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CHAPTER

Neurophysiology of Hypnosis

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Advances in neuroimaging and electrophysiology provide new ways to explore the intricacies of the living human brain (Dolan, 2008; Jacobs & Kahana, 2010). These developments have increased the expectation that neuroscience can elucidate some of the most fundamental questions about the human mind (Choudhury & Slaby, 2011). Hypnosis is part and parcel of this ongoing trend (Oakley & Halligan, 2009, 2013; Raz, 2011a). However, after more than two decades of imaging the hypnotized brain, studies have yet to deliver a reliable neurobiological model of hypnosis (Landry & Raz, 2015). One central obstacle pertains to the inherent complexity of hypnotic phenomena, which emerge from the interaction of multiple factors (Nash & Barnier, 2008). Three factors play a central role in the efficacy of the hypnotic response: interindividual differences in hypnotizability or susceptibility to suggestion, the induction procedure, and the type and content of the (post) hypnotic suggestions (Figure 3.1; Mazzoni, Venneri, McGeown, & Kirsch, 2013; Oakley & Halligan, 2010). This chapter delves into the neuroscience of hypnosis by focusing on these central components. Accordingly, here we examine and summarize neuroimaging and electrophysiological assays of hypnotizability, hypnotic induction, and (post) hypnotic suggestions.

Three conclusions follow from our brief appraisal. First, hypnotic phenomena seem to engage frontal areas of the human brain. In particular, hypnosis involves regions implicated in mental alertness, executive control, top-down regulation, and monitoring processes. Second, hypnosis induces global changes in neural connectivity patterns—in other words, hypnosis emerges from complex brain dynamics. Third, research highlights the ability of (post)hypnotic suggestions to selectively engage relevant brain regions. This aspect underscores the precision of suggestion to target and influence specific perceptual, cognitive, or motor processes.

INTERINDIVIDUAL VARIABILITY

Individuals respond differently to suggestion (Piccione, Hilgard, & Zimbardo, 1989). Researchers typically differentiate highly hypnotizable individuals (HHIs) from low hypnotizable individuals (LHIs) using standardized scales that measure hypnotizability (Heap, Brown, & Oakley, 2004; Laurence, Beaulieu-Prévost, & Du Chéné, 2008). HHIs are distinct in that they possess mental abilities that allow them to produce reliable hypnotic responses to challenging suggestions. However, few psychological and neurobiological correlates predict hypnotizability (Lichtenberg, Bachner-Melman, Ebstein, & Crawford, 2004; Raz, 2005; Tellegen & Atkinson, 1974). The absence of a unique reliable correlate implies that hypnotizability represents a multifactorial sociocognitive construct. Beyond the dichotomy that differentiates HHIs from LHIs, research on hypnotizability reveals that HHIs rarely represent a homogeneous group. Indeed, heterogeneity across HHIs suggests that this group may comprise various subcategories (McConkey & Barnier, 2004; Terhune, Cardeña, & Lindgren, 2011a, 2011b). Certain researchers propose that such variability in hypnosis reflects individual differences in cognitive styles, wherein successful hypnotic responses rely on specific ways to process suggestions and implement cognitive strategies (Barnier, Cox, & McConkey, 2014; Laurence et al., 2008).

At the brain level, hypnotizability correlates with greater brain volume in certain frontal lobe areas (see Figure 3.2; Horton, Crawford, Harrington, & Downs, 2004; Huber, Lui, Duzzi, Pagnoni, &

