

Duje Bralić¹

Neuroimaging evidence for clinical hypnosis and its relationship with the Triple Network Model of Psychopathology: An fMRI perspective

Nevro-slikovni izsledki o klinični hipnozi in njeni povezavi s trojnim mrežnim modelom psihopatologije: Perspektiva funkcijske magnetne resonance (fMRI)

Abstract

Background: The neural correlates of hypnosis remain incompletely characterized despite recognition of its clinical utility. Examining functional connectivity changes in large-scale brain networks during hypnosis can provide insights into cognitive control, dissociation, and self-awareness while guiding optimized clinical use cases across various conditions.

Objectives: This paper aimed to systematically review fMRI studies of hypnosis, qualitatively synthesize evidence regarding its impact on connectivity within and between the default mode, salience, and executive control networks, and offer recommendations for future research by identifying gaps and inconsistencies in existing literature and methodology.

Methods: PubMed, PsycINFO, Scopus and Web of Science and other databases were systematically searched for fMRI studies on hypnosis. Peer-reviewed articles written in English were screened against eligibility criteria. Data were extracted into a standardized form and quality assessed using a Newcastle-Ottawa Scale. A qualitative synthesis was performed focused on hypnosis effects on connectivity within and between the default mode, salience, and central executive networks.

Results: 35 experimental studies met inclusion criteria (n=689 participants). The review found heterogeneous effects on network connectivity during hypnosis, with both increased and decreased connectivity reported depending on suggestions used. The evidence indicates potential therapeutic effects for

¹ Duje Bralić, mag. aplicirane nevroznanosti, specializant sistemske psihoterapije, bralic.duje@outlook.com

pain and anxiety, but overall direct clinical support was limited. Preliminary findings suggest hypnosis impacts connectivity between salience/executive control networks, enhancing top-down regulation of interoception and affect. Reduced connectivity was also reported within default mode regions involved in internal mentation like the posterior cingulate cortex and precuneus.

Conclusions: While the literature exhibits variability in protocols and results, findings overall indicate that hypnosis exerts top-down influence on internal mentation, attentional control, and emotional processing through altering functional interactions between cortical and subcortical brain regions. Inconsistencies arising from methodological variations and heterogeneity of studies constrain definitive conclusions. Addressing these limitations through standardized protocols and comparisons based on universal large scale brain network taxonomy would strengthen the evidence for the neural signature of hypnosis and enhance its applicability in various contexts.

Keywords: hypnosis, fMRI, large scale brain networks, functional connectivity, hypnotizability

Povzetek

Ozadje: Kljub temu da je znanje o nevronskih korelatih hipnoze uporabno za klinično prakso, ostajajo pomanjkljivo opredeljeni. Raziskovanje funkcijske konektivnosti v velikih možganskih omrežjih med hipnozo omogoča nova spoznanja o kognitivnem nadzoru, disociaciji in samozavedanju, kar lahko izboljša učinkovitost klinične uporabe hipnoze pri različnih stanjih.

Namen: V tej študiji gre za sistematični pregled raziskav o hipnozi s pomočjo funkcijske magnetne resonance (fMRI) ter za kvalitativno sintezo izsledkov o vplivu hipnoze na konektivnost znotraj možganskih omrežij in med omrežji za stanje mirovanja (angl. default mode network), poudarjanje (angl. salience network) in izvršitev (angl. central executive control network). Podana so tudi priporočila za bodoče raziskovanje na podlagi vrzeli in nedoslednosti v obstoječi literaturi in metodologiji.

Metoda: V bazah podatkov PubMed, PsycINFO, Scopus, Web of Science idr. smo pregledali študije o hipnozi, ki so bile izvedene s pomočjo fMR tehnologije. Članke, objavljene v angleščini, smo strokovno pregledali glede na merila za upravičenost. Nato smo podatke o študijah zbrali v standardiziran obrazec, kakovost pa ocenili z uporabo lestvice Newcastle-Ottawa. Izvedli smo kvalitativno sintezo, osredotočeno na učinke hipnoze na konektivnost znotraj in med možganskimi omrežji za stanje mirovanja, poudarjanje in izvršitev.

Rezultati: Merila za vključitev je izpolnjevalo 35 študij (n=689 udeležencev). Pri pregledu smo ugotovili heterogene učinke hipnoze na mrežno konektivnost,

pri čemer so, odvisno od uporabljenih sugestij, poročali tako o povečani kot tudi o zmanjšani konektivnosti. Izsledki kažejo na možne terapevtske učinke pri bolečini in tesnobi, vendar se je to v neposredni klinični praksi le delno potrdilo. Predhodne ugotovitve kažejo, da hipnoza vpliva na konektivnost med omrežji za poudarjanje in izvršitev, s čimer spodbuja regulacijo interoceptije in afekta od zgoraj navzdol. Zmanjšana konektivnost se je pokazala tudi v področjih, kot sta posteriorna cingularna skorja in precuneus, ki so povezana s stanjem mirovanja in spontanimi notranjimi introspektivnimi procesi (tj. mišljenjem, ki ni vezano na fizične ali mentalne naloge in ni povezano z zunanjimi dražljaji).

Zaključki: Čeprav se v literaturi pojavljajo različni protokoli in rezultati, ugotovitve na splošno kažejo, da hipnoza od zgoraj navzdol vpliva na notranje introspektivne procese, nadzor pozornosti in čustveno procesiranje s spreminjanjem funkcionalnih interakcij med kortikalnimi in subkortikalnimi možganskimi področji. Nedoslednosti, ki izhajajo iz metodoloških razlik in heterogenosti študij, omejujejo dokončne sklepe. Odpravljanje teh omejitev s standardiziranimi protokoli in primerjavami, ki temeljijo na univerzalni taksonomiji velikih možganskih omrežij, bi utrdilo dokaze o nevronskega podpisu hipnoze in povečalo njeno uporabnost v različnih kontekstih.

Ključne besede: hipnoza, funkcijska magnetna resonance, velika možganska omrežja, funkcijska konektivnost, hipnotibilnost

1.

Introduction

The modern clinical application of hypnosis originated in the 18th century with Franz Mesmer, evolved through the 19th century with contributions from figures like James Braid and Sigmund Freud, and gained widespread use in the 20th century, particularly for pain control and psychological trauma (Pintar & Lynn, 2009). Braid pioneered the 'eye-fixation' technique that involved having the subject focus their gaze on a bright object positioned a few inches above eye level, which induces a state of deep concentration and facilitates the hypnosis. Milton H. Erickson (1901-1980) further advanced the field in the mid-20th century by employing indirect suggestion, metaphor, and storytelling to facilitate trance states and therapeutic change. His techniques were highly individualized and often involved utilizing the patient's own experiences and language patterns to help them access resources within their unconscious mind for problem-solving and healing (Erickson & Rossi, 1979).

Hypnosis is employed in modern clinical settings with a diverse range of applications, including Irritable Bowel Syndrome (IBS), dental phobias, preoperative anxiety and postoperative pain, often serving as an adjunctive treatment

in these medical and psychological settings. It has also shown promise in treating gastrointestinal and dermatological conditions, sleep disorders, and various paediatric issues such as bedwetting and anxiety (Pajntar et al., 2013).

Building on this historical and clinical context, the current paper aims to extend our understanding of hypnosis by presenting new findings from functional magnetic resonance imaging (fMRI) studies, specifically focusing on the neural signature of hypnosis and its link to the triple network model of psychopathology. Situating this literature review at the intersection of hypnosis neuroimaging research and ongoing developments in large scale brain network discussions creates a distinctive contribution in examining the convergence of these domains of clinical and network neuroscience.

1.1. Definitions of hypnosis

Hypnosis, as defined by the American Psychological Association, is a unique state of consciousness (APA Division 30, 2014). It is characterized by focused attention, reduced peripheral awareness, and an enhanced capacity to respond to suggestions. The process to induce this state is termed 'hypnotic induction'. An individual's susceptibility to undergo these changes during hypnosis is referred to as 'hypnotizability'.

While these definitions provide a foundational understanding, the exact neuro-physiological processes underpinning hypnosis and its classification as a 'state' are still debated (Možina, 2022). State theories of hypnosis argue that a unique psychological state is induced, fundamentally altering cognitive processes. Key among these is Hilgard's Neodissociation theory (Lynn & Rhue, 1991), which posits that hypnosis creates a dissociation in the executive control system (ECS), allowing hypnotic suggestions to act on a dissociated part of the ECS. Neurophysiological models like Gruzelier's further emphasize changes in brain function and attention during hypnosis. On the other hand, non-state theories contend that hypnosis does not induce a unique state but is shaped by social and cognitive factors. Spanos' Socio-Cognitive Theory argues that hypnotic behaviour is influenced by attitudes, beliefs, and expectancies, while Kirsch's Response Expectancy Theory focuses on the role of the subject's expectations in shaping their hypnotic experience. Integrative theories like Cold Control Theory and Brown & Oakley's model aim to reconcile these divergent views by incorporating elements from both state and non-state theories. They suggest that both altered cognitive states and social-cognitive factors contribute to the hypnotic experience.

Differences in definitions of hypnosis are also linked to differences in the way hypnosis is researched, where two main approaches prevail: 1) Intrinsic studies

aimed at understanding the nature of hypnosis itself. 2) Instrumental studies using hypnosis as a tool to investigate normal psychological processes (Halligan & Oakley, 2013). Due to advances in technology, neuroimaging studies have begun to map out the unique neural correlates of hypnosis, but with contradictory conclusions, as was found in a meta-analysis by Landry et al. (2017). There are still debates as to whether hypnosis represents a unique "altered state" of consciousness. Vaitl et al. (2005) described altered states as temporary changes in subjective experience and brain function that differ from normal waking consciousness, characterized by changes in various aspects of consciousness and associated with changes in brain dynamics. Comparisons to other "altered states" like meditation have shown different results depending on variations in instructional method, subject experience, focus direction, depth of trance, etc. (Lynn et al., 2015; Halsband & Wolf, 2021). The variability in how individuals experience hypnosis could be attributed to socio-cognitive factors like their susceptibility to non-hypnotic suggestions, motivation, and pre-existing beliefs (Lynn et al., 2015). Additionally, since induction techniques and suggestions are not uniform (Landry et al., 2017), the psycho-physiological response might differ from one person to another.

1.2. Hypnosis as a top-down process

The prefrontal cortex enables top-down control of sensory experiences and perceptions through its extensive connections with sensory, limbic, and thalamic regions. This highlights the brain's remarkable proficiency for meta-cognitive control and capability to transform mental representations into tangible perceptions and experiences (Terhune et al., 2017). This process of cognitive integration can be guided by a top-down approach to directing attention to select, filter and prioritize behaviourally relevant inputs from the environment. In this manner, by leveraging our meta-cognitive abilities, hypnosis serves as a valuable tool in pain management (hypnoanalgesia) and psychotherapeutic settings. It has been of primary interest in clinical settings due to its downstream effects, especially in suppressing networks tied to fear and pain, processing (Halsband & Wolf, 2021; Bicego et al., 2021) in the limbic system, brainstem, thalamic and cortical regions.

