Cognitive Control Processes and Hypnosis

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1. Introduction

The striking changes in perception and conscious awareness that can be achieved with hypnotic induction have fascinated psychologists for many years. How does one account for neurologically healthy subjects who, following hypnotic induction and appropriate suggestions, report to perceive an illusory voice, or negate seeing an object placed right in front of them? To hypnosis researchers, the recent advent of cognitive neuroscience has brought forth great promise, with new techniques such as functional magnetic resonance imaging (fMRI) allowing us to take a peek into the hypnotized brain. However, the benefits of a cross-talk between the fields of hypnosis and cognitive neuroscience research are mutual, for hypnotic suggestions can serve as a rich avenue for the investigation of fundamental brain processes (Raz & Shapiro, 2002). From a cognitive neuroscience perspective, the apparent dissociation between subjective experience and external stimulation observed in hypnotized subjects represents a powerful demonstration of top-down mechanisms affecting bottom-up processes, which are often thought of as automatic or involuntary. Clearly, a thorough understanding of the neural mechanisms underlying hypnosis will contribute substantially to our comprehension of human brain function *per se*.

The fact that hypnotic suggestions may help to effectively override what are traditionally considered automatic or pre-potent processes is of particular intrigue to cognitive neuroscientists, because this ability is regarded as the domain of high-level “cognitive control” processes. Cognitive control connotes a capacity-limited resource that is thought to be required when dealing with situations where mere “automatic” processing would not suffice to produce optimal performance (or may even interfere with optimal performance), and has been closely tied to functions of the frontal lobes (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miller & Cohen, 2001). Situations that require cognitive control include the performance of novel tasks, simultaneous tasks, task switching, and more generally, the need to override pre-potent associations and responses. Does this mean that hypnotic phenomena can simply be equated to an extreme instance of normal top-down cognitive control processes? Probably not: after all, hypnotized subjects seem to be characterized by a *lack* of volition and control over their own actions, with the latter being dictated by the suggestions of the hypnotist. The current chapter is aimed at elucidating this apparently paradoxical relationship between cognitive control and hypnosis, and the brain processes mediating their association.

Before we commence, a few semantic and methodological pointers for the reader unfamiliar with hypnosis jargon are in order. A hypnosis session typically consists of three phases; the *hypnotic induction* (usually involving instructions to focus exclusively on the hypnotists voice, accompanied by a progressive relaxation), followed by a number of *hypnotic suggestions* (for example the suggestion that there is a voice addressing the subject from a non-existent loudspeaker), and finally a *deinduction* (typically a “countdown” for the subject to return to a normal, alert state) that finishes the session. In addition, hypnotic suggestions can be given that exhort the subjects to carry out a particular act in response to a cue given *after* the hypnotic session has concluded, a technique referred to as *post-hypnotic suggestion*. Furthermore, it is important to appreciate that subjects’ susceptibility to hypnosis varies greatly. Therefore, subjects are typically pre-tested with standardized hypnotic induction scripts, such as the Harvard Group Scale of Hypnotic Susceptibility (HGSHS) (Shor & Orne, 1962) or the Stanford Hypnotic Susceptibility Scale (SHSS) (Weitzenhoffer & Hilgard, 1962). Obviously, for different studies to be comparable, it is important that they employ similar subject selection criteria. A typical research design in a hypnosis study compares a dependent measure (for example behavioral performance on an attention task) between pre-selected subjects of very low versus very high hypnotic susceptibility, outside the hypnotic context versus subsequent to hypnotic induction or in response to specific hypnotic suggestions. Hypnotic performance in this kind of design should be observed only in highly susceptible subjects in the hypnosis condition.

Finally, the discussion of cognitive control processes in relation to hypnosis and hypnotic susceptibility in the current chapter does of course take place in the context of previous theorizing, and we will interpret the literature with reference to some major currents in this field, as outlined here. Perhaps not surprisingly, theoretical models of hypnosis have traditionally emphasized the importance of attentional control processes in accounting for hypnotic phenomena (Barber, 1960; Crawford & Gruzelier, 1992; Gruzelier, 1998; Hilgard, 1965; Hilgard, 1977; Karlin, 1979; Krippner & Bindler, 1974; Raz, 2004; Raz & Shapiro, 2002; Tellegen & Atkinson, 1974; Woody & Bowers, 1994). Two broad schools of thought have evolved around this issue. One view proposes that individuals who are highly susceptible to hypnosis possess the ability to strongly focus their attention, and that the hypnotic condition itself is characterized by a state of highly focused attention (Barber, 1960; Spiegel, 2003; Tellegen & Atkinson, 1974). Another view argues that highly susceptible individuals may indeed be particularly adept at focusing their attention, but that once they are hypnotized, control of attention is impaired (Crawford & Gruzelier, 1992; Gruzelier, 1990, 1998; Hilgard, 1965; Hilgard, 1977; Jamieson & Sheehan, 2004; Woody & Bowers, 1994). At the neurophysiological level, many theoretical formulations have hypothesized a crucial involvement of frontal lobe functions in mediating hypnosis and hypnotic susceptibility (Crawford & Gruzelier, 1992; Gruzelier, 1990, 1998; Woody & Bowers, 1994). In the following, these models will be referred to as the “focused attention” and the “impaired attention” views of hypnosis.

We will first review how cognitive control is measured behaviorally, focusing in particular on the use of the color-word Stroop task (MacLeod, 1991; Stroop, 1935) (section 2.1.). This exposition will be followed by a summary of the current literature on the functional neuroanatomy of cognitive control processes (section 2.2.). Then we will conduct a selective review of the behavioral and neuroimaging hypnosis literature in relation to cognitive control processes, as gauged by variants of the Stroop task (section 3). This review will make an important methodological distinction between studies where the hypnotic induction procedure includes suggestions to improve Stroop task performance on the one hand (section 3.2.), and studies that did not incorporate such task-specific suggestions on the other hand (section 3.1.). Based on our discussion of this literature, we will outline a model to resolve the paradoxical relationship of hypnosis and cognitive control.

