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Hypnotic Ability and Baseline Attention: fMRI Findings From Stroop Interference

Michael Lifshitz
McGill University

Amir Raz
McGill University and Sir Mortimer B. Davis
Jewish General Hospital, Montreal,
Québec, Canada

A benchmark experimental conflict task, the Stroop interference effect, probes selective attention. Regarding individual differences, accounts from multiple independent research groups have shown that a specific suggestion to obviate word meaning can reduce the Stroop interference effect in high- but usually not low-hypnotizable participants. Here we report findings from functional magnetic resonance imaging (fMRI) showing that high-hypnotizable participants, compared with low-hypnotizables, may maintain a distinct baseline of attention even outside of hypnosis or suggestion. Although previous neuroimaging investigation of suggestion-induced Stroop reduction implicated a locus of brain regions prominently including the anterior cingulate cortex, here we observed suggestion-free group differences focal to the fusiform gyrus and pulvinar nucleus of the thalamus—regions associated with word reading and visual attention, respectively. We contextualize our findings in terms of earlier efforts that have attempted to link hypnotizability and baseline performance of attention.

Keywords: attention, hypnosis, Stroop effect, fMRI, brain imaging

In the classic Stroop task, proficient readers name the ink color of a displayed word (Stroop, 1935). Responding to the ink color of an incompatible color word (e.g., the word “RED” inked in blue), participants are usually slower and less accurate than identifying the ink color of a congruent item (e.g., “LOT” or “RED” inked in red). This difference in performance constitutes the Stroop interference effect (SIE) and is one of the most robust and well-studied phenomena in attention research (MacLeod, 1991; MacLeod & MacDonald, 2000). With about four thousand citations to Stroop’s original paper, researchers widely believe that many aspects of skilled reading (e.g., the computation of letter identities, word identity, phonology, and semantics) rely on automatic mental processes. Indeed, the standard account maintains that the processing of words occurs involuntarily (e.g., MacLeod, 1991; Neely, 1991) and that the SIE is therefore the “gold standard” for studying executive attention (MacLeod, 1992; cf. Augustinova & Ferrand, 2014). Here we apply functional magnetic resonance imaging (fMRI) to a classic Stroop paradigm and illuminate the baseline neurocognitive differences between high- and low-hypnotizable individuals.

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Michael Lifshitz, Integrated Program in Neuroscience, McGill University; Amir Raz, Departments of Psychiatry, Neurology and Neurosurgery, and Psychology, McGill University, Lady Davis Institute for Medical Research and Clinical Neuroscience and Applied Cognition Laboratory, Institute of Community and Family Psychiatry, Sir Mortimer B. Davis Jewish General Hospital, Montreal, Québec, Canada.

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Correspondence concerning this article should be addressed to Amir Raz, Clinical Neuroscience and Applied Cognition Laboratory, Institute of Community and Family Psychiatry, Sir Mortimer B. Davis Jewish General Hospital, 4333 Chemin de la Côte-Sainte-Catherine, Montreal, QC H3T 1E4, Canada. E-mail: amir.raz@mcgill.ca

Stroop and Hypnotic Phenomena

Some early studies explored the potential marriage of Stroop and hypnosis (e.g., Blum & Graef, 1971; Blum & Wiess, 1986; Dixon, Brunet, & Laurence, 1990; Dixon & Laurence, 1992; Nordby, Hugdahl, Jasiukaitis, & Spiegel, 1999; Sheehan, Donovan, & MacLeod, 1988; Sun, 1994; cf. Spiegel, Cutcomb, Ren, & Pribram, 1985). More recently, a growing body of evidence from multiple independent groups shows that highly hypnotizable participants are able to reduce the SIE given a specific suggestion to thwart reading (Raz, Shapiro, Fan, & Posner, 2002; Raz et al., 2003; Raz & Campbell, 2011; Raz, Fan, & Posner, 2005; Raz, Kirsch, Pollard, & Nitkin-Kaner, 2006; Raz, Moreno-Íniguez, Martin, & Zhu, 2007; Casiglia et al., 2010; Parris & Dienes, 2013; Parris, Dienes, & Hodgson, 2012; Parris, Dienes, Bate, & Gothard, 2014; Sun, 1994). The precise mechanisms underlying this remarkable ability of high-hypnotizable participants remain uncertain (for a review, see Lifshitz et al., 2013; for some interpretations, see Parris, Dienes, & Hodgson, 2013; Augustinova & Ferrand, 2012; Augustinova & Ferrand, 2014). Some of these accounts, moreover, propose that susceptibility to suggestion, rather than explicit hypnotic induction procedures, may be the crucial factor underlying SIE reduction (Raz et al., 2006; Casiglia et al., 2010; Parris & Dienes, 2013; see Kirsch & Braffman, 2001).