1.3. Large scale brain networks

Large-scale brain networks refer to distributed brain systems comprised of interconnected regions that interact to perform cognitive functions (Bressler & Menon, 2010). Structural networks are defined by the physical properties of brain regions (cytoarchitecture) and their physical connections (white matter

pathways). Functional networks, on the other hand, focus on the dynamic interactions between brain regions, which can be based on task-related activations or spontaneous coordinated activity (intrinsic connectivity). In functional networks, edges represent functional relationships like correlation or synchrony. Notable examples include intrinsic functional networks like the default mode, central executive, and salience networks, which display small-world topology conducive to both localized and distributed cognitive processing. Small-world topology refers to a network architecture that combines both localized clustering of connections and short path lengths between nodes, enabling efficient information processing and integration across diverse brain regions.

The field of large-scale brain networks is currently marked by a series of challenges that inhibit a cohesive understanding of how clusters of brain regions interact to facilitate cognitive functions (Uddin et al., 2019). Despite advancements in neuroimaging technologies like fMRI, which have been instrumental in mapping brain structures to their respective functions, the field lacks uniform definitions, naming protocols, and functional characterizations for these networks.

The survey study by Uddin et al. (2023) provides empirical evidence showing variability in how researchers label some of the most commonly studied networks like the default mode network. The authors argue for adopting more anatomically-grounded network labels and using existing parcellation schemes as references to facilitate integration across studies. However, as discussed by Bressler & Menon (2010), functional networks are dynamically configured and shaped by cognitive demands, meaning strict anatomical labels may not fully capture context-dependent reorganization. Bressler & Menon (2010) note the importance of developmental and learning processes in shaping each person's functional network architecture. Uddin et al. (2023) recommend using probabilistic atlases to represent inter-individual variability in spatial topography and network affiliation. However, they acknowledge that current techniques for mapping individual networks have limitations and biases that warrant further research. Capturing individual network variability is also key for understanding variations across the lifespan and in clinical groups (Bressler & Menon, 2010).

This fragmentation is not merely a semantic issue; it impacts both academic investigations aimed at enhancing cognitive neuroscience theories and clinical applications for diagnosing and treating mental disorders. Two core theoretical debates dominate the field at present. The first pertains to the accurate description of these networks, particularly given their dynamic behaviour, the variability from one individual to another, and the possibility of further subdivisions into sub-networks. The second debate focuses on how to integrate

multi-modal data, incorporating not just fMRI, but also other neuroimaging techniques like diffusion tensor imaging (DTI) and electroencephalography (EEG), to construct more comprehensive network models.

To move forward, several steps have been proposed. Standardizing naming conventions for these networks and generating probabilistic atlases to capture inter-individual variability could offer more structured approaches for future research (Uddin et al., 2023). Investigating developmental trajectories in these networks, as well as fostering greater inter-lab collaboration, are also considered important for the field's maturation. Moreover, there is a growing recognition that understanding global brain connectivity is crucial for an understanding of overall neural states, especially in research of various psychopathologies and altered states like hypnosis.

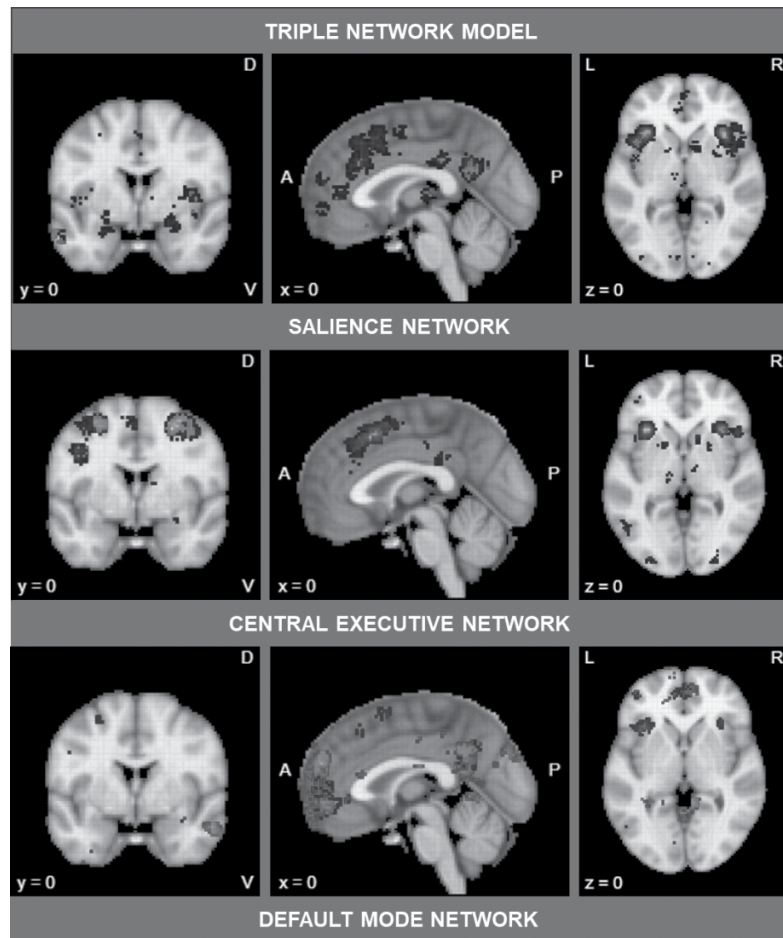
2.

The triple network model of psychopathology

The triple network model (Menon, 2011) proposes that dysfunction in three interconnected brain networks involved in salience mapping, introspective thought, and cognitive control contributes to symptoms across psychiatric disorders. While each disorder has unique clinical features, common network disruptions manifest in different ways, so examining shared neural deficits could inform more effective treatments. Its main components are the Salience network (SN), default mode network (DMN), and central executive network (CEN), shown in Figure 1.

Figure 1

Three networks that are proposed to play a key role across psychiatric disorders. The images have been downloaded from the automated Neurosynth.org (2023) meta-analysis of the terms default mode network, salience network, and frontoparietal network (the term FPN was used instead of Central Executive Network due to nonstandardized issues with naming large scale brain networks). The salience network is a representation of the meta-analysis of 126 studies, Central Executive Network (FPN) of 116 studies, and default mode of 96 studies.



2.1. Salience Network (SN)

The SN, which includes the anterior insula and dorsal anterior cingulate cortex (Menon & Uddin, 2010), is crucial for discerning and prioritizing salient stimuli, facilitating network transitions, overseeing emotional processing, empathy, social cognition, and initiating behavioural responses to significant events. Across disorders, a consistent finding is insular dysfunction marked by reduced connectivity within the SN. This is evident in schizophrenia during acute

psychosis and remission (Manoliu et al., 2013b), major depressive disorder (Manoliu et al., in review), and post-traumatic stress disorder (PTSD) (Leroy et al., 2021). Aberrant SN connectivity also correlates dimensionally with symptom severity, linking to positive symptoms in schizophrenia (Krishnadas et al., 2014) and depressive symptoms in major depressive disorder (Manoliu et al., in review). This highlights insular abnormalities within the SN as a potential transdiagnostic marker. SN dysfunction is proposed to hamper the effective coordination of network dynamics.

2.2. Default Mode Network (DMN)

The DMN is anchored in the medial prefrontal cortex and posterior cingulate cortex and is involved in internally-focused cognition (Buckner et al., 2008). DMN governs introspective activities, mind-wandering, theory of mind, moral reasoning, emotional regulation, memory consolidation, and baseline environmental monitoring, serving as a bridge between our internal thought processes and external perceptions. DMN dysfunction marked by altered within-network connectivity is consistently found in schizophrenia (Krishnadas et al., 2014), major depressive disorder (Manoliu et al., in review), and dissociative identity disorder (Lebois et al., 2022). In particular, hyperconnectivity of the posterior DMN relates to re-experiencing symptoms in PTSD (Leroy et al., 2021) and dissociative symptoms in dissociative identity disorder involving perceptual and memory disturbances (Lebois et al., 2022). This matches the DMN's functions in episodic memory and visual imagery. Other studies also show hyperactivity and hyperconnectivity of the DMN in depression and schizophrenia (Sheline et al., 2009; Whitfield-Gabrieli & Ford, 2012; Zhou et al., 2020).

2.3. Central Executive Network (CEN)

The CEN encompasses dorsolateral prefrontal and posterior parietal regions, and handles externally-focused attention and cognitive control (Seeley et al., 2007). The CEN is pivotal for higher-order cognitive functions like goal-directed attention, working memory, and decision-making, suppressing distractions, facilitating swift information processing, and coordinating with other networks for adaptive behavioural responses to environmental cues. Studies show CEN hyperconnectivity in schizophrenia (Krishnadas et al., 2014), dissociative identity disorder (Lebois et al., 2022), and chronic pain (De Ridder et al., 2022). In dissociative identity disorder, lateral prefrontal hyperconnectivity associates with executive function deficits when dissociated self-states intrude into awareness (Lebois et al., 2022). The findings of CEN activation patterns fit with its role in tonic cognitive control which may become dysregulated.

2.4.

Network interactions and psychopathology

Critically, the triple network model proposes that aberrant SN dysfunction disrupts normal interactions between the DMN and CEN. This is a consistent finding, with altered DMN-CEN connectivity in schizophrenia (Manoliu et al., 2013a), major depressive disorder (Manoliu et al., in review), Alzheimer's disease (Meng et al., 2022), and bipolar disorder (Wang et al., 2020). Dynamic changes in network interactions also occur in schizophrenia (Supekar et al., 2019) and Alzheimer's disease (Meng et al., 2022). Crucially, insular dysfunction correlates with aberrant DMN-CEN interactions in schizophrenia and major depressive disorder (Manoliu et al., 2013a; Manoliu et al., in review), directly linking SN abnormalities to impaired cross-network coordination. The study by Liu et al (2017.) found that individuals with PTSD after a mining disaster had reduced connectivity in nodes of the CEN, DMN, and SN compared to resilient controls. Akiki et al. (2018) propose that in PTSD the DMN and CEN are hypoactive and weakly connected, contributing to intrusive symptoms and emotional control deficits, while the SN is hyperactive and has a low threshold for perceiving threats. Bolton et al. (2020) propose that dysfunction in the right anterior insula's role in transitioning between the CEN and DMN networks may contribute to the onset of psychosis by disrupting the ability to distinguish between internal and external realities, leading to inflexibility and heightened internal awareness. The review by De Ridder et al. (2022) aligns the lateral, medial, and descending pain pathways with the central executive, salience, and default mode networks respectively; it proposes aberrant interactions between these pain networks, particularly deficient descending inhibition, underlie the transition from acute to chronic pain. Dysfunctional connectivity between the salience network and default mode network, as well as between the somatosensory cortex and central executive network, contributes to pain chronification.

The triple network model elucidates how insular dysfunction (SN) and aberrant network interactions result in unstable engagement of the DMN and CEN, which may underpin cognitive-affective deficits in various psychopathologies. While disorders have unique symptoms, this unifying framework emphasizes shared network disruptions. The model provides key candidate networks as targets for monitoring, diagnosis, and potential neuromodulatory treatment across psychiatric disorders. Having established the importance of the triple network model, it is crucial to consider how current literature addresses its relationship with hypnosis.

2.5.