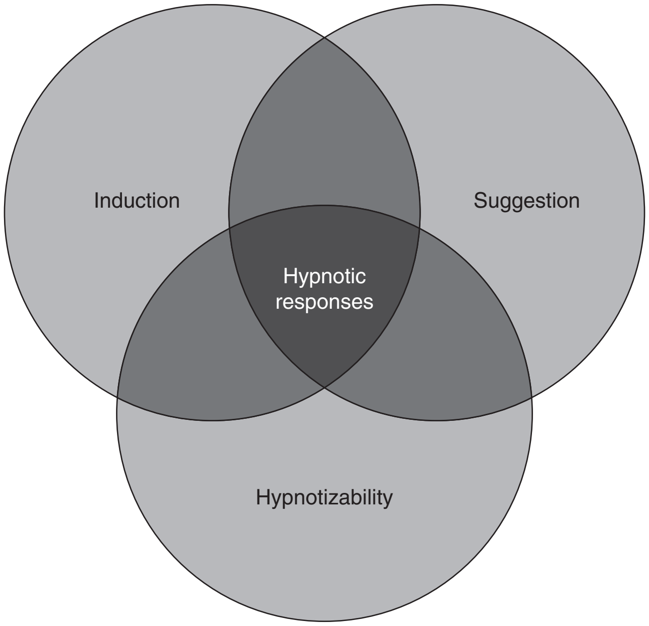

FIGURE 3.1 The hypnotic response is located at the confluence of three central factors: interindividual variability in hypnotizability, the induction procedure, and the content of hypnotic suggestions.

Porro, 2014). Neurocognitive functions associated with these brain regions therefore likely influence hypnotizability. Functional investigations further emphasize these observations. Functional connectivity evaluates the level of synchronicity between distant brain regions to uncover neural networks (Friston, 2011). Functional connectivity assumes that concurrent neural activity between areas reflects neural networks. Consistent with structural evidence, studies reveal functional differences between HHIs and LHIs (Hoeft et al., 2012; Huber et al., 2014). Specifically, HHIs show higher connectivity between the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC; Figure 3.2). Evidence therefore indicates that structural and functional differences of the frontal brain relate to hypnotizability.

Additional findings further emphasize the role of the DLPFC in hypnotizability. Repeated transcranial magnetic stimulation (rTMS) represents an experimental technique that allows researchers to induce a short-lived neural dysfunction of the targeted brain region, thereby producing so-called virtual brain lesions (Pascual-Leone, 1999; Raz & Wolfson, 2010). Cognitive neuroscientists often employ this approach to verify whether the targeted region is necessary for a specific perceptual, cognitive, or motor function (Friston, 2011). A recent study used rTMS to demonstrate that transient dysfunction of the DLPFC increases hypnotizability (Dienes & Hutton, 2013). These observations supplement aforementioned findings on the role of the frontal brain in hypnosis and allude to a causal relationship between frontal neurocognitive functions and hypnotizability. They also hint that altered functioning of the prefrontal cortex influences the reliability of the hypnotic response (Crawford & Gruzelier, 1992). However, despite the importance of this finding, neuropsychological observations with neurological patients hardly yield comparable results (Kihlström, Glisky, McGovern, Rapcsak, & Mennemeier, 2013). Further examination is therefore necessary to better understand the role of the DLPFC in hypnotizability.

The frontal areas identified across triangulate investigations usually converge on executive control, top-down regulation, and monitoring processes (e.g., Nee et al., 2013; Shenhav, Botvinick, & Cohen, 2013). These observations are consistent with executive control theories of hypnosis and intimate that interindividual variability in hypnotic response mainly reflects differences in functions of the frontal lobe. Accordingly, variation in the implementation of attentional and executive neurocognitive routines putatively explains the spectrum of hypnotizability.

INDUCTION

Hypnotic inductions typically aim to induce a heightened level of attentional focus (Maldonado & Spiegel, 2008). Similar to being deeply immersed in a book or a movie, this mental plane of intense absorption steers attention away from irrelevant thoughts and sensory events, while simultaneously increasing focus toward the suggestions. The phenomenology of hypnosis frequently includes deep feelings of relaxation alongside a sensation of mental absorption (Cardeña, Jönsson, Terhune, & Marcusson-Clavertz, 2013). Consistent with this account, the hypnotic induction recruits brain regions implicated in the regulation of attention and mental alertness. In particular, neuroimaging reveals that complex thalamocortical signal changes correlate with increased feelings of mental

