha band activities (localized over motor and visual areas) [36], as well as the fact that mean alpha power seems not to be a predictor of hypnotic susceptibility [54].

Regarding other EEG rhythms, several studies have shown that level of theta activity (associated with inhibition of responses) increased as a function of hypnotizability [46]. It appears that highly hypnotizable subjects generated substantially more theta power than did low subjects, with a larger difference in frontal locations [3,33,54]. In addition, hypnosis (in low and high subjects) seems to increase mean theta power, suggesting an intensification of attentional processes [54]. However, other studies failed to show a significant relationship between theta activity and hypnotizability [9]. Williams et al. [69] have suggested that theta activity is more a relaxation index rather than a trait index of hypnotic susceptibility. Indeed, they showed that theta power was higher during the hypnosis condition in both high and low hypnotizable subjects and did not allow differentiation between these two types of subjects.

Gamma activity also seems to be involved in hypnosis processing, but the interest of this in separating subjects with high from low hypnotizability is still debated. Highly hypnotizable subjects demonstrate a reduction of gamma EEG density, in contrast to subjects with low hypnotizability [9,21,33]. However, other studies found opposite results, i.e. greater 40 Hz spectral amplitudes in high versus low hypnotizable subjects [9,55]. Beta activity was found to discriminate between high and low hypnotizable subjects [9]. Highly hypnotizable subjects seem to be characterized by a lower beta range as compared to low hypnotizable subjects [33].

In a study conducted on one ''virtuoso'' case study of hypnosis, Fingelkurts et al. [21] showed a difference between hypnosis and rest conditions in delta, theta, alpha, beta and gamma frequency bands. The authors suggested that decreased size and stability of delta, beta and gamma activity could be indicative of an increased independence of brain processes, translating an effort to maintain alertness in the hypnotic condition, while increased alpha and theta may indicate that subject was more relaxed and facilitated to process information. Recently, a non-subjective pattern recognition study based on fractal dimension of the EEG signal (i.e. topological and temporal dimensions of the signal) have been reported as the best features for classification of subjects in low, medium or high hypnotizable [3]. By studying coherence of the EEG signal, Kirenskaya et al. [33] showed that baseline EEG differed in coherence between subjects with high and low hypnotizability. Indeed, highly hypnotizable subjects were characterized by higher distributed brain regions coherence within delta, theta, and alpha bands. A study conducted by Hinterberger et al. [25] showed the different states of consciousness that can be observed during a complete hypnotic procedure (relaxation-induction-suggestion-waking up) in one highly hypnotizable subject. The dominant pattern highlighted in this study can be summarized as follows:

- closed-eyes condition may be associated with increased bilateral parietal and occipital alpha, parietal sensory-motor and beta activities;
- hypnotic state seems characterized by increased frontal alpha, decreased central, frontal and parietal gamma bilaterally and increased occipital gamma;
- deep hypnotic state is characterized by distributed reinforcement of activity in all frequency bands;
- the awake state showed reduced activity on all frequency bands in central, frontal and parietal areas, while gamma increased in temporal and prefrontal areas (this last pattern is attributed by the authors to a highly relaxed but mindful wake state).

Finally, event-related potential (ERP) studies have also been used to decode cognitive processes under hypnosis. Some studies demonstrated a reduction in the ERP response during hypnotic procedure, suggesting diminution of perception of stimuli, whereas other studies failed to detect such changes in ERP responses [9,56]. In studies conducted on one ''virtuoso'' of hypnosis [31] as well as in highly hypnotizable subjects [29], the mismatch negativity (MMN — negative component elicited by any change or 'mismatch' in a sequence of monotonous auditory stimuli in inattentive subjects) was found to be larger in hypnosis as compared to the baseline condition. However, this increase of MMN was also shown in subjects with low hypnotizability, suggesting that although related to the hypnosis condition, it could not be attributed to distinctive hypnotic processes per se [29].

How hypnosis can modulate pain perception?