Constraints of existing literature on the neural correlates of hypnosis

Halligan & Oakley (2012) in their review characterized a discernible hypnotic state mediated by alterations in DMN activity, suggesting that hypnotic suggestions exert a modulatory influence on pain perception through engagement of distinct neural substrates. These include hypoactivation in the sensorimotor cortex and hyperactivation in the anterior cingulate cortex, insula (SN) and prefrontal cortex (CEN), when compared to voluntary movements. They highlighted the utility of hypnosis as an experimental paradigm for simulating neurological disorders like neglect and conversion paralysis in neurologically healthy populations.

Sridharan et al. (2008) showed that activating the CEN during complex cognitive tasks consistently deactivates the DMN. In a study of resting state functional connectivity by Hoeft et al. (2012) individuals who were highly susceptible to hypnosis showed a stronger functional connection between the left dorsolateral prefrontal cortex, and the SN. This elevated connectivity was confirmed specifically between the dorsal anterior cingulate cortex and the dorsolateral prefrontal cortex, and these functional differences were not attributed to any structural variations in brain tissue.

Cojan et al. (2015) inferred that highly hypnotizable subjects may exhibit greater right inferior frontal gyrus (part of CEN) functional connectivity with the DMN. This would allow greater cognitive flexibility and dissociation by modulating the link between external and internal processes. The right inferior frontal gyrus is associated with inhibiting task-irrelevant stimuli and related behavioural (motor) responses (Boen et al., 2022; Tiego et al., 2018). This is critical for behavioural control and flexibility in social cognition across aspects like motor preparation, uncertainty appraisal and empowering action initiation in response to stimuli (Boen et al., 2022).

Contrary to these studies pointing to executive control network and top-down mechanisms, Landry et al. (2017) in their meta-analytic study correlated sensory processing as a more reliable hypnosis marker, not executive functions. They showed that hypnosis predominantly activated the lingual gyrus, a key region for visual imagery and processing complex visual stimuli. This could reflect either intrinsic visual components or the nature of the suggestions used in the studies. They acknowledged that meta-analyses can miss the heterogeneity and nuances inherent to hypnotic states, and highlighted the need for standardized imaging methods to better understand the neural correlates of hypnosis. It is worth noting that Spagna et al. (2020) in their meta-analysis of mental imagery unrelated to hypnosis found that prefrontal regions initiate

the necessary processes for mental imagery. This contrast indicates that neural processes underlying hypnosis and visual mental imagery might differ, with hypnosis engaging lingual gyrus that is not responsible for pure mental imagery, at least not without involvement of frontoparietal regions.

Important questions remain regarding the specificity of neurocognitive correlates of hypnotic suggestibility and the way in which suggestions influence internal mentation. High hypnotic suggestibility may involve atypical prefrontal and anterior cingulate functioning and connectivity as well as diminished metacognition (Terhune et al., 2017). Faerman & Spiegel (2021) proposed that hypnotizability involves similar cognitive mechanisms as resolving cognitive conflict and applying learned rules to new situations.

Specifically, error evaluation, mediated by the anterior cingulate cortex (Gawłowska et al., 2018), and implementing logical rules, involving the posterior medial frontal cortex and caudate nucleus (Danielmeier et al., 2011; Tachibana et al., 2009), may relate to hypnotizability. Doi et al. (2020) proposed the caudate nucleus (part of basal ganglia) may integrate ambiguous stimuli and reward context. Connectivity between the posterior medial frontal cortex and caudate nucleus was pronounced during feedback when subjects determined a specific rule, highlighting their interaction during rule identification (Tachibana et al., 2009). This suggests hypnotizability may share cognitive capacities for appraising expected vs. actual outcomes and applying abstract rules, key skills modulated by the anterior cingulate cortex, posterior medial frontal cortex and caudate nucleus.

3. Knowledge gap and rationale for review

Prior neuroimaging studies have associated hypnotizability with activation patterns in regions within the SN, DMN, and CEN (Hoeft et al., 2012; Jiang et al., 2017; Cojan et al., 2015). Abnormalities within these same triple networks have also been independently linked to symptoms across a range of psychiatric disorders (Krishnadas et al., 2014; Leroy et al., 2021; Lebois et al., 2022). However, few studies have linked the results of fMRI studies of hypnosis and modulation of connectivity through the lens of the triple network model despite their supposed mutual relevance. Examining fMRI results of hypnosis studies systematically using the triple network framework may shed light on common mechanisms contributing to both hypnotizability and manifestations of psychopathology (Manoliu et al., 2013a; Manoliu et al., in review). Understanding dynamic connectivity within and between the SN, DMN and CEN during hypnosis could provide key insights into the neural mechanisms underlying this unique state

of consciousness, extending theories on the neural bases of cognitive control, internal awareness, and self-processing (Hoeft et al., 2012; Jiang et al., 2017; Terhune et al., 2017). By mapping functional alterations in the triple networks onto connectivity disruptions observed in conditions like depression and PTSD may elucidate novel brain-based targets for hypnotherapeutic interventions in treating psychiatric symptoms (Lebois et al., 2022; Leroy et al., 2021).

This paper aims to address this knowledge gap by qualitatively synthesizing the evidence from heterogeneous studies on neural correlates of hypnosis and its connection to functional connectivity within and between the salience, executive, and default mode networks. Based on existing evidence, it is expected that hypnosis will modulate connectivity between prefrontal executive regions and the salience network, potentially regulating the balance between external sensory processing and internal mentation. It is also expected that the pattern of network effects will differ based on hypnotizability and other individual differences. This knowledge could inform optimized, network-based applications of hypnosis in treating various conditions, and could help in refining therapeutic approaches and optimizing outcomes for patients.

4. Hypotheses

Based on the existing literature and the identified knowledge gaps, the hypotheses are:

1. Clinical hypnosis exerts discernible effects on the connectivity within and between the components of the triple network model, namely the DMN, SN and FPN.
2. The magnitude and nature of these effects are modulated by individual differences in hypnotizability, connectome and the structural morphology of the brain, the specific induction methods employed, and the type of suggestions provided.
3. The observed alterations in network connectivity during hypnosis can offer insights into the neural underpinnings of various psychiatric disorders, potentially guiding therapeutic interventions.

5. Methods

5.1. Eligibility criteria

A comprehensive search was conducted in relevant databases and only peer-reviewed articles that used fMRI to investigate hypnosis were included. The review excluded case studies or reviews. Inclusion criteria were: studies with

primary research conducted on human participants, available in full-text format, written in English, and examination of hypnosis by fMRI. The review included both resting state and task-based neuroimaging studies. Exclusion criteria were: reviews, editorials, letters, non-English articles, animal studies, single subject studies, and studies without full-text availability.

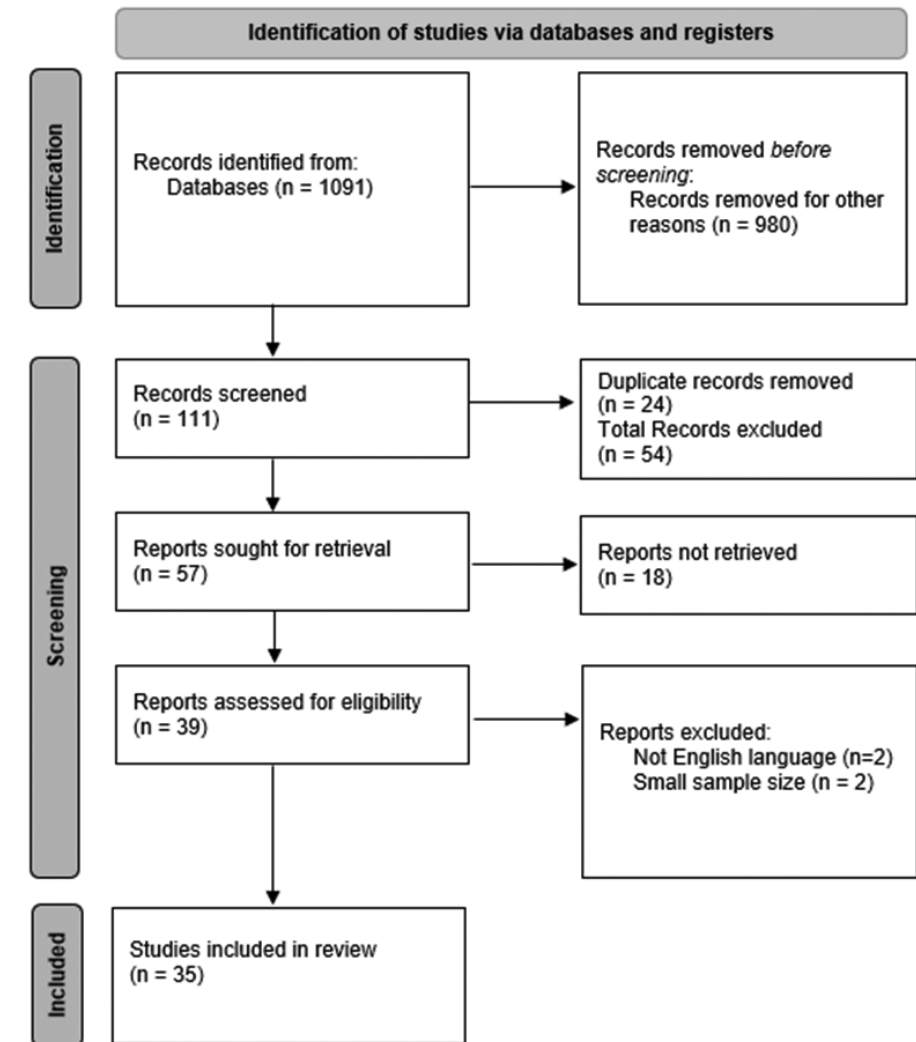
5.2.

Search strategy

Electronic search was done using Herzing Publish or Perish software to retrieve all titles and abstracts of the articles. The full electronic search strategy is provided in Supplementary data (available on request). The final search was conducted on 31 July 2023. For screening and selection relevant databases have been searched (details in Figure 2); PubMed, PsycINFO, Research Gate and Scopus. The search strategy included a combination of controlled vocabulary terms (MeSH in PubMed, Thesaurus terms in PsycINFO) as well as free-text keywords relevant to the research questions

The data bases were searched during the period of May to July 2023. Reference lists of eligible articles were hand-searched for additional relevant records. Grey literature was also searched using Google Scholar and OpenGrey. Out of 111 studies selected for preliminary screening, 54 were removed due to duplication or non-eligibility. Articles that were excluded due to being off-topic upon full-text assessment, review articles, or were published in languages other than English (where the abstract was in English, but not the study itself) are listed in supplementary data with full search strategy. A total of 35 full-text articles were reviewed in-depth to establish their suitability for inclusion in this review.