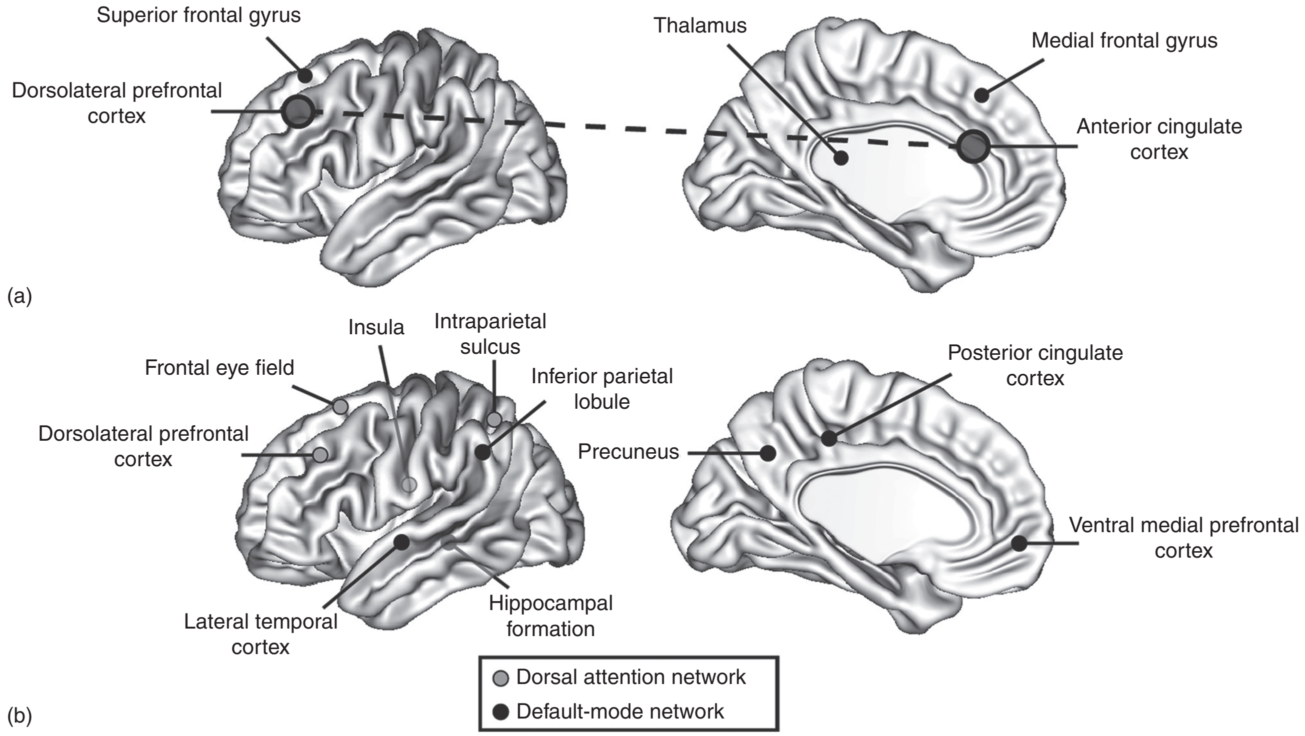

FIGURE 3.2 **(a).** Structural imaging of hypnotizability reports significant differences in brain volume for the superior and medial frontal gyri in HHIs compared with LHIs. Also, numerous reports document findings related to the connection between the DLPFC and the ACC, as well as specific thalamocortical dynamics. These effects relate to hypnotizability and hypnotic induction. **(b).** Hypnotic induction disengages the default mode network, which comprises the lateral temporal cortex, the hippocampal formation, the inferior parietal lobule, the precuneus, the posterior cingulate cortex, and the ventral medial prefrontal cortex, and engages the dorsal attention network, which comprises the DLPFC, the frontal eye field, the insula, and the intraparietal sulcus.

ACC, anterior cingulate cortex; DLPFC, dorsolateral prefrontal cortex; HHI, highly hypnotizable individual.

absorption and relaxation following an induction (Rainville, Hofbauer, Bushnell, Duncan, & Price, 2002). This type of neural dynamic colors the intricacies of hypnotic planes, wherein greater attentional focus and enhanced mental effort often parallel subjective feelings of relaxation—“the effortless effort.”