2. What is Cognitive Control?

In this section we first present the concept of cognitive control and introduce psychological tasks and analysis techniques that purport to measure this construct. We then provide a brief, selective review of research into the functional neuroanatomy of cognitive control processes.

2.1. Psychological Concept and Behavioral Measures of Cognitive Control

The distinction between “controlled” and “automatic” processing, alluded to in the introduction, has a long tradition in theories of attention, where controlled processes have been characterized as requiring attention whereas automatic processes do not (Cattell, 1886; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). The concept of cognitive control closely resembles previous notions of attentional control, such as Shallice’s supervisory attention system (Norman & Shallice, 1986), or Posner’s executive attention system (Posner & DiGirolamo, 1998; Posner & Petersen, 1990). For our current purposes we will adopt the working definition that cognitive control describes the process or collection of processes that underpin the *flexible management of processing resources for optimal task performance*. This includes maintaining a representation of current goals in working memory, gauging the need for strategic performance adjustments, and implementing such adjustments, for example by steering attention towards task-relevant stimulus properties.

The efficiency of cognitive control functions has typically been inferred from traditional selective attention tasks, such as the Stroop task (MacLeod, 1991; Stroop, 1935) or the Eriksen flanker task (Eriksen & Eriksen, 1974), which require subjects to attend and respond to one stimulus dimension (the “target” dimension), while ignoring another stimulus dimension (the “distracter” dimension). The need for controlled attention is manipulated by varying the response-compatibility between target and distracter dimensions, which can either be in conflict with each other (incongruent), unrelated (neutral), or in accordance with each other (congruent). For instance, in a typical Stroop paradigm, subjects are required to name the ink-color in which a word stimulus is presented while ignoring the word-meaning of the stimulus. Here, incongruent stimuli (e.g. the word RED printed in green ink) are typically associated with slower responses than neutral stimuli (e.g. XXXX in green ink), which in turn are identified more slowly than congruent stimuli (e.g. the word GREEN printed in green ink). The differential of incongruent to congruent (or neutral) reaction times constitutes the amount of interference or conflict experienced by the subject.

The amount of conflict incurred from an incongruent distracter, and by inference the degree of controlled attention required for processing the target, is determined by the *relative* strength of processing pathways (i.e. the relative "automaticity") associated with the target and distracter dimensions, respectively, which arise from physical stimulus properties and, importantly, subjects' previous experience with the stimulus dimensions in relation to current task requirements (Cohen, Dunbar, & McClelland, 1990; MacLeod & Dunbar, 1988). For instance, the fact that the word-dimension of Stroop stimuli interferes substantially more with the color-dimension than the other way around is accounted for by the vastly greater experience we have with reading words compared to naming the ink-color of words (Cohen et al., 1990).

The Stroop task has evolved into perhaps the primary psychological measure of high-level, "executive" cognition (MacLeod & MacDonald, 2000) as well as a standard neuropsychological assessment tool of frontal lobe function (Stuss, Floden, Alexander, Levine, & Katz, 2001). The Stroop task has also been suggested as a potent arbitrator between models of cognitive control processes in relation to hypnosis and hypnotic susceptibility (Kirsch & Lynn, 1998), and attentional control in hypnosis has indeed been investigated most extensively with variants of this paradigm (see section 3 below). However, as a measure of cognitive control *per se*, the traditional Stroop interference score, gauged via the subtraction of either neutral or congruent trial reaction times from incongruent ones, is ambiguous. This is because the correct categorization of an incongruent stimulus (compared to a neutral or congruent trial) likely involves manifold processes, such as the detection of response conflict engendered by the incompatible stimulus dimensions, inhibition of the motor response associated with the distracter dimension, selection of the correct response, and strategic adjustments in selective attention for the up-coming trial. Thus, behavioral and neuroimaging assays based on the standard Stroop subtraction capture an aggregate of (at least) conflict-detection and control (conflict-resolution) processes, and cannot unambiguously isolate the specific contribution of cognitive control.

It is possible, however, to dissociate cognitive control components of Stroop task performance from conflict detection by manipulating conflict levels via either the proportion of incongruent-to-congruent trials presented in a given block of trials (Logan & Zbrodoff, 1979, 1982), or by analyzing performance on a given trial type (congruent/incongruent) as a function of the preceding trial type (Gratton, Coles, & Donchin, 1992). This is because subjects appear to strategically adjust the level of control exerted in response to the level of conflict experienced or expected in a given trial or task block, such that control is up-regulated following (and in anticipation of) high conflict, and down-regulated following (and in anticipation of) low conflict (Botvinick et al., 2001), a phenomenon known as “conflict adaptation”. For example, if subjects are presented with a Stroop task where a high proportion of trials are incongruent and a low proportion of trials are congruent, they appear to adjust to the higher level (and likelihood) of conflict by exerting more cognitive control. This is evidenced by lower interference scores in such a condition than when performing a condition where congruent trials are frequent and incongruent trials are rare (Carter et al., 2000; Cohen et al., 1990; Logan & Zbrodoff, 1979, 1982). Thus, through the manipulation of the likelihood of incongruent trials occurring across blocks of trials, it is possible to distinguish between blocks where cognitive control is high and conflict is low (high proportion of incongruent-to-congruent trials), and blocks where cognitive control is low and conflict is high (low proportion of incongruent-to-congruent trials). Adjustments in cognitive control in response to varying levels of conflict can also be observed when presenting congruent and incongruent trials in equal proportions, and analyzing performance on a given trial on the basis of which trial has preceded it. Here, it has been established that interference scores on current trials are reduced following high conflict (incongruent) trials compared to low conflict (congruent) trials, suggesting that conflict leads to a transient up-regulation in control for the up-coming trial (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Egner & Hirsch, 2005a, 2005b; Gratton et al., 1992; Kerns et al., 2004).

In summary, interference scores from traditional selective attention tasks have been widely employed as a *quasi* indicator of cognitive control, but they really constitute a composite measure of numerous high level processes rather than an exclusive estimate of cognitive control. More appropriate assays of the strategic control of selective attention can be obtained by gauging adaptation to varying levels of conflict in variants of the Stroop and flanker paradigms. This more direct probing of cognitive control processes, however, is underrepresented in the general cognitive neuroscience research literature and to date largely unexploited within the field of hypnosis research.