Neuroimaging studies using variations of the SIE link attention conflict in the human brain to the dorsal anterior cingulate cortex (ACC), a region involved in numerous cognitive functions ranging from executive attention to pain experience (Gasquoine, 2013; Shackman et al., 2011; Shenhav, Botvinick, & Cohen, 2013). We previously reported a combined fMRI and event-related potential (ERP) study to illuminate the mechanisms by which suggestion prevented word reading in highly hypnotizable participants (Raz et al., 2005). These data indicated that reduction of the SIE resulted in a dampened signal at both early visual regions and downstream ACC. These findings agree with other reports that attention can modulate neural activity for visual stimuli either early (e.g., Martinez et al., 1999) or late (e.g., Mack, 2002) in the processing hierarchy.

Baseline Differences Between High- and Low-Hypnotizable Participants

Using variations on the classic Stroop procedure, researchers have examined high- versus low-hypnotizable participants outside of hypnosis and obtained inconsistent results (Dixon et al., 1990; Dixon & Laurence, 1992; Rubichi, Ricci, Padovani, & Scaglietti, 2005; Egner, Jamieson, & Gruzelier, 2005; Kallio, Revonsuo, Hamalainen, Markela, & Gruzelier, 2001). In some cases, SIE was significantly larger for the high-hypnotizable participants compared with the low-hypnotizable participants (Dixon et al., 1990; Dixon & Laurence, 1992). Such results imply that, outside of the hypnotic context high-hypnotizable participants had more difficulty resolving Stroop-related conflict than low-hypnotizable participants. Yet, other findings deviate from this pattern, demonstrating either superior hypnosis-free Stroop performance among high- versus low-hypnotizable participants (Rubichi et al., 2005) or comparable performance between groups (Egner et al., 2005; Kallio et al., 2001). Although previous studies from our group typically showed comparable Stroop behavior between high and low-hypnotizable individuals outside of hypnosis, we recently reported findings from a large sample demonstrating baseline group differences in Stroop facilitation and negative priming effects (Raz & Campbell, 2011). Taken together, this mixed bag of outcomes indicates that baseline attention differences between high- and low-hypnotizables may be modest and unpredictable when indexed via behavioral Stroop performance (Egner & Raz, 2007).

In the absence of reliable behavioral distinctions, neuroimaging assays seem to provide an opportunity to reveal subtle cognitive differences via measurable physiological changes. For example, examining differences between patients with ADHD and healthy controls, Bush et al. (1999) reported that despite comparable Stroop performance, the two groups displayed distinct patterns of fMRI signal activation in the ACC. Accordingly, we theorized that, should attention differences exist between high- and low-hypnotizable individuals, they would likely be discernible through an imaging assay measuring neural signal patterns even outside of suggestion and in the absence of behavioral differences. Indeed, recent neuroimaging accounts suggest that highly hypnotizable participants display distinct patterns of resting-state functional connectivity (Huber et al., 2014; Lipari et al., 2012; Hoeft et al., 2012; cf. Blinderman, 2014) as well as alterations in volumetric and morphometric aspects of brain anatomy (Huber et al., 2014; Horton, Crawford, Harrington, & Downs, 2004). Furthermore, these differences appear to center on core attention networks that prominently include the ACC.