Figure 2
PRISMA 2020 flow diagram



5.3. **Studies Included in Qualitative Synthesis**

Table 1
List of full text articles that were included in review

Study ID	Imaging technique	Sample Size (N)	Hypnotizability scales used
Abrahamsen et al. (2011)	fMRI	19	HGSHS:A
Burgmer et al. (2013)	fMRI	19	SHSS
Casiglia et al. (2018)	fMRI	20	HGSHS:A
Casiglia et al. (2019)	fMRI	20	SHSS:A
Cojan et al. (2009)	fMRI	18	HGSHS:A, SHSS:C
Deeley et al. (2012)	fMRI	15	HGSHS:A, SHSS:C
Deeley et al. (2013c)	fMRI	8	HGSHS:A
Deeley et al. (2013b)	fMRI	15	HGSHS:A
Deeley et al. (2013a)	fMRI	8	HGSHS:A
Demertzi et al. (2011)	fMRI	12	None reported
Derbyshire et al. (2009)	fMRI	13	HGSHS:A
Desmarteaux et al. (2021)	fMRI and ASL	24	SHSS:A
Egner et al. (2005)	fMRI and EEG	22	HGSHS-A,SHSS-C
Halsband & Wolf (2016)	fMRI	24	HGSHS
Huber et al. (2014)	fMRI	37	SHSS:A
Jiang et al. (2017)	fMRI	57	HGSHS:A, HIP
Ketai et al. (2021)	fMRI	30	Not reported
Li et al. (2019a)	fMRI	24	SHCS
Li et al. (2019b)	fMRI and EEG	24	SHCS
Lifshitz & Raz (2015)	fMRI	16	HGSHS:A,SHSS:C
Liu et al. (2018)	fMRI	8	None reported
Liu et al. (2020)	fMRI	15	SHSS:C
Lowén et al. (2013)	fMRI	16	Not reported
Ludwig et al. (2014)	fMRI	16	HGSHS:A
McGeown et al. (2015)	fMRI	29	CURSS
Mendelsohn et al. (2008)	fMRI	23	SHSS, HIP
Moujaes et al. (2023)	fMRI	30	None reported
Müller et al. (2013)	fMRI	16	HGSHS:A

Study ID	Imaging technique	Sample Size (N)	Hypnotizability scales used
Pyka et al. (2011)	fMRI	19	SHCS
Raij et al. (2005)	fMRI and EEG	14	SHSS:C
Raij et al. (2009)	fMRI	14	SHSS:C
Raz et al. (2005)	fMRI	16	SHSS:C, HGSHS:A
Vanhaudenhuyse et al. (2009)	fMRI	12	SHCS
Walsh et al. (2015)	fMRI	18	HGSHS:A
Walsh et al. (2017)	fMRI	18	HGSHS:A

5.4. **Data extraction**

A standardized data extraction form was developed to extract relevant information from the included studies. Data extracted includes study characteristics (e.g., authors, year of publication), participant characteristics (e.g., sample size, hypnotizability scales used, hypnotizability scores) and findings of neural imaging.

5.5. **Quality assessment**

In evaluating the risk of bias in non-randomized intervention studies, the author used the Newcastle-Ottawa Scale (NOS), a widely accepted tool for assessing study quality and bias potential. The NOS methodically evaluates studies across three key components: the selection of study groups (with a potential score of 4 points), the comparability of study groups (with a potential score of 2 points), and the assessment of the outcome (with a potential score of 3 points). Higher NOS scores indicate lower bias risk, allowing for categorization of study quality. Results are reported in Figure 3 below:

Table 2
The Newcastle-Ottawa Scale (NOS) results

Study	Selection Score	Comparability Score	Outcome Score	Total NOS Score	Risk of bias
Abrahamsen et al. (2011)	3	2	3	8	Low
Burgmer et al. (2013)	3	2	3	8	Low
Casiglia et al. (2018)	3	2	3	8	Low
Casiglia, E., et al. (2019).	3	2	3	8	Low
Cojan et al. (2009)	3	2	3	8	Low
Deeley et al. (2013c)	3	2	3	8	Low
Deeley et al. (2013b)	2	2	3	7	Low

Study	Selection Score	Comparability Score	Outcome Score	Total NOS Score	Risk of bias
Deeley, Q., et al. (2012).	3	2	3	8	Low
Deeley, Q., et al. (2013a).	3	2	3	8	Low
Demertzi, A., et al. (2011).	3	1	3	7	Low
Derbyshire, S.W., et al. (2009).	2	2	3	7	Low
Desmarteaux, C., et al. (2021).	3	1	3	7	Low
Egner, T., et al. (2005).	3	1	3	7	Low
Halsband, U., & Wolf, T.G. (2016).	2	2	3	7	Low
Huber et al. (2014)	2	2	3	7	Low
Jiang, H., et al. (2017).	2	2	3	7	Low
Ketai et al. (2021)	2	2	3	7	Low
Li, X., et al. (2019).	3	1	3	7	Low
Li, X., et al. (2019).	2	2	3	7	Low
Lifshitz, M., & Raz, A. (2015).	2	2	3	7	Low
Liu et al. (2020)	3	2	3	8	Low
Liu, Y., et al. (2018).	2	1	3	6	Moderate
Lowén et al. (2013)	2	1	3	6	Moderate
Ludwig et al. (2014)	3	2	3	8	Low
McGeown, W.J., et al. (2015).	3	2	3	8	Low
Mendelsohn, A., et al. (2008).	3	1	3	7	Low
Moujaes, F.F., et al. (2023).	3	0	3	6	Moderate
Müller et al. (2013)	3	1	3	7	Low
Pyka, M., et al. (2011).	2	1	2	5	Moderate
Raij et al. (2005)	3	1	3	7	Low
Raij et al. (2009)	2	0	3	5	Moderate
Raz et al. (2005)	2	1	2	5	Moderate
Vanhaudenhuyse, A., et al. (2009).	3	1	2	6	Moderate
Walsh et al. (2015)	2	0	3	5	Moderate
Walsh et al. (2017)	3	1	3	7	Low

6. Large scale brain network taxonomy

For the need of study result synthesis and reporting the cerebral cortex network Uddin et al. (2019) proposed taxonomy was adopted, with its focus on Lateral Frontoparietal Network, Midcingulo-insular Network and Medial Frontoparietal Network that are key for the Triple Network Model of Psychopathology. This was done to ensure some degree of standardized labelling of research findings. The taxonomy of six large-scale brain networks proposed by Uddin et al. (2019) serves as a valuable framework for classifying neuroimaging findings related to hypnosis. It provides a consistent anatomical naming scheme that facilitates cross-study comparison and integrates with broader neurological literature. Covering major functional systems, the framework is comprehensive enough to examine the effects of hypnosis on various brain systems and is versatile in accommodating both task-based and resting-state fMRI studies. The taxonomy aids in linking hypnosis effects to specific brain subsystems related to phenomena like absorption and dissociation. This proposed taxonomy stands as an initial but adaptable framework that aids in synthesizing existing data while allowing for future refinements in the field.

Table 3
Large scale brain networks proposed by Uddin et al. (2019) and their descriptions (adapted by author).

Occipital Network	Anatomical name: Occipital network (ON)
	Cognitive domain: Visual network
	Key areas: Occipital lobe, striate and extrastriate cortex, lateral geniculate nucleus of the thalamus.
	Psychological functions: Visual processing
	Behavioral functions: Visual perception, object recognition, spatial navigation
Pericentral Network	Anatomical name: Pericentral network (PN)
	Cognitive domain: Somatomotor network
	Key areas: Pre- and post-central gyri, supplementary motor cortex, auditory cortex
	Psychological functions: Motor control, somatosensation, audition
	Behavioral functions: Movement, touch, proprioception, hearing

Dorsal Frontoparietal Network	Anatomical name: Dorsal frontoparietal network (D-FPN)
	Cognitive domain: Attention network
	Key areas: Intraparietal sulcus, frontal eye fields, inferior frontal junction
	Psychological functions: Top-down attention, visuospatial orienting
	Behavioral functions: Selective attention, eye movements, working memory
Lateral Frontoparietal Network	Anatomical name: Lateral frontoparietal network (L-FPN)
	Cognitive domain: Control network
	Key areas: Lateral prefrontal cortex, anterior inferior parietal lobe, midcingulate cortex
	Psychological functions: Cognitive control, goal-directed cognition
	Behavioral functions: Planning, reasoning, inhibition, task-switching
Midcingulo-insular Network	Anatomical name: Midcingulo-insular network (M-CIN)
	Cognitive domain: Salience network
	Key areas: Anterior insula, dorsal anterior cingulate cortex
	Psychological functions: Salience detection, empathy, interoception
	Behavioral functions: Identifying relevant stimuli, social cognition, homeostasis
Medial Frontoparietal Network	Anatomical name: Medial frontoparietal network (M-FPN)
	Cognitive domain: Default network
	Key areas: Medial prefrontal cortex, posterior cingulate cortex, inferior parietal lobe
	Psychological functions: Episodic memory, prospection, theory of mind
	Behavioral functions: Recollection, imagination, mentalizing

7.

Results

7.1.

Effects of hypnosis on DMN Connectivity

Multiple studies found hypnosis impacts DMN regions' connectivity, including reduced connectivity in regions like the posterior cingulate cortex, precuneus, and parahippocampal areas (Burgmer et al., 2013; Casiglia et al., 2019; Cojan et al., 2009; Deeley et al., 2012; Demertzi et al., 2011; Jiang et al., 2017; McGeown et al., 2015; Moujaes et al., 2023). This aligns with the hypothesis that hypnosis attenuates internal mentation and mind wandering. However, Pyka et al. (2011) found no changes in the medial prefrontal DMN region during suggested hypnotic paralysis, but did identify posterior cingulate and precuneus as having a significant role in controlling motor representations. This suggests that effects on network connectivity may depend on the specific suggestions.

Increased connectivity between the dorsolateral prefrontal cortex (DLPFC) and posterior DMN regions was reported across multiple studies (Demertzi

et al., 2011; Jiang et al., 2017; McGeown et al., 2015; Pyka et al., 2011), suggesting hypnosis enhances top-down cognitive regulation over internal mental processes. Egner et al. (2005) found evidence for impaired communication between cognitive control and conflict monitoring regions in highly hypnotizable subjects. Huber et al. (2014) reported increased functional connectivity between the visual network and DMN during rest in people with higher hypnotic suggestibility. Deeley et al. (2013b) found distinct patterns of connectivity and neural activation in response to different types of control conditions, with personal control engaging theory of mind and self-processing regions, impersonal control involving object imagery and error monitoring networks, and internal and external personal control showing similarities in representing the intentions of a controlling agent. In a within-subject fMRI study with highly hypnotizable individuals Welsh et al. (2017) found reduced awareness during suggested automatic writing associated with decreased activation in parietal areas, shedding light on the neural correlates of diminished spatial and bodily awareness. This could have potential implications for understanding dissociative disorders and culturally influenced dissociative phenomena.

However, some studies did not have straightforward results in terms of specific regional connectivity that is usually labelled under DMN. Of four studies, two reported significant effects related to the DMN during hypnosis (Mendelsohn et al., 2008; Moujaes et al., 2023), while the other two did not find significant DMN connectivity changes (Pyka et al., 2011; Casiglia et al., 2019). Specifically, Mendelsohn et al. (2008) found increased activity in the left superior frontal gyrus, considered part of the DMN, during memory retrieval after reversing hypnotic amnesia. Moujaes et al. (2023) reported increased connectivity between the primary visual cortex and anterior regions of the DMN during hypnosis. In contrast, Pyka et al. (2011) found no significant changes in connectivity of the medial prefrontal cortex, a core DMN node, during hypnotic paralysis. Similarly, Casiglia et al. (2019) did not report any findings related to the DMN in their study of hypnotic analgesia. Walsh et al. (2017) found reduced connectivity between DMN regions and the supplementary motor area during experiences of thought insertion modelled by hypnosis, and highlighted the key role of the left posterior parietal cortex in reduced awareness of thought and movement. Huber et al. (2014) also reported decreased connectivity between a right frontoparietal network and the thalamus.