During resting-state imaging, researchers examine brain activity in the near absence of concurrent experimental factors, that is, at rest. This approach aims to uncover brain networks by assessing functional connectivity among brain regions (de Luca, Beckmann, de Stefano, Matthews, & Smith, 2006). Using this experimental approach, resting-state investigations of hypnosis have focused mainly on two such brain networks: the default mode network and the prefrontal attention network (see Figure 3.2; Deeley et al., 2012; Demertzi et al., 2011; McGeown, Mazzoni, Venneri, & Kirsch, 2009). The default network comprises several cortical midline structures and typically relates to introspection, mind wandering, and spontaneous cognition (Buckner, Andrews Hanna, & Schacter, 2008; Mason et al., 2007; Smallwood & Schooler, 2015). The induction procedure links to a reduction in default network activity, which proposes that this hypnotic procedure reduces introspection and spontaneous cognition. This neural pattern joins a concurrent engagement of the prefrontal attention network (Raz & Buhle, 2006). The simultaneous reduction in default network activity and increase in attention network activity could therefore reflect a marked reduction in spontaneous cognition and increased attention focus in anticipation of upcoming instructions. According to this view, a heightened level of response preparation involves the recruitment of the alerting network and facilitates the subsequent production of hypnotic responses to suggestion (Kirsch, 1997). Consistent with this interpretation, the induction procedure instigates increased neural

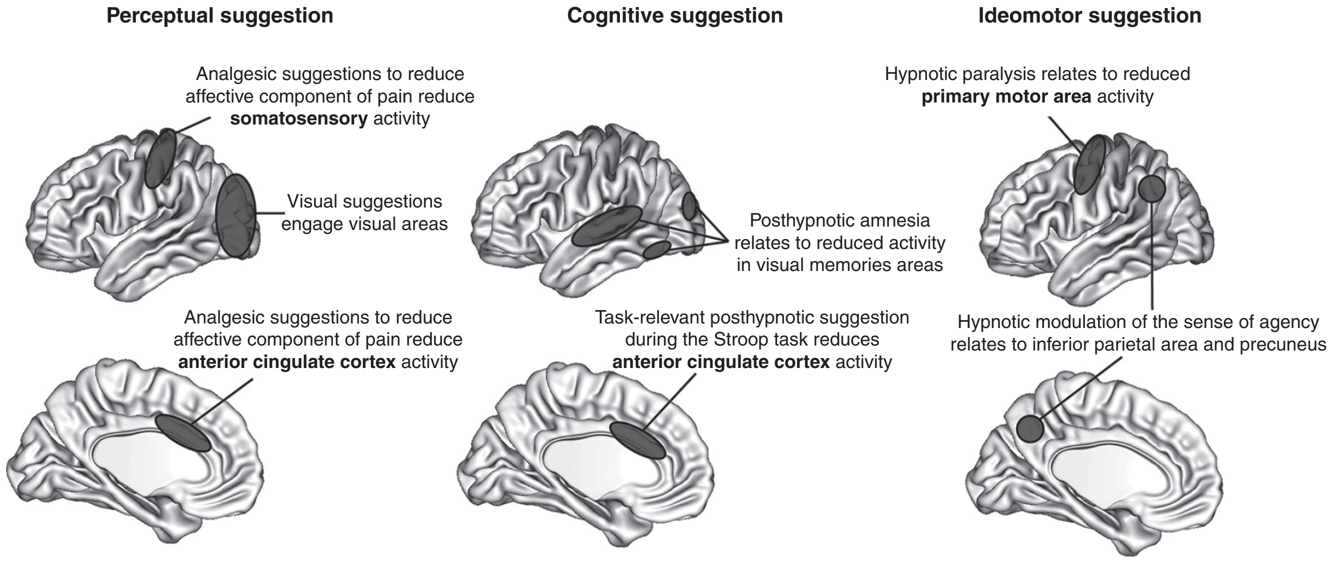

FIGURE 3.3 Suggestion alters neural activity in corresponding brain regions. Perceptual suggestions alter sensory and perceptual brain networks; cognitive suggestions alter brain networks related to cognitive processes; and ideomotor suggestions alter brain networks involved in the planning, production, and monitoring of action.

activity during hypnotic response (McGeown et al., 2012). Induction-related increases in mental alertness and focused attention thus appear to act as hypnotic facilitators (Lifshitz & Raz, 2012).