In the present study, we aimed to associate hypnotizability with differences in brain activation using the classic Stroop task in the absence of hypnosis. Here we present a reexamination of an earlier effort (Raz et al., 2005), focusing our current analysis on incongruent Stroop trials in the no-suggestion conditions. Whereas in our original account (Raz et al., 2005) we observed a lack of behavioral differences at baseline, here we report the results of a subsequent whole brain analysis. Comparable behavioral performance between groups provided an opportunity to isolate subtle variance in cognitive processing observable via changes in brain activation. Based on previous findings probing brain (e.g., Raz et al., 2005) and behavior (e.g., Dixon et al., 1990; Dixon & Laurence, 1992), we hypothesized that compared with low-hypnotizable controls, high-hypnotizable participants would display heightened automaticity of word-stimulus processing. Specifically, we predicted elevated fMRI signals from structures associated with attention conflict (e.g., ACC) and word reading (e.g., fusiform gyrus).

Method

Participants

Sixteen neurologically healthy participants aged 20–35 years ($M = 27$ years) volunteered for this study, which was approved by the institutional review board for the rights of human subjects in research. All participants—right-handed with English as their first language—were drawn from a pool of 95 volunteers who had previously been individually screened for hypnotic susceptibility using both the Harvard Group Scale of Hypnotic Susceptibility: Form A (Shor & Orne, 1962) and the Stanford Hypnotic Susceptibility Scale: Form C (absent the anosmia to ammonia challenge) (Weitzenhoffer & Hilgard, 1962). The eight high-hypnotizable participants (four female, four male) scored in the high-hypnotizable range (10–11 out of a possible 11), whereas the eight control participants (four female, four male) scored in the low-hypnotizable range (1–2 out of a possible 11). Every participant received $75 for a single fMRI session lasting about 90 min.

Stimuli

As described in Raz et al. (2005), stimuli consisted of an English word written in one of four ink colors (red, blue, green, or yellow) appearing at the center of the computer screen where a black fixation cross was visible. All characters were displayed in upper case font against a white background and the stimuli roughly subtended visual angles of 05° vertically, and 1.3° to 1.9° horizontally (depending on word length). Two classes of words were used: color words (RED, BLUE, GREEN, and YELLOW) and neutral words (LOT, SHIP, KNIFE, and FLOWER), the latter class being frequency- as well as length-matched to the former. A congruent condition consisted of a color word inked in its own color. A neutral condition consisted of a neutral word inked in any one of the four colors. An incongruent condition consisted of a color word inked in any of the three colors other than its own.

Procedure

Preceding the experiment, an experimenter notified participants that the purpose of the study was to investigate the effects of suggestion on cognitive performance. Participants were told that hypnotic inductions and suggestions would be administered at certain points during the experiment and that they would be asked to play a computer game (i.e., the Stroop task) while they were in the scanner with the experimenter and technologist present at the console room. After receiving an explanation of the procedures, participants provided written informed consent. Subsequent to a standard hypnotic induction (Weitzenhoffer & Hilgard, 1962), a posthypnotic suggestion to perceive the stimulus words as gibberish from a foreign language was verbally presented to all participants on half the blocks (Raz et al., 2005). We counterbalanced the order to minimize the influence of carryover effects between the suggestion and no-suggestion conditions. The present analysis concerns the no-suggestion blocks only.

At least one full-length practice block preceded the fMRI scan for each subject. Practice was part of a simulation-and-acclimation procedure run on a mock scanner before the actual scan. The sham scan, performed on a replica of the actual scanner, confirmed that participants were able to prepare for and understand the task, proficiently map the four colors to the appropriate response keys, and respond quickly and accurately. As part of this training session, participants completed at least 176 experimental trials.

Participants were exhorted to focus their eyes upon a fixation cross at the center of the screen. Then, a stimulus would appear on the screen replacing the crosshair. The stimulus remained on the screen for a maximum of 2 s or until participants responded. Following a response, the fixation cross was redisplayed at the center for a variable duration contingent upon the subject's reaction time (RT). At this point, a new stimulus appeared on the screen again, replacing the fixation cross and beginning the next trial.

Participants lied supine and motionless at a viewing distance of approximately 25 cm from a color liquid crystal display. During each trial, participants indicated the ink color in which a word was written by depressing one of four keys on a response pad using the index and middle fingers of each hand. The IFIS-SA acquisition system (http://www.invivocorp.com/fmri/ifis.php) and E-Prime-a suite of applications provided by Psychology Software Tools, Inc. (Sharpsburg, PA; http://www.pstnet.com)—facilitated experimental control and behavioral data collection.