Within the DMN specifically, findings are limited. One study by McGeown et al. (2009) found reduced deactivation of the medial prefrontal cortex component of the DMN during a Stroop task following hypnotic suggestion, indicating reduced suspension of the DMN. The discrepancy in DMN findings may relate

to differences in the specific hypnotic suggestions used across these studies. The studies of Mendelsohn et al. (2008) and Moujaes et al. (2023) involved visual imagery and memory-related suggestions which could engage the DMN, while Pyka et al. (2011) and Casiglia et al. (2019) used motor-focused suggestions that may not modulate DMN activity. Variability in analysis methods may also contribute, as DMN connectivity was not a targeted outcome in the latter studies, as could differences in experimental tasks and suggestions used across studies.

7.2. **Effects of hypnosis on connectivity between SN and CEN**

A few studies showed hypnosis impacts connectivity between salience network hubs like the anterior cingulate cortex (ACC), anterior insula, and lateral prefrontal cortex (Desmarteaux et al., 2021; Jiang et al., 2017; Li et al., 2019). This enhanced connectivity between salience and cognitive control areas might reflect greater top-down regulation over interoceptive and affective processes during hypnotically suggested analgesia and smoking cessation.

Initial evidence shows hypnotic analgesia impacts pain-related networks (Abrahamsen et al., 2011; Casiglia et al., 2019; Ketaj et al.; Raij et al., 2009; Raij et al. 2005) and hypnosis can reduce anxiety network activity in phobias (Halsband & Wolf, 2016). During a hypnotic analgesic task (Casiglia et al., 2019), activation was seen in the dlPFC and ACC. The increased coordination between dlPFC and salience regions may allow hypnotic suggestions to more effectively modulate pain, craving, or other internally-generated states mediated by the anterior insula and ACC.

McGeown et al. (2009) found that a post-hypnotic suggestion reduced deactivation of the anterior cingulate cortex, a hub of the SN, during a cognitive control task. This indicates sustained engagement of the SN. Raz et al. (2005) similarly reported reduced activation in the anterior cingulate cortex during a Stroop task after a hypnotic suggestion, reflecting reduced cognitive control and conflict monitoring by the SN.

In a randomized controlled trial by Lowén et al. (2013), involving women with irritable bowel syndrome (IBS) and healthy controls, gut-directed hypnotherapy led to reduced activation in pain-related brain regions, including the insula and prefrontal cortex, during high-intensity rectal distension and its anticipation. This suggests that hypnosis improves patients' capacity to mentally diminish the perception of bodily sensations from the gut and/or diminishes the influence of emotional factors in intensifying sensory experiences.

7.3. **Other functional connectivity findings**

Some studies demonstrated altered connectivity between sensory cortices and higher-order associative areas during hypnosis (Halsband & Wolf, 2016; Moujaes et al., 2023; Vanhaudenhuyse et al., 2009). Halsband and Wolf (2016) observed reduced connectivity between visual processing regions, such as the fusiform gyrus, and higher-order visual areas when addressing dental phobic stimuli. Increased activation was noted in the calcarine cortex, a visual area, during hypnosis (Liu et al., 2020). Moujaes et al. (2023) demonstrated decreased connectivity within the primary visual network and increased connectivity between the primary visual cortex, superior temporal gyrus, anterior default mode network, and limbic areas; additionally, Vanhaudenhuyse et al. (2009) reported increased connectivity between the primary somatosensory cortex and regions including the prefrontal cortex and insula during hypnotic analgesia. These findings suggest that hypnosis induces complex modulatory effects on connectivity between lower-level sensory cortices and higher-order multimodal areas involved in memory, emotion, language, and internal mentation. Pyka et al. (2011) identified the posterior cingulate cortex and precuneus as having a significant role in controlling motor representations during suggested hypnotic paralysis.

The supplementary motor area exhibited reduced activation in several studies involving hypnotic paralysis or loss of control over movement (Burgmer et al., 2013; Cojan et al., 2009; Deeley et al., 2013a; Deeley et al., 2013c). Casiglia et al. (2019) found that hypnotic analgesia led to reduced activity in the primary somatosensory cortex and supplementary motor area compared to pain perception without hypnosis. The study by Walsh et al. (2015) found increased cerebellum and parietal cortex activation in cases of alien control of movement, and reduced supplementary motor area (SMA) activity, implying the SMA's role in high-level executive control of thought and movement, along with distinctive functional connectivity patterns between the SMA and primary motor cortex (M1) for thought insertion and alien control of movement experiences.

A subset of studies provided evidence that individual differences in hypnotic depth and susceptibility influence the degree of connectivity changes under hypnosis (Egner et al., 2005; McGeown et al., 2015). In the study by McGeown et al. (2015), participants who reported greater depth of hypnosis showed reduced connectivity within default mode network regions compared to those who reported less hypnotic depth. This would suggest that the degree of alteration in functional connections between brain networks under hypnosis depends on an individual level of hypnotic suggestibility and how deeply they experience the hypnotic state.

The utilization of hypnosis alongside motor imagery tasks was associated by Müller et al. (2013) with heightened neural activation in regions such as the medial frontal cortex, putamen, and inferior parietal cortex, signifying enhanced attention and processing. This was particularly facilitated by increased activity in the thalamus which reflected gating of attention and arousal by hypnosis.

Individual differences in hypnotizability

Raz et al. (2005) found that a hypnotic suggestion reduced Stroop interference and anterior cingulate cortex activation during the task for highly hypnotizable but not for less hypnotizable participants. McGeown et al. (2009) found that a posthypnotic suggestion reduced Stroop interference to a greater extent in high versus low suggestible participants. Ludwig et al. (2014) reported that a posthypnotic suggestion elicited greater reductions in snack valuation and activation in value processing regions for highly suggestible individuals versus those given an autosuggestion. This also indicates hypnotizability impacts hypnotic responses. McGeown et al. (2015) found that self-reported depth of hypnosis correlated with reduced DMN connectivity and increased anterior cingulate and medial prefrontal cortex gray matter volume. This suggests highly hypnotizable individuals show greater modulation of DMN regions involved in internal mentation. Jiang et al. (2017) found that highly hypnotizable individuals displayed decreased DMN connectivity and increased connectivity between cognitive control and interoceptive networks during hypnosis compared to rest. Less hypnotizable individuals did not show these differential connectivity patterns.

Egner et al. (2005) demonstrated reduced coupling between the anterior cingulate cortex and lateral prefrontal cortex during hypnosis specifically in highly hypnotizable subjects compared to those with low hypnotizability. This implies that for highly suggestible individuals, hypnosis may decouple or disrupt normal interactions between brain regions involved in cognitive control (lateral PFC) and performance monitoring/conflict detection (ACC). The study by Huber et al. (2014) revealed that hypnotic suggestibility in healthy women is associated with distinct patterns of gray matter volume and resting state functional connectivity, particularly involving sensory-motor areas and regions related to imagery and self-processing, but it is hard to generalize on this conclusion due to the limited sample and population.

8. Discussion

8.1. Limitations

Taxonomy differences related to large scale brain networks were notably pronounced during the review. In the study by Demertzi et al. (2011), the authors used

‘default mode and extrinsic network’ relying on previous research by Golland et al (2006) that proposed neuroanatomic partitioning of the posterior cortex into two global networks based on sensory dependent activation. For example, what was grouped under Default mode network in the study by Demertzi et al. (2011) was classified under 3 different networks (FPN, MFN, PCN) by the author of this review by using a taxonomy proposed by Uddin et al (2019). This is not indicating that either of the two approaches is correct, it only shows how interpretation, sharing and communication of results is harder when there is no shared taxonomy to be relied on.

Variability in MRI scanner hardware and protocols due to continuous technological evolution across the time span of the reviewed studies (2005 to 2023.) poses significant challenges for cross-study comparisons, meta-analyses, and the generalizability of research findings. Differences in scanner field strengths, from 1.5T to 3T, introduce variables that affect comparability. Variations in imaging protocols, the use of different software packages for pre-processing and analysis further confound direct comparisons between studies. Specific implementations and optimizations, variability in statistical approaches based on study design contribute to inconsistencies in research outcomes or validity of potential cross-study comparisons. Divergent methods for functional connectivity analysis coupled with lack of comprehensive methodological details make it difficult to harmonize and compare connectivity findings, affecting reproducibility and the assessment of study quality.

The results from the Newcastle-Ottawa Scale show that most of the studies are non-randomized. Non-randomized studies are more susceptible to bias due to the absence of randomization, limiting their internal validity, potentially reducing their generalizability to broader populations or settings, complicating the establishment of causality by making it harder to rule out confounding variables, and rendering their findings lower in the hierarchy of evidence compared to randomized controlled trials, with a heightened susceptibility to publication bias favouring studies with positive results. Generalizability is limited further due to predominantly healthy participant samples rather than clinical populations. More rigorous control conditions to isolate effects of hypnosis itself are needed in study design.

Other variables that are mostly missing as points of examination in studies are subcortical regions, mirror neurons, circadian rhythm and sociocultural factors. The majority of research on hypnosis has focused on cortical regions with limited investigation into subcortical structures like the thalamus, basal ganglia, amygdala, hippocampus, brainstem, and cerebellum, with some notable exceptions (Müller et al., 2013; Ludwig et al., 2014; Walsh et al., 2015).

These subcortical regions may play a key modulatory role in hypnotizability and suggestion response particularly in functions related to motivation, arousal, motor control, and memory. Only one study (Burgmer et al., 2013) directly examined the involvement of the mirror neuron system during hypnotically-induced paralysis and found reduced activation in sensorimotor regions during movement observation and imitation under paralysis. This is a major lacuna, as mirror neurons may facilitate responses to hypnotic suggestions involving imagined or observed actions, which is especially important in a psychotherapeutic setting.

Also, none of the studies measured or controlled for the time of day or circadian factors. The time of hypnosis induction and scanning impacts the overall neurochemical and physiological state but this is not considered as a factor influencing the imaging results in any of the examined studies. Sociocultural factors like ethnicity, beliefs about consciousness and stigma towards hypnosis could strongly affect responses, but none of the studies addressed this in examining the response to hypnotic suggestion. These gaps limit generalization of results across various populations, individuals and clinical applications.

For these reasons, many findings were study-specific and showed differences based on the specific suggestions and tasks used, highlighting the context- and suggestion-dependent nature of hypnosis. Replication of findings across different studies is limited, likely due to the differences in imaging hardware, experimental paradigms, analysis methods and statistical thresholds employed. This can significantly hinder the consolidation of a unified body of evidence and may impede the field's progress by obstructing the pooling of data for more robust analyses. Therefore, standardizing methodologies, increasing transparency and unifying network taxonomies are essential for more reliable and generalizable conclusions in future research.

8.2.