2. 2. Neural Substrates of Cognitive Control

Not surprisingly, the classic interference tasks introduced in the previous section have formed the bedrock of neuroimaging research dedicated to outlining neural substrates of cognitive control processes. It is well established that a network of medial and lateral frontal cortices, particularly the dorsal anterior cingulate cortex (dACC) and lateral prefrontal cortex (lPFC), as well as parietal cortex, are more active when processing incongruent stimuli as compared to neutral or congruent ones (Barch et al., 2001; Bench et al., 1993; Carter, Mintun, & Cohen, 1995;

Casey et al., 2000; Durston et al., 2003; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Hazeltine, Bunge, Scanlon, & Gabrieli, 2003; Leung, Skudlarski, Gatenby, Peterson, & Gore, 2000; Milham, Banich, Claus, & Cohen, 2003; Milham et al., 2001; Pardo, Pardo, Janer, & Raichle, 1990; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001). Reliable co-activation in these regions in attentionally demanding conditions has led to the generally accepted notion of a fronto-parietal "executive attention" network, but the delineation of the distinct functional contributions of each sub-region within this network remains very much a work-in-progress, especially given that largely overlapping areas appear to be involved in a variety of other cognitive tasks as well (Duncan & Owen, 2000).

As discussed previously in the context of behavioral variables, a dissociation of the neural correlates of cognitive control from other processes inherent in the processing of incongruent trials *per se* may be achieved through the use of conflict adaptation paradigms. A number of studies have pursued this approach specifically in order to differentiate neural substrates of conflict detection from those of cognitive control. Focusing on the role of the dACC within this context, it has been shown that activity in this region primarily co-varies with the degree of conflict elicited by an incongruent stimulus, rather than with strategic control processes associated with conflict resolution (Botvinick et al., 1999; Carter et al., 2000; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000). For example, dACC is more activated by incongruent trials under conditions of low control (after a congruent trial) than by incongruent trials under conditions of high control (after an incongruent trial) (Botvinick et al., 1999; Kerns et al., 2004), supporting the conceptualization of the dACC as an evaluative conflict monitoring system (Botvinick et al., 2001). While a rapidly growing body of evidence lends support to this model of dACC function (Botvinick, Cohen, & Carter, 2004), it remains a possibility that other sub-regions of this area are involved in more strategic (Posner & DiGirolamo, 1998; Weissman, Warner, & Woldorff, 2004) and volitional processes (Nachev, Rees, Parton, Kennard, & Husain, 2005).

Neural correlates of cognitive control, on the other hand, have been localized to the lPFC (Egner & Hirsch, 2005a, 2005b; Kerns et al., 2004; MacDonald et al., 2000). For instance, when analyzing conflict adaptation effects in a Stroop task, it has been shown that regions in lPFC exhibit an opposite activation pattern to that reported for the dACC: Activity in lPFC is higher under conditions of high control and low conflict than under conditions of low control and high conflict (Egner & Hirsch, 2005a, 2005b; Kerns et al., 2004), and the degree of lPFC activation is positively correlated with the degree of conflict reduction across individuals (Egner & Hirsch, 2005a). Furthermore, it has been demonstrated that lPFC is particularly activated after trials on which the dACC exhibited high activation due to conflict, and the degree of such lPFC recruitment predicts the level of conflict reduction on the subsequent trial (Kerns et al., 2004). This superior conflict resolution has recently been shown to be related to the functional interaction between lPFC and early perceptual processing regions, resulting in an attentional amplification of the neural representation of task-relevant stimulus properties (Egner & Hirsch, 2005b). In a different paradigm that sought to dissociate strategic control from conflict monitoring processes, MacDonald and colleagues (MacDonald et al., 2000) found increased lPFC activity in preparation for cued more difficult (color-naming) compared easier (word-naming) Stroop trials, but no differential response to the actual conflict induced by the subsequently presented stimulus (incongruent versus congruent). The dACC, on the other hand, showed the opposite pattern of results, with more activation to incongruent than congruent stimuli, but no difference in activity with respect to the cue period.

In conclusion, based on studies that have attempted to explicitly tease apart conflict and control processes, it appears that the fronto-parietal executive attention network can be broken down into a component that is primarily involved with detecting conflict (the dACC), and another component primarily dedicated to strategic adjustments in control (the lPFC). With reference to the well-documented role of the parietal cortex in attentional orienting (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Hopfinger, Buonocore, & Mangun, 2000; Mort et al., 2003), one parsimonious view would suggest that parietal regions may mediate the actual implementation of control, for example by directly biasing visual information processing in response to control signals from lPFC (Durston et al., 2003; Egner & Hirsch, 2005a). However, many details of the functional interaction between components of the executive control system sketched out above remain unknown. Furthermore, performance adjustments of the type described here may arise from various sources additional to or instead of processing conflict, including lower level priming phenomena (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., In Press) and expectancy effects (Gratton et al., 1992) (cf. Egner & Hirsch, 2005b).

3. Hypnosis and Hypnotic Susceptibility in Relation to Executive Control Processes

In this section we will conduct a selective review of the hypnosis research literature that speaks directly to the nature of the involvement of cognitive control processes in hypnosis and hypnotic susceptibility. Particularly, the exposition will focus on studies that have employed variants of the Stroop protocol, and highlight implications with respect to the assumptions underlying the “focused attention” and “impaired attention” models of hypnosis (cf. Egner, Jamieson, & Gruzelier, 2005) that were alluded to previously. Note that these views make opposing predictions with respect to the effects of hypnosis on Stroop task performance: The focused attention model asserts that highly susceptible subjects are characterized by focused attention during hypnosis, and should therefore predict low interference effects, compared to baseline as well as relative to subjects with low susceptibility. The impaired attention view, on the other hand, predicts that highly susceptible individuals should exhibit poorer

Stroop performance in hypnosis than at baseline and in comparison with subjects of low susceptibility, due to an inhibition or dissociation of executive control functions. In discussing the research literature in this regard, an important methodological distinction will be drawn between studies where Stroop protocols were performed under conditions that included specific hypnotic instructions to promote particular cognitive strategies aimed at overriding the Stroop effect, and studies that did not contain any task-specific hypnotic instructions.