Hypnosis combined with local anesthesia and conscious sedation in patients undergoing surgery, a technique also called 'hypnosedation', is associated with improved intraoperative comfort and reduced anxiety and pain, diminished intraoperative requirements for anxiolytic and analgesic drugs, optimal surgical conditions and a faster recovery of the patient [19]. Indications for surgical procedures under local anesthesia and hypnosedation are listed in Table 2. A retrospective behavioral study on 337 patients showed that hypnosis as an adjunct procedure to conscious intravenous sedation provides better perioperative pain and anxiety relief as compared to simple intravenous sedation or relaxation procedure [15]. A prospective study on patients undergoing plastic surgery confirmed these observations, i.e. decreased peri- and postoperative anxiety, pain and signs of discomfort as well as better surgical conditions in hypnosis group as compared to a control group [16]. Hypnosis proposed to patients suffering chronic pain after spinal cord injury, compared to direct current stimulation (tDCS), neurofeedback and meditation was shown to result in decreased pain intensity perception (the same effect also being observed for meditation), while tDCS

Table 2 Surgical interventions using hypnosedation as a routine analgesic procedure.

Minor surgery	Major surgery
Correction of scars	Thyroid lobectomy
Extraction of wisdom teeth	Total thyroidectomy
Correction of prominent ears	Parathyroïdectomy
Turbinoplasty — septoplasty	Breath prothesis
Nose fracture	Correction of mammary ptosis
Burn dressing changes	Head and neck lifting
Blepharoplasty	Head—neck cancer with reconstruction
Liposuction	Septorhinoplasty
Breath adenomectomy	Debridement—skin grafting
Hysteroscopy	Maxillofacial reconstruction
Removal of osteosynthesis material	Tubal ligation
Inferior limb varicose vein	Vaginal hysterectomy
	Umbilical or inguinal hernia

Adapted from [20].

and neurofeedback did not [30]. A recent meta-analysis comprising a total of 2597 patients undergoing surgical or medical procedures revealed effects of hypnosis on various pre- and postoperative factors such as emotional distress, pain, medication consumption, physiological parameters, recovery, and surgical procedure time as compared to standard care alone or an attention control [57]. By applying the hypnotic procedure we routinely used in surgery, we showed that affective (unpleasantness) as well as sensory (perceived intensity) components of pain perception were both reduced as compared to control conditions [17,16,18].

Brain mechanisms underlying the modulation of pain perception under hypnotic condition have been investigated by a growing number of neuroimaging studies. In PET studies, the modulatory effect of hypnosis was shown to be mediated by the anterior cingulate cortex (ACC) [17,48,50,49]. In addition, studies have demonstrated increased modulation of the ACC and a large cortical and subcortical network, encompassing prefrontal, insular, and pregenual cortices, pre-SMA, thalami, striatum and brainstem in the context of hypnosis [17,18,48,50,49]. In an fMRI study, painful stimulation in a normal alert state resulted in brain activation within a network encompassing cortical and subcortical brain areas (i.e. ACC, premotor, dorsolateral, prefrontal, primary somatosensory and bilateral insular cortices, thalamus, bilateral striatum and brainstem) while the same stimuli perceived under hypnosis failed to elicit any cerebral activation [63]. We also demonstrated a hypnosis-related increase in functional connectivity between primary somatosensory cortex (S1) and anterior insular and prefrontal cortices [63]. These results are not limited to healthy volunteers but are also observed in pathological states, such as patients suffering from fibromyalgia or chronic pain (Table 3). In a combined EEG and fMRI study, Rainville et al. [49] reported a reduction of the hypnosis-related increases in occipital and delta activity when subjects were painfully stimulated.