Apparatus

A 3.0 Tesla General Electric scanner acquired blood-oxygenation-level-dependent (BOLD) images. For the functional part, image volumes were collected continuously using a T2*-weighted gradient echo-planar imaging (EPI) sequence (echo time [TE] = 35 ms, repetition time [TR] = 2000 ms, flip angle = 80°) with an in-plane resolution of 3.44 × 3.44 mm (64 × 64 matrix; 220 mm field of view). To cover the whole brain, 24 5-mm slices (1-mm skip between slices) were acquired along the anterior-commissure–posterior-commissure plane as determined by the mid-sagittal section. For the structural part, we used a T1-weighted sequence in the same orientation as the functional sequences to provide detailed anatomical images aligned to the functional scans. High-resolution structural images were also acquired for the purpose of cross-subject registration. Scanning consisted of an event-related design with jittered intertrial intervals randomly chosen from an exponential distribution ranging from 3–15 s (M = 6 s). Each session consisted of eight 38-trial blocks, with the first two trials of each block being buffer trials. Block-administration order was counterbalanced across groups and sessions.

Results

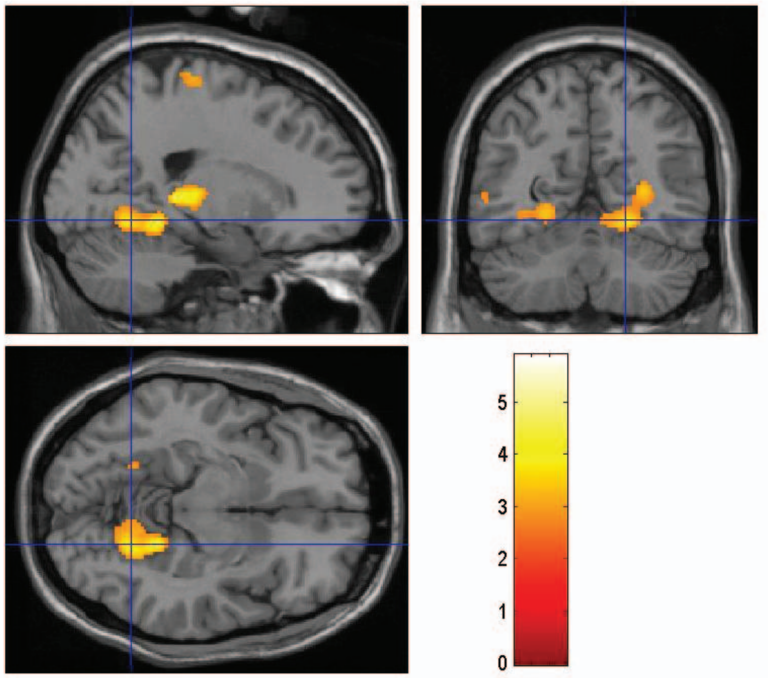
Behavioral Analysis

Incorrect responses and mistrials were discarded from all analysis. The remaining RT data were subjected to a recursive outlier analysis in which measurements 2 SD either above or below the mean score for each subject in each condition were eliminated from further analyses (Van Selst & Jolicoeur, 1994). This process eliminated 2% of the raw data. Accuracy and RTs for the present data set were reported in Raz et al. (2005). We found no significant performance differences between high- and low-suggestible individuals outside of suggestion.

Neuroimaging

In line with our previous neuroimaging protocols (e.g., Raz, Lamar, Buhle, Kane, & Peterson, 2007) we used statistical parametric mapping software (SPM, http://www.fil.ion.ucl.ac.uk/spm) to analyze the fMRI data. The imaging time series was realigned, spatially normalized to stereotactic Talairach space, and smoothed with a Gaussian kernel. A generalized linear model (GLM) identified voxels activated during the experimental conditions. High-pass filtering removed participant-specific low-frequency drift in signal and proportional scaling removed global changes. A statistical threshold of $p < .01$ was used.