3. 1. Cognitive control in the absence of task-specific hypnotic suggestion.

An early study that produced suggestive data on systematic differences in higher cognitive processing between individuals of low and high hypnotic susceptibility was conducted by Blum and Graef (Blum & Graef, 1971). These authors sought to differentiate low susceptible “simulators” from highly susceptible hypnotic subjects by comparing Stroop performance in response to a post-hypnotic suggestion procedure that aimed at manipulating arousal levels. Highly susceptible subjects exhibited increased Stroop interference scores with decreasing arousal, and higher interference across all levels of this manipulation than low susceptible subjects, suggesting less efficient attentional processing in the highly susceptible individuals. Note, however, that these results do not speak directly to cognitive processing during hypnosis, as the data were collected outside hypnosis (in response to a post-hypnotic suggestion). Furthermore, a very small sample size (5 highly susceptible and 2 low susceptible subjects) precluded the use of inferential statistics. Therefore, this study may arguably serve primarily as a suggestive historical antecedent for subsequent research, rather than as strong evidence for impaired cognition in hypnotic responders.

In an influential study, Sheehan, Donovan, and MacLeod (Sheehan, Donovan, & MacLeod, 1988) provided the basic conceptual and empirical framework for addressing the relation between Stroop performance and hypnotic phenomena. Their study assessed color-naming of incongruent Stroop stimuli in subjects of low and high susceptibility, once at baseline, once after hypnotic induction without task-specific suggestions, and once after hypnotic induction that included task-specific suggestions to override the Stroop effect. The instruction for overcoming Stroop interference consisted of exhorting the subjects to focus attention only on the bottom portion of the last letter of the color-word stimulus, so as to be aware of the ink color only. Sheehan et al.'s (1988) results showed a hypnosis by susceptibility interaction effect, as reaction times slowed from baseline to hypnosis in subjects of high but not of low susceptibility. Conversely, highly susceptible individuals displayed a trend for improved performance with task-specific suggestions, which was not evident in subjects of low susceptibility (see also section 3.2. below). In addition, highly susceptible subjects reported the spontaneous use of cognitive strategies for Stroop performance at baseline, but not in the hypnotic condition without task-specific instructions. Subjects of low susceptibility, on the other hand, reported consistently using spontaneous cognitive strategies across these two conditions.

In order to ascertain the reliability of these data, Jamieson and Sheehan conducted an extensive quasi-replication of the Sheehan et al. study, employing a large sample of 66 low and 66 highly susceptible participants (Jamieson & Sheehan, 2004). Participants performed a mixed color-/word-naming Stroop task, containing incongruent stimuli only, once at baseline and once following hypnotic induction. Both color- and word-naming reaction times were slowed in the hypnotic condition, but this effect did not interact with hypnotic susceptibility. The amount of errors committed, on the other hand, displayed a hypnosis by susceptibility interaction effect mirroring the one reported by Sheehan et al. (1988) for RT data: highly susceptible individuals' performance deteriorated from baseline to hypnosis, but this was not the case for subjects of low susceptibility. Subsequent to the behavioral experiment, subjects were asked to report whether and how frequently they used any of three possible spontaneous strategies; sub-vocal rehearsal of task instructions ("word, "color"), an "experiential strategy" that consisted of "just letting responses happen", or a positional strategy that consisted of focusing on a small aspect of the overall stimulus. The use of the rehearsal strategy dropped from baseline to hypnosis, and tended to do so more in highly susceptible subjects. The use of the experiential strategy, on the other hand, increased from baseline to hypnosis, and this was more significantly the case in highly susceptible participants. The authors concluded from these data that hypnosis appears to both impair attentional control and the self-directed use of cognitive strategies (Jamieson & Sheehan, 2004).

What aspect of attentional control in particular might be affected by hypnotic induction? Kaiser and colleagues (Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997) examined the relation between hypnosis and performance on a Stroop-like task while measuring electric brain activity in the form of event-related potentials (ERPs).. Specifically, their study assessed ERPs related to error-processing, namely the error-related negativity (N_E) (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Gross, Coles, Meyer, & Donchin, 1993) and the subsequent error-related positivity (P_E) (Falkenstein et al., 1991), two response-locked ERP components occurring after an error has been committed. The N_E was originally interpreted as directly reflecting the detection of an error (Falkenstein et al., 1991; Gehring et al., 1993), but has since been re-conceptualized as representing the comparator process between the intended and the correct response, which precedes error detection (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000), or as reflecting post-response conflict-monitoring processes (Yeung, Cohen, & Botvinick, 2004). In either of these scenarios, the N_E is clearly proposed to constitute an important sub-process of cognitive control, namely the evaluation of a current response, which is thought to underlie strategic adjustments in performance. Modeling of the likely neural source underlying this ERP component has implicated the dACC (Dehaene, Posner, & Tucker, 1994; Miltner, Braun, & Coles, 1997), a notion that has found corroboration in a number of fMRI studies (Carter et al., 1998; Kiehl, Liddle, & Hopfinger, 2000; Menon, Adleman, White, Glover, & Reiss, 2001;

Ullsperger & von Cramon, 2001). The later P_E component, also emanating from medial frontal cortex (Herrmann, Rommler, Ehlis, Heidrich, & Fallgatter, 2004; Van Veen & Carter, 2002), is partly independent of the N_E but more reliably predicts post-error slowing (Hajcak, McDonald, & Simons, 2003; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001), and has thus been proposed to reflect the becoming consciously aware of a committed error, which may be more directly related to performance adjustments than the N_E (Hajcak et al., 2003; Nieuwenhuis et al., 2001) (see also Jamieson and Woody, this volume).