Conclusion

The first hypothesis that clinical hypnosis impacts connectivity within and between default mode, salience, and executive control networks finds initial evidentiary support in the literature reviewed. Specifically, multiple studies demonstrate that hypnosis alters connectivity within default mode network regions involved in internal mentation, including reduced connectivity in hubs like the posterior cingulate cortex and precuneus. Enhanced connectivity between the default mode network and cognitive control regions like the dorsolateral prefrontal cortex has also been observed across several studies. This aligns with the hypothesis that hypnosis may allow greater top-down regulation of internal mental processes. In this regard, it may be useful for

treating maladaptive decision-making like addiction (e.g. smoking) and for pain management. Systematic investigation examining connectivity changes both within each of the triple networks and between them during hypnosis has yet to be conducted. Most studies focus on connectivity effects in one or two networks and/or their component regions. Further research is required to fully evaluate the hypothesized effects of hypnosis on connectivity patterns across the default mode, salience, and executive control network.

Existing evidence provides provisional support for the second hypothesis, as some studies have shown that individual differences modulate network effects. A significant limitation lies in the absence of direct comparisons between induction methods and the lack of connectivity analyses stratified by hypnotizability, hindering a comprehensive assessment of this hypothesis. No studies directly manipulated or analysed the effects of different induction methods.

For the third hypothesis on clinical implications, evidence shows hypnotic analgesia impacts pain-related networks and hypnosis can reduce anxiety network activity in phobias. But direct testing of therapeutic effects in patient populations compared to healthy controls is limited. Only a couple studies examine clinical samples, while most focus on healthy participants. The small sample sizes and lack of clinical populations in these studies constrain generalizability. More research is required to evaluate whether neuromodulation of brain networks under hypnosis can improve outcomes in psychiatric disorders. The current evidence provides hints but does not definitively demonstrate the proposed clinical relevance.

fMRI studies have provided deeper insights into the neural correlates of hypnosis, but variability in protocols and lack of standardization make cross-study comparisons challenging. As MRI hardware and analysis methods improve, newer studies need to optimize and validate their protocols while maintaining enough methodological commonality with previous work to enable replications and meta-analyses. Detailed reporting of protocols and analysis procedures is essential. Resolving the issues of taxonomy of large-scale brain networks also requires a multi-faceted approach, which includes adopting standardized reporting metrics, facilitating cross-lab collaborations, and continuously reassessing data and theoretical frameworks. Only by addressing these taxonomic and research challenges can the field hope to build a universal classification system, thereby enabling more robust cross-study comparisons and fostering progress in cognitive and clinical neuroscience.

There is potential for hypnosis to address executive functioning deficits and model psychiatric symptoms, yet the absence of extensive clinical testing in relevant patient populations underscores the need for further research and

validation. While neural changes induced by hypnosis suggest therapeutic possibilities, the current literature lacks robust clinical support for clinical application, with the notable exception of pain management. Direct clinical support and testing of applications in terms of the triple network model of psychopathology remains sparse in the covered literature. In practical terms, clear communication of intended goals of hypnosis, assessing hypnotizability, considering the sociocultural factors and forming a strong therapeutic relationship remain the key tenets for the effective clinical use of hypnosis.

This study has achieved its first objective, conducting a qualitative synthesis of the fMRI literature about neural correlates of hypnosis. Employing quantitative meta-analysis which would require narrowing the criteria in a very heterogeneous subject, may be unsuitable due to challenges in aggregating diverse data, undermining statistical validity, and potentially obscuring meaningful findings, thereby limiting its generalizability and accuracy. In addressing the second objective, which involves the assessment of triple network connectivity, there has been some progress, but a more systematic and focused approach is needed for a comprehensive exploration. Additionally, while the third objective of providing recommendations has been met, enriching the discussion with insights into clinical implications would enhance the overall strength of this objective.

8.3. **Proposals for further research**

Key avenues for future research include network-focused connectivity analyses, systematic comparisons based on hypnotizability and induction methods, and extension into clinical populations. Refining methodologies will help produce more definitive tests of the stated hypotheses. It is imperative to adhere to a set of rigorous methodological guidelines that enhance the replicability, clarity, and generalizability of the results for specific clinical populations. The methodology section should elucidate the specific parcellation schemes and analytic techniques that were employed for network identification to foster transparency and facilitate the comparison of results across multiple studies. It should also include the description of hypnosis induction and suggestion protocols, and previous experience of subjects with hypnosis. The influence of subcortical regions on the cortical networks under study should not be overlooked. Attention should be paid to elucidating how these regions may modulate the hypnotic state and clinical outcomes. Collecting diverse data, including physiological measures (e.g., heart rate, skin conductance), and subjective reports, is essential in order to comprehensively measure brain states related to hypnosis; integrating these datasets facilitates a holistic understanding of hypnosis and enables rigorous statistical analysis, enhancing the validity of findings.

In terms of data sharing, it is advisable to consult and reference standard atlases in the field when labelling large scale brain networks, rather than exclusively relying on cognitive or functional labels like 'default mode'. Providing anatomical labels in conjunction with functional ones could offer additional clarity and facilitate a more robust understanding of the networks. Furthermore, any deviations in network topography or variations in connectivity strength from established atlases should be thoroughly discussed, particularly if they pertain to regions such as the prefrontal and parietal cortices where individual variability tends to be high.

Complementing fMRI data with evidence from other modalities like electroencephalography (EEG) can provide a more comprehensive view of network function. This multimodal approach would help to situate the study within a broader context, thereby increasing its scientific merit. Standards for data sharing and network analysis reporting should be cited to lend further credibility to the study. The ultimate objective of any research in this domain should be to meticulously characterize the networks under investigation and to situate these findings within the broader scientific literature. Such an approach is particularly important given the current challenges associated with replicating and comparing network neuroscience results across different studies.

9. **Concluding statement**

This literature review shows that hypnosis is a context and suggestion dependent phenomenon with individual variability, aligning with the insight of Graham Barnes (2002), who emphasized exactly the context-dependent nature of hypnosis in his work on psychotherapy. It synthesizes evidence on the neural correlates of hypnosis, focusing on functional connectivity changes within and between large-scale brain networks. The findings tentatively support the theory that hypnotic suggestions exert top-down influence on internal mentation, attentional control, and emotional processing through altering functional interactions between cortical and subcortical brain regions. Connection to the triple network model of psychopathology cannot be sufficiently proved by the existing body of evidence, but there is evidence that this might be an area worthy of further exploration. Hypnosis in this regard could be used to model some psychiatric phenomena like dissociation, which could be useful in a study of various psychopathologies with similar neural signatures. However, variations in protocols and limited clinical outcomes constrain conclusions. By highlighting gaps, this review informs future research needed to elucidate the neurocognitive mechanisms and clinical potential of hypnosis.

References

Abrahamsen, R., Dietz, M., Lodahl, S., Roepstorff, A., Zachariae, R., Østergaard, L., & Svensson, P. (2011). Effect of hypnotic pain modulation on brain activity in patients with temporomandibular disorder pain. *Ugeskrift for Laeger*, 173(6), 442-452.

Akiki, T. J., Averill, C. L., & Abdallah, C. G. (2017). A Network-Based Neurobiological Model of PTSD: Evidence From Structural and Functional Neuroimaging Studies. *Current Psychiatry Reports*, 19(11). <https://doi.org/10.1007/s11920-017-0840-4>

American Psychological Association (APA) Division 30, Society of Psychological Hypnosis. (2014). Hypnosis: What it is and how it can help you feel better [Brochure].

Barnes, G. (2002). Hypnosis as condition for psychotherapy. *Hypnos*, XXIX(4), 149–163.

Bicego, A., Rousseaux, F., Faymonville, M.-E., Nyssen, A.-S., & Vanhaudenhuyse, A. (2021). Neurophysiology of hypnosis in chronic pain: A review of recent literature. *American Journal of Clinical Hypnosis*, 64(1), 62–80.

Boen, E., Dardenne, B., Collette, F., & Salmon, E. (2022). Structural Parcelation of the Right Inferior Frontal Gyrus. *Frontiers in Human Neuroscience*, 16.

Bolton, T. A. W., Wotruba, D., Buechler, R., Theodoridou, A., Michels, L., Kollias, S., Rössler, W., Heekeren, K., & Van De Ville, D. (2020). Triple Network Model Dynamically Revisited: Lower Salience Network State Switching in Pre-psychosis. *Frontiers in Physiology*, 11. <https://doi.org/10.3389/fphys.2020.00066>

Bressler, S. L., & Menon, V. (2010). Large-scale brain networks in cognition: emerging methods and principles. *Trends in Cognitive Sciences*, 14(6), 277-290.

Bressler, S. L., & Menon, V. (2010). Large-scale brain networks in cognition: emerging methods and principles. *Trends in Cognitive Sciences*, 14(6), 277-290.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: Anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, 1124(1), 1-38.

Burgmer, M., Kugel, H., Pfleiderer, B., Ewert, A., Lenzen, T., Pioch, R., . . . & Konrad, C. (2013). The mirror neuron system under hypnosis–Brain substrates of voluntary and involuntary motor activation in hypnotic paralysis. *Cortex*, 49(2), 437-445. <https://doi.org/10.1016/j.cortex.2012.05.023>

Casiglia, E., Finatti, F., Gasparotti, F., Stabile, M. R., Mitolo, M., Albertini, F., Facco, E., Lapenta, A. M., Tikhonoff, V., & Venneri, A. (2018). Functional magnetic resonance imaging demonstrates that hypnosis is conscious and voluntary. *Psychology*, 9(7), 1571-1581. <https://doi.org/10.4236/psych.2018.97095>

Casiglia, E., Finatti, F., Tikhonoff, V., Stabile, M. R., Mitolo, M., Gasparotti, F., Albertini, F., Lapenta, A. M., & Venneri, A. (2019). Granone's plastic monoideism demonstrated by functional magnetic resonance imaging (fMRI). *Psychology*, 10(3), 434-448. <https://doi.org/10.4236/psych.2019.104030>

Cojan, Y., Piguet, C., & Vuilleumier, P. (2015). What makes your brain suggestible? Hypnotizability is associated with differential brain activity during attention outside hypnosis. *NeuroImage*, 117, 367–374.

Cojan, Y., Waber, L., Schwartz, S., Rossier, L., Forster, A., & Vuilleumier, P. (2009). The brain under self-control: Modulation of inhibitory and monitoring cortical networks during hypnotic paralysis. *Neuron*, 62(6), 862-875. <https://doi.org/10.1016/j.neuron.2009.05.021>

Danielmeier, C., Eichele, T., Forstmann, B. U., Tittgemeyer, M., & Ullsperger, M. (2011). Posterior Medial Frontal Cortex Activity Predicts Post-Error Adaptations in Task-Related Visual and Motor Areas. *Journal of Neuroscience*, 31(5), 1780–1789.