According to theories of hypnosis, one characteristic of hypnotic procedures is the inhibition of afferent nociceptive transmission. This inhibition can be explained by the dramatically decreased activity in the thalamus that is observed under hypnosis [18]. The thalamus has also been shown to correlate with pain perception threshold while activation of the midline area (i.e. posterior cingulate cortex) correlates with intensity of the stimulation and ACC with unpleasantness of the stimulation [61]. It has been proposed that the reported increased functional connectivity between mid-cingulate cortex, thalamus and brainstem might be related to pain-relevant arousal or attention mechanisms [32,50]. These observations can lead to the hypothesis that hypnosis involves subcortical gating processes on cortical activation that underlies the decreased subjective pain perception reported by subjects under hypnosis. The basal ganglia are known to encode and initiate basic movement patterns expressed through premotor pathways and have also been proposed to support basic attentional mechanisms facilitating the calling up of motor programs and thoughts [18,63]. In accordance with the reported decreases in premotor cortex activation in hypnosis, results of the different studies suggest that hypnosis may diminish anxiety, defensive and emotional reactions to pain by reducing activation of both cortical and subcortical areas [16]. The increased modulation of insular activity is in line with role of this structure in pain affect and pain intensity coding [49]. Modulation of frontal area activity may reflect disruption in cognitive attentional, appraisal and memory systems that can influence perception of environmental stimulation during hypnosis [18,63]. Finally, ACC is a brain area reported in several studies on executive attention, detection of errors, monitoring of conflict between competing cognitive processes and was shown to correlate with the difficulty of the task performed as well as with relaxation state of subjects [50]. Rainville et al. [50] proposed that engagement of the cognitive and neurophysiologic processes implied in each of those accounts may be accompanied by subjective experience of increased mental absorption as reported by subjects under hypnosis. In addition, ACC has also been considered to be involved in the ''suffering'' component of pain and affective reactions associated with pain unpleasantness [65]. Its decreased activity during hypnosis reflects the decreased unpleasantness of the stimulation reported by subjects under hypnosis. Finally, the observed reduction in occipital and delta activity during painful stimulation was proposed to reflect disruption of relaxation and/or imagery processes by pain during hypnosis [49].

Hypnosis as a substitute for hysteria?

Hysteria, now referred to as ''conversion disorder'', is defined as loss or distortion of a neurological function (e.g. paralysis, anesthesia, blindness, etc.) that is not explained by any organic neurological lesion or medical disease, arising in relation to some psychological stress or conflict, but not consciously produced or intentionally feigned [2]. Charcot hypothesized that hypnosis and hysteria are characterized by similar brain processes. According to Charcot, dysfunctional processes within the central nervous system affecting activity of motor or sensory pathways without permanent

Table 3 Modulation of the pain cerebral network during hypnosis.

Reference	Technique	Number of subjects	Results
Healthy volunteers			
Rainville et al. [48]	PET	8	Modulation of pain-related activity in ACC correlated with unpleasantness
Rainville et al. [49]	PET/EEG	8	Reduction of hypnosis-related increases in occipital and delta activity during painful stimulation
Faymonville et al. [17]	PET	11	Activation in the R extrastriate area, R ACC, and corpus callosum with painful stimulation during hypnosis (as compared to control conditions)
Hofbauer et al. [27]	PET	10	Pain-related activation in R contralateral S1, S2, ACC, and insular cortex during hypnosis (analogous to that observed in normal state). Hypnotic modulation of the intensity of pain sensation led to changes in pain-evoked activity within S1
Rainville et al. [50]	PET	10	Modulation of pain-related activity in ACC, thalamus and brainstem, correlated with mental relaxation and mental absorption
Faymonville et al. [18]	PET	19	Greater functional modulation between midcingulate cortex and bilateral insula, pregenual anterior cingulate cortex, pre-SMA, R prefrontal cortex and striatum, thalamus and brainstem during hypnosis (as compared to normal state)
Derbyshire et al. [13]	fMRI	8	Activation of thalamus, ACC, cerebellum, S2, insula, inferior parietal and prefrontal cortices in hypnotically-induced pain (same activation observed in real stimulation condition) Additional activity in midinsula, S1, and orbitofrontal cortex, and decreased activation in ACC during hypnotically-induced pain
Röder et al. [51]	fMRI	7	Reduced activation in controlateral somatosensory, parietal, and prefrontal cortices, putamen and ipsilateral amygdala during hypnosis-induced depersonalization (characterized by reduced pain perception)
Vanhaudenhuyse et al. [63]	fMRI	13	Non-painful sensory stimulation: activation of R S1, bilateral insula and brainstem in normal wakefulness. No activation in hypnotic state Painful stimulation: brainstem, R thalamus, bilateral striatum, R S1, bilateral insula, ACC, R middle frontal gyrus and R premotor cortex activation in normal wakefulness. No activation in hypnotic state Regions activating more in normal as compared to hypnosis during painful as compared to non-painful stimulation: thalamus, bilateral striatum and ACC
Patients			
Wik et al. [68]	PET	8 fibromyalgia	Hypnosis increased activation in bilateral subcallosial cingulate gyrus, R thalamus, L inferior parietal cortex and decreased activity in bilateral PCC and posterior part of the anterior cingulate gyrus
Derbyshire et al. [14]	fMRI	13 fibromyalgia	Greater activation in cerebellum, anterior midcingulate cortex and anterior and posterior with hypnosis, correlating with reported changes in pain
Abrahamsen et al. [1]	fMRI	19 temporomandibular disorders	Hypnotic hypoalgesia: activation in the posterior insula Hypnotic hyperalgesia: activation in the R posterior insula, middle frontal gyrus and L supramarginal gyrus
Nusbaum et al. [44]	PET	14 chronic low-back pain	Hypnoanalgesic suggestion associated with activations in L anterior insula and nucleus accumbens, lenticular and caudate nuclei bilaterally, and ACC. Deactivations appeared in L precuneus and R PCC