Subtracting the fMRI signals of the low-hypnotizable participants from that of the high hypnotizable participants for the global SIE (incongruent–congruent) in the no-suggestion condition revealed focal differences at the fusiform gyrus, bordering on the angular gyrus, and at the pulvinar nucleus of the thalamus (for a complete list of significant regional changes, see Figure 1). Examination of ACC activation



Area	X	Y	Z	Z-score	P	Voxels
Right pulvinar	18	-34	4	4.11	0.000	366
Right fusiform gyrus	22	-44	-10	3.41	0.000	609
Left middle temporal gyrus	-54	-62	6	2.92	0.002	74
Left fusiform gyrus	-22	-60	-4	2.92	0.002	127
Left brainstem	-4	-22	-4	2.79	0.003	215
Right precentral gyrus	20	-24	70	2.68	0.004	60

Figure 1. Difference between high- and low-hypnotizable participants on the SIE (I-C). Table displays Talairach coordinates corresponding to clusters of significant activity (Lancaster et al., 2000). We emphasize the pulvinar and fusiform regions because they passed a higher statistical threshold ($p < .001$). The crosshair indicates the peak of the largest cluster of significant activity, focal to the right fusiform gyrus. See the online article for the color version of this figure.

in the no-suggestion condition disclosed no significant difference between the groups.

Discussion

The fMRI results indicate that when performing the Stroop task using manual response and without suggestion, highly hypnotizable participants, compared with low-hypnotizable individuals, exhibited increased signal at both the fusiform gyrus and the pulvinar nucleus of the thalamus. The observed intensification in fMRI signal is interpretable as either regional activation or inhibitory processing (Raz et al., 2005). The fusiform gyrus is a component of the visual system thought to possess a cortical specialization for written symbols and likely acquires its expertise for reading through progressive adaptation of a preexisting infero-temporal pathway for visual object recognition (McCandliss, Cohen & Dehaene, 2003; Dehaene & Cohen, 2011). The pulvinar gyrus is believed to carry out different mental operations involved in the act of orienting attention in visual space and connecting cortical attention networks to sensory areas that contain information about the target features such as color, motion, or form (Saalman & Kastner, 2011).

Our results partially support our hypotheses. Whereas we did not observe the predicted increase in conflict-related ACC activity, we found increase of fMRI signal in the pulvinar nucleus. This result likely reflects a distinct style of orienting-response preparation among high hypnotizables. In addition, the predicted intensification of activity in the fusiform gyrus among high, compared with low, hypnotizables appears to partially support the notion that high hypnotizables display heightened automaticity of visual word processing at baseline. Indeed, this fusiform signal enhancement represents the inverse of our previous findings examining the same individuals following a posthypnotic suggestion to de-automatize reading, wherein high hypnotizables demonstrated a dampening in the fusiform area (Raz et al., 2005). The present findings extend previous reports indicating that hypnotizability can alter deeply ingrained neural processing following either hypnotic induction (e.g., Egner et al., 2005) or specific suggestions (e.g., Mazzoni, Venneri, McGeown, & Kirsch, 2013; Pyka et al., 2011; Raz et al., 2005; Terhune, Cardeña, & Lindgren, 2010; for reviews, see Oakley & Halligan, 2013; Landry & Raz, in press). We have shown that functional brain differences may exist between high- and low-hypnotizable participants even in the absence of hypnosis or suggestion. Such baseline differences could potentially cloud the interpretation of comparisons between groups following induction or suggestion. Our findings show that in cases of comparable behavioral performance, imaging can serve crucially as a vehicular phenotype to index and discern distinct neural computations (cf. Fan, Fossella, Sommer, Wu & Posner, 2003).