Despite increased attention, hypnotic inductions without task-specific suggestion typically relate to poor performance, for example, in the context of the Stroop paradigm (e.g., Jamieson & Sheehan, 2004). According to dissociation theorists, a disconnect between executive and supervisory processes during hypnosis may account for this impairment (Woody & Farvolden, 1998; Woody & Sadler, 2008). This interruption thus hinders cognitive control and prevents flexible adjustment of attention, for example, in the Stroop color-naming task (Terhune, Cardeña, & Lindgren, 2011c). At the neural level, distinct activation profiles of the DLPFC and ACC index this decoupling of executive control and monitoring processes (see Figure 3.2; Egner, Jamieson, & Gruzelier, 2005). Moreover, concurrent desynchronized oscillatory patterns between these brain regions likely denote a breakdown in cortical communication, whereas reduced frontoparietal synchronized activity relates to experiences of dissociation (Terhune et al., 2011a). Hence, dissociation theorists view the induction procedure as altering functional connectivity between anterior and posterior areas implicated in higher order cognitive processes.

Electrophysiological studies of hypnotic induction reveal general fluctuations in neural activity. These changes denote reduced synchronicity among cerebral regions. Specifically, HHIs show less phase synchronization over the frontal areas following a hypnotic induction (Baghdadi & Nasrabadi, 2012). They also exhibit distinct global neural oscillatory patterns (de Pascalis, 2007; Fingelkurts, Fingelkurts, Kallio, & Revonsuo, 2007). These neurophysiological oscillations occur alongside induction instructions, marked by a general boost in neural activity near the end of the induction procedure (Hinterberger, Schöner, & Halsband, 2011). These results not only underscore widespread induction-related neural patterns but also demonstrate how stepwise induction procedures encompass various brain dynamics. The ACC could be involved in such global brain changes (Tang, Rothbart, & Posner, 2012). Overall, hypnotic inductions relate to global oscillatory patterns across many brain networks. Neural fluctuations enable the coordination of brain networks as well as the emergence of complex brain functions (Buzsaki, 2006). Therefore, hypnotic modulations of neural alternations underlie the effect of induction over higher cognitive functions.

Several phenomenological experiences often accompany hypnotic induction (Cardeña, 2005). Because multiple facets of hypnosis primarily surface subjectively, methodological frameworks that combine measures of brain activity and subjective reports provide vital information frequently obviated by the prevalent experimental approaches in cognitive neuroscience (Cusumano & Raz, 2014; Lifshitz, Cusumano, & Raz, 2013). Neurophenomenological investigations of hypnosis document that several subjective dimensions of hypnosis correspond to specific neurophysiological fluctuations (Cardeña et al., 2013). For example, self-perceived hypnotic depth relates to particular synchronized neural patterns. These results further validate the authenticity of self-reported phenomenological experience during hypnosis. Yet, matching widespread neural dynamics to specific subjective experience remains a challenge and induction-related neural fluctuations are difficult to interpret.

In summary, brain imaging of hypnotic induction relates to complex neural dynamics that include the alerting and executive networks. These neural patterns parallel enhanced mental absorption. Concomitant decreased default mode network activity in HHIs proposes that the hypnotic induction also reduces introspection and the generation of internal thoughts. These findings therefore support the notion that HHIs respond to the induction procedure by engaging attention in anticipation of an upcoming suggestion and disengaging it from irrelevant thoughts and sensory events. Furthermore, altered brain connectivity is congruent with the idea that induction-related attention phenomena decouple executive control from monitoring processes (Brown & Oakley, 2004). Electrophysiological investigations have identified neural dynamics that match these dissociation patterns (Lee et al., 2007). Under this lens, fluctuations in brain connectivity seem to subserve various conscious experiences during hypnosis.

SUGGESTION

In hypnosis, suggestions are communicable representations in the form of verbal statements capable of yielding a perceptual, cognitive, or motor response (Halligan & Oakley, 2014). Previous studies document the wide range of suggestion-related effects (Michael, Garry, & Kirsch, 2012). Critically, these studies also report that reliable hypnotic responses to suggestion scantily require a formal induction procedure (Mazzoni et al., 2009; Raz, Kirsch, Pollard, & Nitkin-Kaner, 2006). Findings from studies using brain imaging corroborate these notions (McGeown et al., 2012). A reliable hypnotic response even in the absence of an induction procedure may well capture the centrality of hypnotic responsiveness.