fMRI: functional magnetic resonance imaging; EEG: electroencephalographic; R: right; L: left; ACC: anterior cingulate cortex; S1: primary somatosensory cortex; S2: secondary somatosensory cortex; SMA: supplementary motor area; PCC: posterior cingulate cortex.

Table 4 Studies on hypnosis and hysteria symptoms in healthy volunteers and patients.

Reference	Technique	Number of subjects	Tasks	Results
Hypnotically suggested motor paralysis tasks in healthy subjects				
Halligan et al. [24]	PET	1	Attempt movement of the suggested paralyzed left leg	Activation of R orbitofrontal cortex and ACC (activation not observed when subject attempted to move the right non paralyzed leg)
Ward et al. [67]	EMG/PET	12	Attempt to move and rest during: — hypnotically suggested paralysis of the left leg — normal left leg with instruction to feign the same paralysis	EMG: no muscle activity during any condition PET: — suggested paralysis: increased activation in bilateral putamen, L thalamus, L SMA, L cerebellum, R posterior medial orbitofrontal — feigned paralysis: increased activation in L prefrontal, L inferior parietal, R parietal operculum, R SMA, R ventral premotor, bilateral cerebellar — attempt movement vs. rest during suggested paralysis: decreased activation in the R middle occipital gyrus — attempt movement vs. rest during feigned paralysis: no decrease
Cojan et al. [7]	fMRI	18	Go/Nogo hand movement: — normal — hypnotically suggested paralysis of hand — simulation of hand paralysis	— Motor preparation phase: activation of contralateral M1 in all conditions. Somatosensory activation during hypnosis and simulation for hand movement. Activation of precuneus during hypnosis for hand movement — Motor execution: L M1 and cerebellum activation for R hand movement in all conditions
Deeley et al. [11]	fMRI	8	Hands movements in: — normal — hypnotically suggested paralysis of hand	— Normal condition: activation in controlateral SMA and primary sensorimotor cortices and ipsilateral cerebellum — Paralysis condition: activation in bilateral SMA, R precentral gyrus, R ACC, R S1, R M1, bilateral cerebellum. Deactivation of L S1 — Normal > paralysis: activation in R S1, R M1, L cerebellum —Paralysis > normal: R SMA, bilateral cingulate gyri
Cojan et al. [8]	EEG	24	Go/Nogo hand movement tasks in: — normal — hypnotically suggested paralysis of left hand — simulation of left hand paralysis	Similar preparatory activations in all conditions (indicating preserved motor intentions) P3 peak with specific higher activity in R inferior frontal cortex during hypnotically suggested paralysis
Hypnotizability and conversion disorders				
Roelofs et al. [52]	Behavioral	9 high/8 low hypnotizable healthy	Implicit and explicit mental hand-rotation of hypnotically suggested paralysis of arm	— Implicit: hypnotic susceptibility does not affect reaction time of mental imagery — Explicit: inability to imagine right hand rotating in 11% of high hypnotizable vs. 3% of low hypnotizable. Slowing observed for the mental rotations with the paralyzed arm in high hypnotizable