Kaiser et al. (1997) required subjects to push “left” or “right” buttons in response to arrow stimuli that pointed either to the left or right. In order to induce response conflict, the arrows could either be of green color, requiring a response congruent with the direction of the arrow, or of red color, requiring a response incongruent with the direction of the arrow. Error rates displayed a hypnosis by susceptibility interaction effect, as errors increased significantly from baseline to hypnosis in highly susceptible but not in low susceptible subjects. Furthermore, this effect was evident for the incongruent condition, but not the congruent one. Reaction times were slower on incongruent compared to congruent trials, but this effect did not interact with hypnosis or susceptibility variables. The ERP data disclosed no effects involving the N_E, but a marginal interaction effect with respect to the P_E component, as highly susceptible participants showed a decrease in P_E amplitude from baseline to hypnosis, which was not the case for low susceptible subjects. The authors interpreted the behavioral findings as supportive of the proposition that hypnosis in highly hypnotizable subjects involves the inhibition of frontal executive functions (reflected in impaired performance on incongruent trials). From the ERP results, the authors concluded that while early error-processing (reflected in the N_E) appears to remain intact, hypnosis seems to attenuate consequent processes of contextual updating of the error occurrence, resulting in failed modulation of behavior.

In a further ERP study, Nordby and associates (Nordby, Hugdahl, Jasiukaitis, & Spiegel, 1999) employed a modified version of the color-naming Stroop task, where stimuli were presented in the left and right peripheral visual fields (rather than centrally). Behavioral and ERP data were acquired from low and high susceptible subjects, at baseline and following hypnotic induction. While there were no effects involving reaction times, a large increase in error rate was observed in the highly susceptible group only when going from baseline to hypnosis conditions. The authors further found that highly hypnotizable individuals displayed an attenuated P3a amplitude as well as faster N2b latencies in their ERPs, compared to low susceptible indiviuals, but these differences did not interact with hypnosis. The behavioral results of this study mirror other findings of selectively impaired Stroop performance in highly susceptible subjects under hypnosis (Jamieson & Sheehan, 2004; Kaiser et al., 1997; Sheehan et al., 1988). The ERP data were interpreted by the authors as reflecting a general failure in attentional orienting or disengagement of spatial attention in highly susceptible individuals (Nordby et al., 1999).

The data from the studies reviewed thus far are clearly in general accordance with an impaired attention view of hypnosis, in that all of them have reported performance detriments during hypnosis that were specific to highly susceptible individuals. Impairments have sometimes manifested in slowed response times (Sheehan et al., 1988), but more often in increased error rates (Jamieson & Sheehan, 2004; Kaiser et al., 1997; Nordby et al., 1999), and appear to be accompanied by a decrease in the use of spontaneous cognitive strategies (Jamieson & Sheehan, 2004; Sheehan et al., 1988). None of these studies have documented any evidence for Stroop performance improvements under hypnosis, a prediction of the focused attention account. A number of issues should be noted, however, that prevent the drawing of very specific conclusions with respect to the type of performance impairment that may be associated with hypnosis. After all, performance on a Stroop task may be affected by a host of processes that are not directly related to cognitive control. With respect to the methodological considerations reviewed in section 2, none of the Stroop-type hypnosis studies reviewed above contained any manipulations aimed at parsing different aspects of executive processes during Stroop performance. Therefore, it cannot be deduced from these investigation whether the performance changes in highly susceptible subjects under hypnosis were underpinned by an impairment of conflict detection, of signaling between conflict monitoring and cognitive control systems, of the proper maintenance and implementation of task-set variables by the cognitive control system, or other attendant processes. Furthermore, in studies that exclusively employ incongruent stimuli (Jamieson & Sheehan, 2004; Sheehan et al., 1988), it is impossible to distinguish a deficit in attentional selection of the task-relevant stimulus dimension from a generic performance decrement that may encompass processing of all stimuli, irrespective of whether they require attentional selection or not (such as neutral or congruent stimuli). This problem was avoided by Kaiser and colleagues (Kaiser et al., 1997), who showed that hypnosis effects on performance were specific to the processing of incongruent trials and not present in congruent ones. In addition, their ERP data supplies evidence for the impairment of a more closely circumscribed facet of executive processing, namely the contextual updating of performance evaluation information that is necessary for successful behavioral adjustments. Regarding this latter interpretation, however, Kaiser and associates have unfortunately not provided evidence that behavioral modulation after error commission was specifically affected in highly susceptible subjects during hypnosis. Specifically, the degree of so-called “post-error slowing”, a tendency to produce slower but more accurate responses following an error trial (Rabbitt, 1966), should have been affected in the highly susceptible individuals.

Let us now turn to a small number of studies that have made some attempts at isolating strategic control processes in Stroop performance in relation to hypnotic susceptibility and hypnosis. Dixon and colleagues (Dixon, Brunet, & Laurence, 1990) conducted an intricate experiment that employed a Stroop-task variant where a color-word (“blue”, “green”, “red”, or “yellow”, presented in black ink) immediately preceded the presentation of a colored rectangle (blue, green, red, or yellow), the color of which subjects were required to name. The word primes could be congruent or incongruent with respect to the subsequent rectangle color. Levels of conflict/control were varied in a block-wise fashion, by presenting a low congruent-to-incongruent stimulus ratio (75 % incongruent) in one condition of the experiment, and a high congruent-to-incongruent ratio (25% incongruent) in another condition. Recall from section 2 that a block with a high proportion of incongruent stimuli should be associated with high cognitive control, which in turn should result in small Stroop interference scores. Conversely, blocks with a low proportion of incongruent trials should be associated with low cognitive control and consequently exhibit high interference scores. The degree to which subjects employ strategic control processes to optimize performance can thus be gauged by assessing the reduction in interference between low control and high control blocks. The authors also manipulated the degree to which the distracter word information could influence color-naming. The color-words were presented either for a duration that was well above subjects’ perceptual threshold, or for a duration where subjects could not confidently identify the meaning of the word. Both conflict/control versions of the task were run at both threshold levels in subjects of low, moderate, and high hypnotic susceptibility, at baseline only.