Our behavioral results (see Raz et al., 2005) echo similar findings in the literature (e.g., MacLeod & Sheehan, 2003; Raz et al., 2002; Raz et al., 2007; Schatzman, 1980; cf. Raz & Campbell, 2011). We found no significant difference in RTs to incongruent stimuli between high- and low-hypnotizable participants at baseline. These findings coalesce with a handful of accounts reporting a lack of relationship between hypnotizability and other (non-Stroop) measures of attention in the absence of hypnosis (Dienes, Brown, Hutton, et al., 2009; Varga, Németh, & Szekely, 2011; Iani, Ricci, Baroni, & Rubichi, 2009; for positive results, see Iani, Ricci, Gherri, & Rubichi, 2006). Yet, previous studies employing verbal response with variations of the Stroop task found that high- compared with low-hypnotizable participants displayed greater Stroop automaticity (i.e., slower responses on incongruent trials) outside of hypnosis (Dixon et al., 1990; Dixon & Laurence, 1992). These results were congruous with earlier data reported by Blum and Graef (1971) who attempted to probe SIE differences between simulators (i.e., role enactors) and veridical high-hypnotizable participants. The notion of baseline Stroop differences has received further support from a series of experiments from the laboratory of Jean-Roch Laurence at Concordia University (Montreal, QC, Canada). For example, adapting experimental procedures from MacLeod and Dunbar (1988), Laurence and his students showed that high hypnotizability was linked to greater interference on incongruent trials of a Stroop-like task (Laurence, Blatt, Maestri, & Khodaverdi-Khani, 1997). In addition, they conducted an ERP study with 10 high- and 10 low-hypnotizable participants using a modified key-press Stroop and found that, whereas high-hypnotizable participants elicited a brainwave signal indexing an early onset automatic process—low-hypnotizable controls did not educe this component (Laurence, Slako, & Le Beau, 1998). Furthermore, an experiment examining attention performance using "paper-and-pencil" tests showed that, on the Wisconsin Card Sort Test of set shifting (Berg, 1948), for example, the high-hypnotizable participants scored consistently higher than the low-hypnotizable participants (Moghrabi, 2004). These findings intimate that even outside of hypnosis high-hypnotizable participants may maintain distinct attention capacities compared with low-hypnotizable controls.

Some researchers have been unsuccessful in reproducing variations in attention between high- and low-hypnotizable participants. One study employed an fMRI approach with SIE—similar to the present design—but detected neither behavioral nor neural differences between high- and low-hypnotizable individuals at baseline (Egner, Jamieson, & Gruzelier, 2005). Yet, in contrast to the present study, those authors constrained their investigation to predetermined regions of interests (e.g., the ACC and dorsolateral prefrontal cortex); thus, their analysis would have been insensitive to the activity we observed via our whole-brain approach. In addition, Jonathan Oakman of the University of Waterloo, Canada, obtained (unpublished) null results when investigating behavioral disparities using button-press responses (personal communication from Jonathan Oakman, June 2004). Although in such cases the differential effect (i.e., greater interference for highly hypnotizable participants compared with low-hypnotizable controls) may be present, perhaps its components are insufficiently vigorous to reach significance and may even be suppressed as a function of the methods used to acquire the data (i.e., manual vs. verbal response). Indeed, naming ink colors seems more "natural" than the less-ballistic key press (requiring a mapping transformation from the concept of ink color to the correct key). In this regard, the collective findings of Dixon and Laurence (e.g., Dixon, Labelle, & Laurence, 1996) indicated that SIE differences between high- and low-hypnotizable individuals may be more conspicuous using verbal (vs. key-press) response (cf. Augustinova & Ferrand, 2014). Future research would benefit from directly comparing such response modalities, as well as from assaying participants across the entire range of hypnotizability (i.e., including medium hypnotizables). Nonetheless, neuroimaging can apodictically reveal differences between high- and low-hypnotizable participants even if these differences are less readily evident from a manual-response RT paradigm. Indeed, the present fMRI data show fusiform and pulvinar activations that could not have been captured by an RT design.

Conclusion

Here we reconsider fMRI data focusing on Stroop interference in the absence of hypnosis or suggestion. Our findings indicate that highly hypnotizable persons significantly differ from low-hypnotizable controls in brain activity mostly around the fusiform and pulvinar. Such effects likely relate to the way words are processed and to an attention network concerned with sensory orienting, respectively. Our study lends an additional piece to the ongoing puzzle of unlocking the cognitive and biological basis of hypnotizability (Barnier, Cox, & McConkey, 2014; Santarcangelo, 2014). The present findings enhance our understanding of individual differences and variability of attention, illuminate the neural correlates of suggestibility and self-regulation, and hold promise for advancing applications of mind–body medicine.

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