Table 4 (*Continued*)

Reference	Technique	Number of subjects	Tasks	Results
Terhune et al. [59]	Behavioral	21 low/30 high suggestible healthy	Assessment of dissociative tendencies according hypnotic susceptibility	Highly suggestible subjects were more responsive to hallucination suggestions, involuntariness, impairment of working memory capacity and reported greater pathological dissociative and fantasy-proneness symptoms
Bliss et al. [6]	Behavioral	17 patients with severe hysteria/49 controls	Hypnotic susceptibility	Significant higher rate of hypnotizability in patients as compared to controls
Kuyk et al. [35]	Behavioral	17 epileptic/20 pseudo-epileptic patients	Hypnosis used to recall ictus memories	Higher rate of hypnotizability in pseudo-epileptic vs. epileptic patients
Goldstein et al. [23]	Behavioral	20 pseudo-epileptic patients/20 healthy controls	Hypnotic susceptibility measured by dissociation and absorption levels	Higher level of dissociation in pseudo-epileptic patients than in controls Higher level of absorption in controls as compared to patients
Litwin et al. [37]	Behavioral	31 epileptic/10 pseudo-epileptic/4 non classified patients	Dissociation, hypnotizability and absorption measurement	No difference in hypnotizability and absorption between epileptic and pseudo-epileptic patients 80% pseudo-epileptic patients presented dissociative symptoms, while 45% of epileptic patients
Roelofs et al. [53]	Behavioral	50 conversion disorders patients 50 affective disorders patients	Hypnotic susceptibility	Patients with a conversion disorder were more susceptible to hypnotic suggestions than patients with an affective disorder Hypnotic susceptibility was correlated with the number of conversion symptoms: patients who are more susceptible to hypnotic suggestions display more conversion symptoms
Hypnosis as treatment of conversion disorder symptoms				
Moene et al. [40]	Behavioral	7 motor conversion disorders patients	Comprehensive clinical treatment including hypnosis	Recovery from motor disorders in all patients. Relapse of symptoms in 3 patients
Moene et al. [41]	Behavioral	45 motor conversion disorder patients: 24 hypnosis/21 controls	Hypnosis vs. comprehensive program	Significant symptom reduction independent of the treatment condition in all patients
Moene et al. [42]	Behavioral	44 conversion disorder patients: 20 hypnosis/24 controls	Hypnosis vs. waiting list condition (control)	Significant effect of hypnosis-based treatment in reducing symptoms and impairments in domains of physical, daily-life and social activities

fMRI: functional magnetic resonance imaging; EEG: electroencephalography; EMG: Electromyography; PET: positon emission tomography; L: left; R: right; SMA: supplementary motor area; M1: motor cortex; ACC: anterior cingulate cortex; S1: primary sensory cortex.

damage can explain hysterical losses in motor or sensory functions, and could be induced by particular ideas, suggestion, or psychological states [66]. Several authors have hypothesized that psychological processes, such as affective or motivational factors, might induce distortion of sensory and motor inputs, resulting in their exclusion from conscious awareness [66]. Kirsch mentioned that ''hypnotized subjects are asked to experience paralysis, amnesia, anesthesia, involuntary movements and hallucinations. Hypnotizability is measured as the number of conversion and dissociation symptoms that the person is able to display'' [34]. Subjects under hypnosis are thus suggested to consciously demonstrate motor or sensory phenomena, while patients with hysteria have unconscious fixed ideas based on unconscious suggestions or autosuggestions that remain isolated from the rest of their mind and are expressed through motor or sensory disturbances [5]. According to Janet, dissociation can be seen as a ''narrowing of the field of consciousness'' resulting in the compartmentalization of normally integrated mental functions, while Freud proposed that dissociative processes result from a psychological defense mechanism that converts emotional distress into physical symptoms [5].