De Ridder, D., Vanneste, S., Smith, M., & Adhia, D. (2022). Pain and the Triple Network Model. *Frontiers in Neurology*, 13. <https://doi.org/10.3389/fneur.2022.757241>

Deeley, Q., Oakley, D. A., Toone, B., Giampietro, V., Brammer, M. J., Williams, S. C. R., & Halligan, P. W. (2012). Modulating the Default Mode Network Using Hypnosis. *International Journal of Clinical and Experimental Hypnosis*, 60(2), 206–228. <https://doi.org/10.1080/00207144.2012.648070>

Deeley, Q., Oakley, D. A., Toone, B., Bell, V., Walsh, E., Marquand, A. F., Giampietro, V., Brammer, M. J., Williams, S. C. R., Mehta, M. A., & Halligan, P. W. (2013). The functional anatomy of suggested limb paralysis. *Cortex*, 49(2), 411-422. <https://doi.org/10.1016/j.cortex.2012.09.016>

Deeley, Q., Walsh, E., Oakley, D. A., Bell, V., Koppel, C., Mehta, M. A., & Halligan, P. W. (2013). Using hypnotic suggestion to model loss of control and awareness of movements: An exploratory fMRI study. *PLoS ONE*, 8(10), e78324. <https://doi.org/10.1371/journal.pone.0078324>

Demertzi, A., Soddu, A., Faymonville, M. E., Bahri, M. A., Gosseries, O., Vanhaudenhuyse, A., Phillips, C., Maquet, P., Noirhomme, Q., Luxen, A., & Laureys, S. (2011). Hypnotic modulation of resting state fMRI default mode and extrinsic network connectivity. *Progress in Brain Research*, 193, 309–322. <https://doi.org/10.1016/B978-0-444-53839-0.00020-X>

Derbyshire, S. W., Whalley, M. G., Stenger, V. A., & Oakley, D. A. (2009). Fibromyalgia pain and its modulation by hypnotic and non-hypnotic suggestion: An fMRI analysis. *European Journal of Pain*, 13(5), 542-550. <https://doi.org/10.1016/j.ejpain.2008.06.010>

Desmarteaux, C., Streff, A., Chen, J.-I., Houzé, B., Piché, M., & Rainville, P. (2021). Brain responses to hypnotic verbal suggestions predict pain modulation. *Frontiers in Pain Research*, 2, Article 757384. <https://doi.org/10.3389/fpain.2021.757384>

DeSouza, D., Stimpson, K., L. Baltusis, M. Sacchet, Gu, M., Hurd, R., Wu, H., Yeomans, D., Williams, N., & Spiegel, D. (2020). Association between Anterior Cingulate Neurochemical Concentration and Individual Differences in Hypnotizability. *Cerebral Cortex*.

Doi, T., Fan, Y., Gold, J. I., & Ding, L. (2020). The caudate nucleus contributes causally to decisions that balance reward and uncertain visual information. *ELife*, 9, e56694.

Egner, T., Jamieson, G., & Gruzelier, J. (2005). Hypnosis decouples cognitive control from conflict monitoring processes of the frontal lobe. *NeuroImage*, 27(4), 969-978. <https://doi.org/10.1016/j.neuroimage.2005.05.002>

Erickson, M. H., & Rossi, E. L. (1979). Hypnotherapy: An Exploratory Case-book. Irvington.

Faerman, A., & Spiegel, D. (2021). Shared cognitive mechanisms of hypnotizability with executive functioning and information salience. *Scientific Reports*, 11(1), 5704.

Fingelkurts, A. A., Fingelkurts, A. A., Kallio, S., & Revonsuo, A. (2007). Cortex functional connectivity as a neurophysiological correlate of hypnosis: An EEG case study. *Neuropsychologia*, 45(7), 1452–1462.

Fromek, R. C., & Young, L. J. (2021). Oxytocin, Neural Plasticity, and Social Behavior. *Annual Review of Neuroscience*, 44(1), 359–381.

Gawlowska, M., Aleksandra Domagalik, Beldzik, E., Marek, T., & Justyna Mojsa-Kaja. (2018). Dynamics of error-related activity in deterministic learning - an EEG and fMRI study. 8(1).

Golland, Y., Bentin, S., Gelbard, H., Benjamini, Y., Heller, R., Nir, Y., Hasson, U., & Malach, R. (2006). Extrinsic and Intrinsic Systems in the Posterior Cortex of the Human Brain Revealed during Natural Sensory Stimulation. *Cerebral Cortex*, 17(4), 766–777. <https://doi.org/10.1093/cercor/bhk030>

Halligan, P. W., & Oakley, D. A. (2013). Hypnosis and cognitive neuroscience: Bridging the gap. *Cortex*, 49(2), 359-364. <https://doi.org/10.1016/j.cortex.2012.12.002>

Halsband, U., & Wolf, T. G. (2016). Functional changes in brain activity after hypnosis in patients with dental phobia. *Journal of Physiology-Paris*, 110(4), 423-431. <https://doi.org/10.1016/j.jphysparis.2016.10.001>

Halsband, U., & Wolf, T. G. (2021). Current neuroscientific research database findings of brain activity changes after hypnosis. *American Journal of Clinical Hypnosis*, 63(4), 372–388.

Hoef, F., Gabrieli, J. D. E., Whitfield-Gabrieli, S., Haas, B. W., Bammer, R., Menon, V., & Spiegel, D. (2012). Functional Brain Basis of Hypnotizability. *Archives of General Psychiatry*, 69(10), 1064.

Huber, A., Lui, F., Duzzi, D., Pagnoni, G., & Porro, C.A. (2014). Structural and functional cerebral correlates of hypnotic suggestibility. *PLoS ONE*, 9(3), e93187. <https://doi.org/10.1371/journal.pone.0093187>

Jamieson, G. A., & Burgess, A. P. (2014). Hypnotic induction is followed by state-like changes in the organization of EEG functional connectivity in the theta and beta frequency bands in high-hypnotically susceptible individuals. *Frontiers in Human Neuroscience*, 8.

Jiang, H., White, M. P., Greicius, M. D., Waelde, L. C., & Spiegel, D. (2017). Brain Activity and Functional Connectivity Associated with Hypnosis. *Cerebral Cortex*, 27(8), 4083–4093.

- Keshmiri, S., Alimardani, M., Shiomi, M., Sumioka, H., Ishiguro, H., & Hiraki, K. (2020). Higher hypnotic suggestibility is associated with the lower EEG signal variability in theta, alpha, and beta frequency bands. *PLoS One*, 15(4), e0230853.
- Krishnadas, R., Ryali, S., Chen, T., Uddin, L., Supekar, K., Palaniyappan, L., & Menon, V. (2014). Resting state functional hyperconnectivity within a triple network model in paranoid schizophrenia [Abstract]. *The Lancet*, 383, S93. [https://doi.org/10.1016/S0140-6736\(14\)60259-3](https://doi.org/10.1016/S0140-6736(14)60259-3)
- Landry, M., Lifshitz, M., & Raz, A. (2017). Brain correlates of hypnosis: A systematic review and meta-analytic exploration. *Neuroscience & Biobehavioral Reviews*, 81, 75–98.
- Lebois, L. A. M., Kumar, P., Palermo, C. A., Lambros, A. M., O'Connor, L., Wolff, J. D., Baker, J. T., Gruber, S. A., Lewis-Schroeder, N., Ressler, K. J., Robinson, M. A., Winternitz, S., Nickerson, L. D., & Kaufman, M. L. (2022). Categorical and dimensional brain network-based models of trauma-related dissociative subtypes. *MedRxiv*. <https://doi.org/10.1101/2022.04.29.22274474>
- Leroy, A., Very, E., Birmes, P., Szafrarczyk, S., Lopes, R., Faure, C., Duhem, S., Grandgenèvre, P., Warembourg, F., Vaiva, G., & Jardri, R. (2021). Insular cortex influence on intrusivity: Treatment response induces changes in the effective connectivity of the anterior insula in post-traumatic stress disorder. *BioRxiv*. <https://doi.org/10.1101/2020.10.01.319269>
- Li, X., Chen, L., Ma, R., Wang, H., Wan, L., Bu, J., Hong, W., Lv, W., Yang, Y., Rao, H., & Zhang, X. (2019). The neural mechanisms of immediate and follow-up of the treatment effect of hypnosis on smoking craving. *Brain Imaging and Behavior*. <https://doi.org/10.1007/s11682-019-00072-0>
- Li, X., Chen, L., Ma, R., Wang, H., Wan, L., Wang, Y., ... Zhang, X. (2019). The top-down regulation from the prefrontal cortex to insula via hypnotic aversion suggestions reduces smoking craving. *Human Brain Mapping*, 40(6), 1718–1728. <https://doi.org/10.1002/hbm.24483>
- Lifshitz, M., & Raz, A. (2015). Hypnotic ability and baseline attention: fMRI findings from Stroop interference. *Psychology of Consciousness: Theory, Research, and Practice*, 2(2), 134–143. <https://doi.org/10.1037/cns0000050>
- Liu, Y., Li, L., Li, B., Feng, N., Li, L., Zhang, X., Lu, H., & Yin, H. (2017). Decreased Triple Network Connectivity in Patients with Recent Onset Post-Traumatic Stress Disorder after a Single Prolonged Trauma Exposure. *Scientific reports*, 7(1), 12625. <https://doi.org/10.1038/s41598-017-12964-6>
- Liu, Y., He, Y., Li, R., Yu, S., Xu, J., & Xie, Y. (2020). Coupled temporal fluctuation and global signal synchronization of spontaneous brain activity in hypnosis for respiration control: An fMRI study. *Neuroscience*, 429, 56–67. <https://doi.org/10.1016/j.neuroscience.2019.12.032>
- Liu, Y., Qin, W., Li, R., Yu, S., He, Y., & Xie, Y. (2018). Investigation on the neural mechanism of hypnosis-based respiratory control using functional MRI. *Contrast Media & Molecular Imaging*, 2018, 8182542. <https://doi.org/10.1155/2018/8182542>
- Long, X.-Y., Zuo, X.-N., Kiviniemi, V., Yang, Y., Zou, Q.-H., Zhu, C.-Z., ... & Zang, Y.-F. (2008). Default mode network as revealed with multiple methods for resting-state functional MRI analysis. *Journal of Neuroscience Methods*, 171(2), 349–355.
- Lowén, M. B. O., Mayer, E. A., Sjöberg, M., Tillisch, K., Naliboff, B. D., Labus, J. S., ... & Walter, S. A. (2013). Effect of hypnotherapy and educational intervention on brain response to visceral stimulus in the irritable bowel syndrome. *Alimentary Pharmacology & Therapeutics*, 37(12), 1184–1197. <https://doi.org/10.1111/apt.12319>
- Ludwig, V. U., Stelzel, C., Krutlak, H., Magrabi, A., Steimke, R., Paschke, L. M., ... & Walter, H. (2014). The suggestible brain: posthypnotic effects on value-based decision-making. *Social Cognitive and Affective Neuroscience*, 9(9), 1281–1288. <https://doi.org/10.1093/scan/nst110>
- Lynn, S. J., & Rhue, J. W. (1991). *Theories of hypnosis: current models and perspectives*. Guilford Press.
- Lynn, S. J., Green, J. P., Kirsch, I., Capafons, A., Lilienfeld, S. O., Laurence, J.-R., & Montgomery, G. H. (2015). Grounding Hypnosis in Science: The “New” APA Division 30 Definition of Hypnosis as a Step Backward. *American Journal of Clinical Hypnosis*, 57(4), 390–401.
- Manoliu, A., Meng, C., Brandl, F., Doll, A., Tahmasian, M., Scherr, M., ... & Sorg, C. (in review). Insular dysfunction within the salience network is associated with severity of symptoms and aberrant inter-network connectivity in major depressive disorder.