Consistent with top-down views of hypnosis (Raz, 2011b), suggestion-related hypnotic phenomena involve a wide spectrum of frontal activation patterns (Landry & Raz, 2015). Hypnotic suggestions notably relate to the prefrontal and anterior cingulate cortices. Responses to suggestion, moreover, exert their actions through frontal neurocognitive functions (Rainville, Hofbauer, et al., 1999). However, isolating the neural mechanisms of hypnotic responses remains a challenging enterprise because suggestion-related frontal activations vary across studies. This heterogeneity of frontal patterns likely stems from a combination of factors: the content of the suggestion, the quality of the interaction with the operator, interindividual variability, and contextual considerations. Consequently, the recruitment of frontal executive functions and top-down regulation processes during the hypnotic response may well denote inter- and intraindividual cognitive strategies (McConkey & Barnier, 2004).

The domain of (post)hypnotic suggestions includes a broad collection of perceptual, cognitive, and ideomotor phenomena (Woody & Sadler, 2008). Neuroimaging appears to validate these effects at the brain level (see Figure 3.3; del Casale et al., 2012; Kihlström, 2013). However, these studies only show that hypnotic suggestion can selectively modulate corresponding cortical areas and that these effects are consistent with first-person reports. In this manner, neuroimaging of hypnotic response to suggestion validates the potential of hypnosis to reliably act upon targeted aspects of emotion, cognition, thought, and action. Box 3.1 summarizes a few neurophysiological observations related to these different domains of suggestion.

The heterogeneity of neural patterns across the different types of suggestion proposes that brain processes combine in various ways to yield a wide range of hypnotic phenomena. The content of suggestions thus represents a prominent component of hypnosis that compels researchers and clinicians to pay close attention to the way they formulate their instructions (Spiegel & Barabasz, 1988). Even

BOX 3.1 SUMMARY OF HYPNOTIC SUGGESTIONS AND RELATED NEUROPHYSIOLOGICAL OBSERVATIONS

Perceptual Suggestion. Suggestions intended to alter visual perception engage the visual areas (see Figure 3.3; Kosslyn, Thompson, Costantini-Ferrando, Alpert, & Spiegel, 2000; McGeown et al., 2012). Electrophysiological findings intimate that such altered visual perception reflects early modulations of sensory processing (Koivisto, Kirjanen, Revonsuo, & Kallio, 2013). Hypnotic analgesia also engages the corresponding brain areas, wherein this type of suggestion modulates the pain neuromatrix (Jensen & Patterson, 2014). Critically, evidence demonstrates that different suggestions for analgesia can influence distinct aspects of pain perception, as well as their neural correlates (see Figure 3.3; Hofbauer, Rainville, Duncan, & Bushnell, 2001; Rainville, Carrier, Hofbauer, Bushnell, & Duncan, 1999; Rainville, Duncan, Price, Carrier, & Bushnell, 1997). Specifically, suggestions intended to suppress affective dimensions of nociception (i.e., the unpleasant aspects of pain perception) relate to reduced activity in the ACC, whereas suggestions intended to suppress pain intensity (i.e., the sensory quality of pain perception) modulate neural activity in the sensory brain area. Overall, evidence confirms that hypnotic responses to perceptual suggestions involve modulations of perceptual and sensory brain networks.

Cognitive Suggestion. We previously described how induction alone yields poor Stroop performances in HHIs. In contrast, task-relevant suggestions can produce the opposite effect and improve performance (Lifshitz, Aubert Bonn, Fischer, Kashem, & Raz, 2013; Raz, Shapiro, Fan, & Posner, 2002). Indeed, carefully crafted suggestion to impair reading ability causes significant improvement in the Stroop task for HHIs. Moreover, the Stroop paradigm relates to increased ACC activity, which likely reflects cognitive interference triggered by a task-irrelevant automatic response (Shenhav et al., 2013). Hypnotic suggestions for alexia also suppress this characteristic neural response of the Stroop task (see Figure 3.3; Raz, Fan, & Posner, 2005). These behavioral and neuroimaging observations demonstrate how posthypnotic suggestions can assist top-down regulation processes to appropriately manage cognitive conflict and effectively override ballistic processes. These results sharply contrast with performance on the Stroop task following an induction alone. This distinction highlights essential psychological facets of hypnotic inductions and suggestions: whereas the induction alone corresponds to an inability to self-initiate a reliable task-relevant strategy, hypnotic suggestions actually foster a steadfast response through efficient top-down stratagems (Egner & Raz, 2007). Evidence therefore demonstrates the effectiveness of cognitive suggestions to heighten executive control.