Evidence from neuroimaging studies indicates that primary sensory as well as motor cortices processing remain functionally intact in patients with hysterical sensory-motor disorders, suggesting that dissociation may result from disturbance of executive regions modulating attention, response selection and inhibition such as for example the prefrontal cortex [5]. Hypnotic procedures can induce symptoms similar to those seen in hysteria and may permit better understanding of neural processes of conversion disorders (see Table 4). According to Halligan et al. [24] hysterical and hypnotic paralysis share common neural systems involving contralateral prefrontal regions. The authors used PET to explore hypnotically suggested left leg paralysis as an analogue for conversion paralysis in one subject and showed similar brain activity (i.e. right ACC and right orbitofrontal cortex) to that reported in clinical conversion patient with comparable leg paralysis [24]. Later study on a larger cohort of subjects confirmed the involvement of orbitofrontal cortex [67], as well as of ACC [11] in hypnotically suggested motor paralysis. Both of these brain areas were proposed to be involved in active inhibition of movement by disconnecting premotor/prefrontal areas from primary motor cortex [45]. A recent EEG study in healthy volunteers reported a distinctive EEG topographic activity pattern during hypnotic paralysis with a specific source in right inferior frontal cortex, as compared to the control condition, indicating the key role of this brain region in executive control mechanisms [8].

In healthy volunteers, behavioral studies have shown that highly hypnotizable subjects, as compared to subjects with low hypnotizability, were more responsive to suggested hysteria symptoms such as motor paralysis [66], pathological dissociative and fantasy-proneness symptoms [59]. Results of the hypnotizability of patients with dissociative symptoms were more heterogeneous (Table 4). The level of hypnotizability was shown to correlate with the number of conversion symptoms presented by patients [53]. For example, pseudo-epileptic patients (defined by the demonstration of paroxysmal involuntary behavior patterns mimicking epileptic events) were shown to present more dissociative symptoms as compared to epileptic patients [23,37]. Some studies have reported higher rates of hypnotizability in patients with conversion disorders as compared to controls or patients with other pathological states (e.g. affective disorders) [6,35,53], while others have shown no difference in both hypnotizability and absorption (defined as the tendency to become fully involved in a perceptual, imaginative, or ideational experience) between patients with conversion disorders and controls [37]. A last study showed higher level of absorption in control subjects as compared to patients [23].

Finally, few studies have tested whether hypnosis-based treatment shows effect for patients with conversion disorders (Table 4). A first study has shown that comprehensive clinical management (i.e. consisting of explaining the symptoms, psychotherapy, physiotherapy and group therapy) including hypnosis can have positive effects in the reduction of conversion symptoms of patients [40]. The specific effect of hypnosis alone was not studied and thus cannot be strictly linked to the observed reduction of symptoms. An additional study has shown that symptom reduction was observed independently of the treatment condition (i.e. comprehensive program vs hypnosis added to a comprehensive program) [41]. Later, significant treatment results were reported for hypnosis-based therapy in patients with conversion disorders as compared to a no-treatment group [42]. These studies showed that hypnosis did not show additional value as part of a comprehensive treatment program but can be an effective treatment by itself for patients with conversion disorders.

Conclusion

We have discussed here the use of hypnosis in clinical settings as well as in neuroscience research, with the goal of learning more about the nature of hypnosis itself and its impact on sensory perceptions and pathological disorders such as conversion symptoms. If neuronal correlates of hypnotic state are still not completely understood, neuroimaging studies emphasize that hypnosis results in reduced activity of the extrinsic brain network involved in the environment and sensory perception. Findings on pain and hypnosis reinforce the idea that not only pharmacological but also psychological strategies can modulate the interconnected network of cortical and subcortical regions that participate in the processing of noxious stimuli and decrease significantly pain sensation in subjects. Finally, while we cannot clearly conclude that conversion disorders and hypnotically suggested conversion symptoms share strictly the same neuropsychological processes, studies nevertheless suggest many parallels between the features of clinical conversion symptoms and hypnosis. Hypnosis can be considered as a useful analogue for creating conversion and dissociation symptoms in healthy subjects, by the generation and easy termination of clinically similar experiences in laboratory conditions [46].

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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