- Manoliu, A., Riedl, V., Doll, A., Bauml, J. G., Muhlau, M., Schwerthoffer, D., ... & Sorg, C. (2013). Insular dysfunction reflects altered between-network connectivity and severity of negative symptoms in schizophrenia during psychotic remission. *Frontiers in Human Neuroscience*, 7. <https://doi.org/10.3389/fnhum.2013.00200>
- Manoliu, A., Riedl, V., Zherdin, A., Muhlau, M., Schwerthoffer, D., Scherr, M., ... & Sorg, C. (2013). Aberrant dependence of default mode/central executive network interactions on anterior insular salience network activity in schizophrenia. *Schizophrenia Bulletin*, 39(2), 428–437. <https://doi.org/10.1093/schbul/sbs077>
- McGeown, W. J., Mazzoni, G., Vannucci, M., Venneri, A. (2015). Structural and functional correlates of hypnotic depth and suggestibility. *Psychiatry Research: Neuroimaging*, 231(2), 151–159. <https://doi.org/10.1016/j.psychres.2014.11.001>
- Mendelsohn, A., Chalamish, Y., Solomonovich, A., & Dudai, Y. (2008). Mesmerizing memories: Brain substrates of episodic memory suppression in posthypnotic amnesia. *Neuron*, 57(1), 159–170. <https://doi.org/10.1016/j.neuron.2007.11.022>
- Meng, X., Wu, Y., Liang, Y., Zhang, D., Xu, Z., Yang, X., & Meng, L. (2022). A triple-network dynamic connection study in Alzheimer's disease. *Frontiers in Psychiatry*, 13, 862958. <https://doi.org/10.3389/fpsy.2022.862958>
- Menon, V. (2011). Large-scale brain networks and psychopathology: A unifying triple network model. *Trends in Cognitive Sciences*, 15(10), 483–506. <https://doi.org/10.1016/j.tics.2011.08.003>
- Menon, V., & Uddin, L. Q. (2010). Saliency, switching, attention and control: A network model of insula function. *Brain Structure and Function*, 214(5–6), 655–667. <https://doi.org/10.1007/s00429-010-0262-0>
- Moujaes, F. F., Rieser, N. M., Phillips, C., de Matos, N. M. P., Brügger, M., Dürler, P., Smigielski, L., Stämpfli, P., Seifritz, E., Vollenweider, F. X., Anticevic, A., & Preller, K. H. (2023). Comparing neural correlates of consciousness: From psychedelics to hypnosis and meditation. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*. <https://doi.org/10.1016/j.bpsc.2023.07.003>
- Možina, M. (2022). Hipnopsihoterapija. In N. Podgornik Pulec (Ed.), *Sodobne metode v psihoterapiji in energijski psihologiji* (pp. 127–191). Faculty of Social Sciences, University of Ss. Cyril and Methodus in Trnava.
- Müller, K., Bacht, K., Prochnow, D., Schramm, S., Seitz, R. J., & Kathmann, N. (2013). Activation of thalamus in motor imagery results from gating by hypnosis. *NeuroImage*, 66, 361–367. <https://doi.org/10.1016/j.neuroimage.2012.10.073>
- Neurosynth. (2023). <https://neurosynth.org/>
- Pajntar, M., Areh, I., & Možina, M. (2013). Ali je hipnoza učinkovita pri zdravljenju telesnih in duševnih težav?
- Kairos – Slovenian Journal of Psychotherapy, 7(1–2), 19–31.
- Pintar, J., & Lynn, S. J. (2009). *Hypnosis*. John Wiley & Sons.
- Pyka, M., Burgmer, M., Lenzen, T., Pioch, R., Dannlowski, U., Pfleiderer, B., Ewert, A. W., Heuft, G., Arolt, V., & Konrad, C. (2011). Brain correlates of hypnotic paralysis—A resting-state fMRI study. *NeuroImage*, 56(4), 2173–2182. <https://doi.org/10.1016/j.neuroimage.2011.03.078>
- Raichle, M. E. (2015). The Brain's Default Mode Network. *Annual Review of Neuroscience*, 38(1), 433–447.
- Raij, T. T., Numminen, J., Närva, S., Hiltunen, J., & Hari, R. (2005). Brain correlates of subjective reality of physically and psychologically induced pain. *Proceedings of the National Academy of Sciences*, 102(6), 2147–2151. <https://doi.org/10.1073/pnas.0409542102>
- Raij, T. T., Numminen, J., Närvanen, S., Hiltunen, J., & Hari, R. (2009). Strength of prefrontal activation predicts intensity of suggestion-induced pain. *Human Brain Mapping*, 30(8), 2890–2897. <https://doi.org/10.1002/hbm.20716>
- Raz, A., Fan, J., & Posner, M. I. (2005). Hypnotic suggestion reduces conflict in the human brain. *Proceedings of the National Academy of Sciences*, 102(28), 9978–9983. <https://doi.org/10.1073/pnas.0503064102>
- Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., Reiss, A. L., & Greicius, M. D. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neuroscience*, 27(9), 2349–2356. <https://doi.org/10.1523/JNEUROSCI.5587-06.2007>

- Sheline, Y. I., Barch, D. M., Price, J. L., Rundle, M. M., Vaishnavi, S. N., Snyder, A. Z., Mintun, M. A., Wang, S., Coalson, R. S., & Raichle, M. E. (2009). The default mode network and self-referential processes in depression. *Proceedings of the National Academy of Sciences*, 106(6), 1942–1947.
- Shin, L. M., & Liberzon, I. (2009). The Neurocircuitry of Fear, Stress, and Anxiety Disorders. *Neuropsychopharmacology*, 35(1), 169–191.
- Spagna, A., Hajhajate, D., Liu, J., & Bartolomeo, P. (2020). Visual mental imagery engages the left fusiform gyrus, but not the early visual cortex: A meta-analysis of neuroimaging evidence. *BioRxiv (Cold Spring Harbor Laboratory)*. <https://doi.org/10.1101/2020.02.06.937151>
- Spiegel, D., & King, R. (1992). Hypnotizability and CSF HVA levels among psychiatric patients. *Biological Psychiatry*, 31(1), 95–98.
- Sridharan, D., Levitin, D. J., & Menon, V. (2008). A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. *Proceedings of the National Academy of Sciences of the United States of America*, 105(34), 12569–12574.
- Supekari, K., Cai, W., Krishnadas, R., Palaniyappan, L., & Menon, V. (2019). Dysregulated Brain Dynamics in a Triple-Network Saliency Model of Schizophrenia and Its Relation to Psychosis. *Biological Psychiatry*, 85(1), 60–69. <https://doi.org/10.1016/j.biopsych.2018.07.20>
- Tachibana, K., Suzuki, K., Mori, E., Miura, N., Kawashima, R., Horie, K., Sato, S., Tanji, J., & Mushiake, H. (2009). Neural activity in the human brain signals logical rule identification. *Journal of Neurophysiology*, 102(3), 1526–1537.
- Terhune, D. B., Cleeremans, A., Raz, A., & Lynn, S. J. (2017). Hypnosis and top-down regulation of consciousness. *Neuroscience & Biobehavioral Reviews*, 81, 59–74.
- Tiego, J., Testa, R., Bellgrove, M. A., Pantelis, C., & Whittle, S. (2018). A Hierarchical Model of Inhibitory Control. *Frontiers in Psychology*, 9.
- Uddin, L. Q., Betzel, R. F., Cohen, J. R., Damoiseaux, J. S., De Brigard, F., Eickhoff, S. B., ... & Spreng, R. N. (2023). Controversies and progress on standardization of large-scale brain network nomenclature. *Network Neuroscience*, 7(3), 864–905.
- Uddin, L. Q., Yeo, B. T., & Spreng, R. N. (2019). Towards a universal taxonomy of macro-scale functional human brain networks. *Brain Topography*, 32(6), 926–942.
- Uddin, L. Q., Betzel, R. F., Cohen, J. R., Damoiseaux, J. S., De Brigard, F., Eickhoff, S. B., Fornito, A., Gratton, C., Gordon, E. M., Laird, A. R., Larson-Prior, L., McIntosh, A. R., Nickerson, L. D., Pessoa, L., Pinho, A. L., Poldrack, R. A., Razi, A., Sadaghiani, S., Shine, J. M., Yendiki, A., Yeo, B. T. T., & Spreng, R. N. (2023). Controversies and progress on standardization of large-scale brain network nomenclature. *Network Neuroscience*. Advance online publication. https://doi.org/10.1162/netn_a_00323
- Uddin, L. Q., Yeo, B. T. T., & Spreng, R. N. (2019). Towards a universal taxonomy of macro-scale functional human brain networks. *Brain Topography*, 32(6), 926–942. <https://doi.org/10.1007/s10548-019-00744-6>
- Université de Sherbrooke. (2018, October 30). The Role of the Endocannabinoids During the Analgesia Caused by Hypnosis and Meditation. *Clinicaltrials.gov*.
- Vaitl, D., Birbaumer, N., Gruzelier, J., Jamieson, G. A., Kotchoubey, B., Kübler, A., Lehmann, D., Miltner, W. H. R., Ott, U., Pütz, P., Sammer, G., Strauch, I., Strehl, U., Wackermann, J., & Weiss, T. (2005). Psychobiology of Altered States of Consciousness. *Psychological Bulletin*, 131(1), 98–127. <https://doi.org/10.1037/0033-2909.131.1.98>
- Vanhaudenhuyse, A., Boly, M., Balteau, E., Schnakers, C., Moonen, G., Luxen, A., Lamy, M., Degueldre, C., Brichant, J. F., Maquet, P., Laureys, S., & Faymonville, M. E. (2009). Pain and non-pain processing during hypnosis: A thulium-YAG event-related fMRI study. *NeuroImage*, 47(3), 1047–1054. <https://doi.org/10.1016/j.neuroimage.2009.05.031>
- Vanhaudenhuyse, A., Laureys, S., & Faymonville, M.-E. (2014). Neurophysiology of hypnosis. *Neurophysiologie Clinique/Clinical Neurophysiology*, 44(4), 343–353.
- Walsh, E., Oakley, D. A., Halligan, P. W., Mehta, M. A., & Deeley, Q. (2017). Brain mechanisms for loss of awareness of thought and movement. *Social Cognitive and Affective Neuroscience*, 12(5), 793–801. <https://doi.org/10.1093/scan/nsw185>

- Walsh, E., Oakley, D. A., Halligan, P. W., Mehta, M. A., & Deeley, Q. (2015). The functional anatomy and connectivity of thought insertion and alien control of movement. *Cortex*, 64, 380–393. <https://doi.org/10.1016/j.cortex.2014.09.012>
- Wang, J., Wang, Y., Huang, H., Jia, Y., Zheng, S., Zhong, S., Chen, G., Huang, L., & Huang, R. (2020). Altered Functional Connectivity in Patients with Subcortical Vascular Cognitive Impairment—No Dementia. *Frontiers in Neurology*, 11.