Dixon et al. (1990) found a hypnotic susceptibility by congruency interaction effect, as highly susceptible subjects exhibited significantly elevated interference scores in terms of reaction times. While there was no significant 3-way interaction effect involving susceptibility, congruency, and conflict/control variables, the authors present some intriguing simple effects data: with supra-threshold distracter stimuli, when going from low to high control conditions, low susceptible subjects displayed an abolished interference effect, whereas highly susceptible subjects did still show significant interference in the high control condition. These data can be interpreted as indicating that highly susceptible subjects were less successful at adjusting their attentional strategy than subjects with low susceptibility. (Note that the authors of the study favor a slightly different terminology and interpretation, concluding that highly susceptible subjects display a higher degree of automaticity in processing the color-word information). Unfortunately, this study did not include hypnotic induction as an experimental factor, and therefore cannot speak to any potential interaction between susceptibility and hypnosis variables.

In a follow-up experiment, Dixon and Laurence (Dixon & Laurence, 1992) sought to further separate automatic from strategic processing by varying the time interval between a color-word prime (“blue” or “red”, in back ink) and a subsequent colored rectangle (in blue or red ink) that subjects were required to categorize. The prime words were predictive of the opposite color in the subsequent rectangle, that is if the prime word was “blue”, on 75% of the trials the subsequent stimulus was red, and vice versa. The authors reasoned that at short prime-to-probe intervals, automatic processing would prevail and a Stroop interference effect would be evident, whereas at longer intervals, strategic processing could be implemented and the Stroop effect reversed (Logan, Zbrodoff, & Williamson, 1984). Subjects of low and high hypnotizability underwent testing at seven different prime-to-probe intervals. Stroop interference was reversed when going from short to long prime-to-probe intervals, attributable to the implementation of strategic processing. This effect, however, interacted with hypnotic susceptibility, as only the highly susceptible subjects displayed significant interference effects at the shortest prime-to-probe interval, and showed a reverse interference effect at a shorter prime-to-probe interval than low susceptible subjects. The authors interpreted these data as indicating that highly susceptible subjects show a greater automaticity of word-processing, due to greater interference at short prime-to-probe intervals, but *also* that highly susceptible individuals are better at implementing strategic adjustments than individuals with low susceptibility. Again, these data unfortunately do not address the effects of hypnotic induction, as the task was administered at baseline only.

The studies of Dixon and colleagues, while explicitly manipulating strategic control processes in Stroop performance, allow only for limited conclusions to be drawn with respect to models of attentional control and hypnosis. This is primarily because these investigations did not assess the interaction of hypnosis with hypnotic susceptibility, which is where the divergence of predictions from the focused and impaired attention models of hypnosis becomes apparent. Outside the hypnotic context, both views accommodate the assumption that highly susceptible subjects may be more adept at strongly engaging their attention compared to subjects of low susceptibility. Furthermore, with respect to the efficiency of strategic processing at baseline, results from the two studies by Dixon and associates are arguably inconsistent. The first study (Dixon et al., 1990) showed higher interference scores in highly susceptible subjects, and particularly so in a condition consisting of 75% incongruent trials, i.e. under conditions of high strategic control, suggesting *deficient* control processes in highly susceptible subjects. In the second study (Dixon & Laurence, 1992), on the other hand, strategic reversal of the Stroop effect was evident at shorter prime-to-probe intervals in high than in low susceptible individuals, which suggests *better* strategic use of prime information in highly susceptible subjects. Therefore, on the basis of these results, it appears difficult to draw firm conclusions regarding the relation between hypnotic susceptibility and efficient operation of cognitive control mechanisms.

A study that was specifically geared towards contrasting predictions of the focused and impaired attention models of hypnosis at the neural level, was recently conducted by Egner, Jamieson, and Gruzelier (Egner et al., 2005). These authors carried out a combined fMRI and EEG study, using a Stroop task with congruent and incongruent color-words, which were subject to either color-naming or word-naming instructions, alternating between blocks of trials. Thus, there were 4 trial types of varying conflict; namely congruent word-naming trials (low conflict), incongruent word-naming and congruent color-naming trials (moderate conflict), and incongruent color-naming trials (high conflict). Based on the model of conflict-monitoring and cognitive control outlined in section 2, it was expected that dACC activity would co-vary positively with conflict levels. Cognitive control processes, on the other hand, were expected to be more highly engaged during color-naming trials than during word-naming trials (MacDonald et al., 2000). Egner and colleagues assessed conflict- and control-related brain activity in subjects of low and high hypnotic susceptibility, once at baseline and once after a hypnotic induction, with the order of conditions counterbalanced across groups. In addition, the same paradigm was repeated for all subjects in the EEG laboratory. Note that the focused attention model would predict that highly susceptible subjects exhibit less conflict-related dACC activation than low susceptible ones, both at baseline and particularly during hypnosis. The impaired attention model, on the other hand, would predict that highly susceptible subjects experience more conflict in the hypnotic condition, both compared to baseline and to low susceptible subjects.

The authors found that, at equal behavioral performance, conflict-related dACC activity did not differ between groups at baseline, but was significantly increased in highly susceptible subjects after hypnotic induction, in comparison to baseline and in comparison to low susceptible subjects. This interaction corresponds precisely to the hypotheses derived from the impaired attention model of hypnosis. Next, the authors assessed how control-related activity, detected in left lPFC, varied with hypnosis and hypnotic susceptibility. In contrast to conflict-related activation in the dACC, there was no difference between groups and conditions in the control-related lPFC activation. From these data, the authors concluded that, while highly susceptible subjects experienced increased conflict in the hypnotic condition, they did not recruit additional cognitive control resources (reflected by lPFC activation) in order to resolve that conflict, which suggests a breakdown in communication between conflict-detection and control processes. In support of this interpretation, EEG coherence data, reflecting functional connectivity between neuronal populations underlying different scalp sites (Miltner, Braun, Arnold, Witte, & Taub, 1999; Tallon-Baudry & Bertrand, 1999), showed that coherence between the mid-frontal electrode site (overlying the dACC) and the left lateral frontal site (overlying lPFC) in the high frequency gamma range was reduced in highly susceptible subjects after hypnotic induction, but not in low susceptible participants. These data were interpreted as further corroboration of a possible disruption of functional interaction between medial frontal conflict-monitoring and lateral frontal control functions in hypnosis (Egner et al., 2005).