Neuroimaging studies of posthypnotic amnesia likewise document distinct neural responses (see Figure 3.3; Allen, Iacono, Laravuso, & Dunn, 1995; Mendelsohn, Chalamish, Solomonovich, & Dudai, 2008). These reports notably isolate cortical networks implicated in memory retrieval processes. These results are therefore consistent with the notion that posthypnotic amnesia mainly results from retrieval deficits (Kihlström, 1997). Importantly, again evidence supports the idea that suggestions target corresponding brain processes.

Ideomotor Suggestions. Ideomotor suggestions alter the preparation, execution, and monitoring of actions (Cojan et al., 2009). This type of suggestion thus influences the production of specific movements (e.g., Halligan, Athwal, Oakley, & Frackowiak, 2000) and the inherent sense of agency that typically accompanies voluntary movements (i.e., the feeling of control over one's actions; Blakemore, Oakley, & Frith, 2003). Hypnotic paralysis recruits distinct neural circuits than feigned paralysis, which underlines the neural specificity of the hypnotic response to ideomotor suggestions from mere simulation (Cojan et al., 2009; Ward, Oakley, Frackowiak, & Halligan, 2003). Hypnotic paralysis also affects primary motor activity, yet hardly perturbs preparatory motor activity (see Figure 3.3; Cojan et al., 2009; Deeley et al., 2013). Hence, action inhibition during paralysis occurs late in the chain of the ideomotor hierarchy. Altered feelings of agency during hypnosis refer to a diminished sense of control during the production of actions (Polito, Barnier, Woody, & Connors, 2014). These distortions of the self notably relate to areas involved in action monitoring such as the precuneus, inferior parietal area, and the cerebellum (Blakemore et al., 2003; Deeley et al., 2014). These observations provide meaningful information concerning the neural substrates of agency.

minute differences in the formatting of suggestions may cause distinct neural responses (Barabasz et al., 1999). Nonetheless, beyond this variability, these findings highlight the ability of suggestions to selectively engage specific brain networks that correspond to the content of these instructions. The neuroscience of hypnosis therefore demonstrates how hypnosis can target specific perceptual, cognitive, or ideomotor processes (Landry, Appourchaux, & Raz, 2014).

CONCLUSION

Hypnotic phenomena index an interaction among many psychosocial factors. Three prominent factors tower: interindividual variability in hypnotizability, the induction procedure, and the content of hypnotic suggestions (Mazzoni et al., 2013; Oakley & Halligan, 2010). In this chapter, we briefly discussed neuroscientific evidence related to these factors. For example, we showed how numerous findings attest to the centrality of the frontal brain in hypnosis. These observations implicate neural networks related to mental alertness, executive control, top-down regulation, and cognitive monitoring. In particular, evidence shows that hypnotizability, a psychological trait, relates to structural and functional specificities, likely coded within the frontal brain. Studies also report that the induction procedure recruits central nodes of the control networks involved in mobilizing attention. This neural response may reflect a form of mental preparation, perhaps a strategy, to produce a fitting hypnotic response. Moreover, neuroimaging of hypnosis denotes altered connectivity patterns between anterior and posterior areas, thereby supporting dissociation views of hypnosis. Finally, evidence confirms the efficacy of hypnotic suggestions to reliably engage focal brain networks. Overall, ongoing investigations concerning the neural correlates of hypnosis afford researchers and clinicians better scientific understanding regarding the underlying brain mechanisms that subserve hypnotic phenomena. Such findings deliver a reliable framework that contributes to the development of a general theory of hypnosis.

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