In summary, studies examining behavioral and neural correlates of Stroop-type task performance with respect to hypnosis and hypnotic susceptibility in the absence of task-specific hypnotic instructions have produced some consistent and many convergent findings. The most replicable finding is that highly susceptible subjects suffer performance decrements after hypnotic induction, while subjects of low susceptibility do not (Jamieson & Sheehan, 2004; Kaiser et al., 1997; Nordby et al., 1999; Sheehan et al., 1988). The precise nature of impaired attention performance under hypnosis, however, remains an intriguing issue for future empirical investigation. For instance, no study as of yet has assessed performance on a conflict-adaptation Stroop protocol, arguably the most appropriate measure of cognitive control processes (as outlined in section 2), as a function of hypnosis and hypnotic susceptibility. Nevertheless, the evidence reviewed here unequivocally supports an impaired attention view over a focused attention view of hypnosis, thus lending credence to models that postulate the hypnotic condition to be characterized by an inhibition (Crawford & Gruzelier, 1992; Gruzelier, 1990, 1998) or dissociation (Woody & Bowers, 1994) of frontal lobe cognitive control functions. Two convergent findings from Kaiser et al. (1997) and Egner et al. (2005) provide grounds for some interesting speculation regarding a possible mechanism for such a deficit in frontal control. Both of these studies have shown that the mechanism underlying the detection of conflict or errors appears to remain intact in hypnosis. However, it may be the case that a later processing stage, which underlies conscious awareness of error commission and/or the communication of the detected processing conflict to cortical regions implementing performance adjustments, is affected during hypnosis. This conjecture is based on the finding that in highly susceptible subjects under hypnosis, the error-related positivity (P_E) is diminished (Kaiser et al., 1997), and the functional interaction between medial frontal and lateral frontal sites is disrupted (Egner et al., 2005). Consequently, even though the conflict-monitoring system may detect high conflict levels, there is no resultant strategic adjustment in cognitive control processes (Egner et al., 2005). This suggested refinement of the dissociated control view of hypnosis (see also Jamieson and Woody, this volume) may serve to guide and constrain future rigorous empirical testing of the psychological and neural substrates of hypnotic phenomena.

3. 2. Cognitive control in response to task-specific hypnotic instructions

In the previous section we have reviewed evidence to suggest that cognitive control processes are specifically impaired in highly susceptible individuals after a generic hypnotic induction. Recall, however, that when Sheehan and colleagues instructed subjects to employ a specific cognitive strategy aimed at overriding the Stroop effect, it was the highly susceptible subjects who benefited significantly from this intervention (Sheehan et al., 1988). This would suggest that, while cognitive control may be generally suppressed or dissociated during instruction-free hypnosis, this condition does nevertheless lend itself to the efficient implementation of an externally instructed strategy. In the following, a number of studies will be reviewed where task-specific instructions to overcome Stroop interference have been employed. Note that here, hypnosis is employed in the attempt to override what is considered a highly automatic process (word reading). In this way, these hypnotic suggestions serve precisely the kind of function that usually is associated with cognitive control processes.

In a series of studies, Raz and colleagues (Raz, Fan, & Posner, 2005; Raz et al., 2003; Raz, Shapiro, Fan, & Posner, 2002) have assessed Stroop performance in response to task-specific post-hypnotic suggestions. In these studies, performance by subjects of high and low hypnotic susceptibility was compared at baseline and in response to a post-hypnotic trigger. The hypnotic suggestion that was supposed to be recalled by the post-hypnotic trigger (e.g. a handclap) was to treat the word-stimuli as if they were presented in an unfamiliar foreign language. This manipulation was aimed at preventing the “automatic” processing of the word meaning, and to thus reduce Stroop interference. In an initial study, subjects of high and low susceptibility were required to indicate the ink color of congruent or incongruent color-words, or neutral word stimuli (Raz et al., 2002). Raz and colleagues found that, in terms of RT data, highly susceptible subjects experienced Stroop interference at baseline, but that both Stroop interference and facilitation effects were successfully abolished in response to the post-hypnotic suggestion, whereas participants with low susceptibility exhibited comparable Stroop interference and facilitation effects between the two conditions. The authors concluded that post-hypnotic suggestion, presumably operating via a top-down mechanism, can effectively overcome the highly automatic word-reading process. The authors further emphasized that the nature of the post-hypnotic suggestion did not reflect an overtly attentional strategy, such as only focusing on a single letter of the word stimuli.

In a follow-up investigation, Raz and associates endeavored to substantiate these results while excluding the possibility that highly susceptible subjects may have achieved the reduction of Stroop interference by alternative means, other than by implementation of the post-hypnotic instruction (Raz et al., 2003). Specifically, the authors precluded the possibility of intentional visual blurring by pharmacologically inducing cycloplegia, the paralysis of the ocular muscles subserving visual accommodation. Furthermore, gaze orientation was monitored via video surveillance. Performance on a Stroop task identical to that in the previous study (Raz et al., 2002) was compared between conditions of a fixed crisp visual focus and a fixed blurred visual focus, at baseline. Performance was also assessed in response to a post-hypnotic suggestion (as above), given to highly susceptible subjects only, and an instruction to avert the gaze from the central stimulus, given to low susceptible subjects only. The RT data showed that significant Stroop effects were evident under clear vision and to a lesser extent under blurred vision conditions, but were abolished in highly susceptible subjects under post-hypnotic suggestions and in low susceptible subjects that had been instructed to “look away” from the stimulus. From these data, the authors concluded that the abolition of Stroop interference in highly susceptible subjects under post-hypnotic suggestions could not be attributed to intentional blurring of visual focus, but rather appears to represent a genuine suppression of lexical word processing (Raz et al., 2003).

Finally, Raz, Fan and Posner conducted a combined fMRI and EEG investigation in order to elucidate the neural correlates of post-hypnotic elimination of Stroop interference (Raz et al., 2005). A color-naming Stroop task was administered to subjects of high and low susceptibility while undergoing fMRI scanning. Subsequently, ERP data were acquired from the highly susceptible subjects only. The task was broken down into blocks, and half of the blocks were preceded by a post-hypnotic trigger (recalling the same type of instructions as in the previous studies), while the other half were not. RT data showed that highly susceptible individuals had a significantly reduced interference effect during the fMRI session, while there was no effect of suggestion on low susceptible individuals' performance. In addition, highly susceptible subjects abolished Stroop interference after post-hypnotic suggestion during the EEG session. Both of these findings were accompanied by corresponding improvements in accuracy. Regarding the fMRI data, the authors reported an interaction effect in a rostral portion of the ACC, as activation in this region was significantly reduced with suggestion in the highly susceptible individuals only. Highly susceptible participants furthermore displayed a concurrent reduction in activity in extrastriate visual cortex. ERP data from mid-occipital and mid-frontal electrode sites indicated that relatively early components of the stimulus-locked response (P100, N100) were suppressed and delayed under post-hypnotic suggestion, for both congruent and incongruent trials. Raz and associates interpreted these data as showing that post-hypnotic suggestion leads to decreased conflict in highly susceptible participants (as reflected in reduced ACC activity and behavioral interference), and that this effect may be mediated by top-down suppression of the visual processing stream, even though this dampening of visual processing appears to be generic rather than specific to word processing (Raz et al., 2005).

In summary, studies that have employed task-specific instructions aimed at overcoming Stroop interference have shown that such externally instructed cognitive strategies are more successfully implemented by highly susceptible subjects than by low susceptible subjects. These data have stemmed partly from a hypnotic context (Sheehan et al., 1988), but mostly from responses to post-hypnotic suggestions (Raz et al., 2005; Raz et al., 2003; Raz et al., 2002). A general concern when comparing some of these data to the results reviewed previously (section 3.1.) is that it is not entirely clear how exactly post-hypnotic responses correspond to responses after induction -- i.e., “during” hypnosis. Keeping this caveat in mind, these data nevertheless appear to pose a conundrum: why would highly susceptible subjects exhibit impaired cognitive control after an instruction-free hypnotic induction, but also display superior ability at implementing a suggested strategic instruction to improve task performance? One way in which these data may be reconciled is the proposition that hypnosis constitutes a state of dissociated attentional control that impairs the *internal* generation and implementation of strategic performance adjustments, but at the same time makes the hypnotized individual highly amenable to carrying out *externally* suggested task strategies. Recall that impaired performance after hypnotic induction has been characterized by a lack in the use of self-generated task strategies (Jamieson & Sheehan, 2004; Sheehan et al., 1988). During hypnosis, the cognitive control system may lack the internal input signals from the conflict-monitoring system and thus fail to implement strategic performance adjustments (Egner et al., 2005; Kaiser et al., 1997). However, when furnished with a specific task strategy externally (i.e., at the hands of the hypnotist), the cognitive control system can implement this strategy in a highly efficient manner (Raz et al., 2005; Raz et al., 2003; Raz et al., 2002; Sheehan et al., 1988). It is an intriguing conjecture that the high efficiency in implementing external hypnotic instructions is precisely due to the fact that task-processing is unencumbered by signals from internal performance monitoring mechanisms, and may consequently be performed in a more automatic manner, akin to a "contention scheduling" system (Norman & Shallice, 1986) (see also Woody & Bowers, 1994; Jamieson & Woody, this volume).

This proposal can easily be tested empirically. Specifically, in order to integrate the seemingly disparate findings from instruction-free versus task-specific instruction studies, it would be desirable to assess both instruction-free and externally suggested strategy conditions in the same study, and to combine this manipulation with a Stroop task variant that explicitly isolates on-task cognitive control processes. In this context, the view advocated here would firstly predict that instruction-free performance would be inferior, but instructed performance would be superior in highly susceptible individuals (as in Sheehan et al., 1988). Secondly, this view would suggest that while overall Stroop interference may be reduced in highly susceptible individuals subsequent to external strategic task instructions, their performance should nevertheless be relatively immune to conflict-driven sequential performance effects (i.e. conflict adaptation) that arise from the ongoing interaction between the subjects and the stimulus history. Similarly, highly susceptible subjects would in this context be expected to show a failure in post-error slowing of their responses. Thus, while highly susceptible subjects may be superior at implementing an externally suggested strategy on a cognitive task, such as the Stroop protocol, their performance should also be highly inflexible, so that they would perform very poorly when task contingencies change. This could alternatively be tested in a variety of task-switching paradigms, which also offer a rich set of low- and high-level cognitive variables for manipulation (Monsell, 2003), but have to our knowledge not been much exploited in hypnosis research.

4. Conclusions

In this chapter we have selectively reviewed the research literature pertaining to cognitive control processes and their neural instantiation in relation to hypnosis and hypnotic susceptibility. A discussion of commonly employed measures of cognitive control, particularly the Stroop task, has highlighted shortcomings of the traditional interference effect measure. We have concluded that the application of recent advances in the dissociation of various sub-components of Stroop task performance, specifically the fractionation into conflict-monitoring and strategic control processes, would be highly informative to the hypnosis research enterprise. The hypnosis literature as it stands to date is concordant with an "impaired attention" view of hypnosis, as highly susceptible individuals exhibit replicable attention performance detriments after generic hypnotic induction, which are accompanied by a lack of self-generated task strategies. However, if hypnotic induction is combined with task-specific strategic suggestions, highly susceptible individuals can perform exceptionally well. This has been demonstrated both with hypnotic, and particularly with post-hypnotic suggestions. We have interpreted these findings as indicating that hypnosis impairs the internal generation and implementation of strategic performance adjustments, but permits for very efficient implementation of externally suggested strategies. Neurophysiological data suggest that conflict and errors are detected normally in hypnosis, but that their detection apparently does not result in appropriate subsequent performance adjustments. The costs and benefits of hypnotic performance could be related to a breakdown in communication between a medial frontal performance-monitoring system and a lateral frontal cognitive control system. On the one hand, a lack of input from an internal conflict-monitoring system to top-down control regions results in inflexible, and therefore often poor performance. On the other hand, implementation of an externally suggested task strategy may proceed in an automatic fashion, unencumbered by signals from ongoing internal performance-monitoring.

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