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ENHANCING IMPLICIT LEARNING WITH POSTHYPNOTIC SUGGESTION: AN ERP STUDY

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Abstract

Can posthypnotic suggestion (PHS) enhance cognitive abilities? The authors tested behaviorally and with event-related potentials (ERP) if sequential learning (SL), the ability to learn statistical regularities, can be enhanced with PHS. Thirty adults were assessed with the Stanford Hypnotic Susceptibility Scale (Form C) and an auditory SL task. Before this task, half the sample received a PHS to enhance SL, and the other half received the same suggestion under normal waking state. Response times and ERPs indicated a strong effect of PHS. Compared to the control group, PHS inverted, attenuated, or left unaffected the response time SL effect in low, medium, and high hypnotizability participants, respectively. These results suggest that PHS cannot be used to enhance SL.

Keywords

posthypnotic suggestion; hypnosis; implicit learning; statistical learning; sequential learning; P600; ERP

Hypnosis can be considered a state of focused attention, concentration, and inner absorption with a relative suspension of peripheral awareness (Laureys, Maquet, & Faymonville, 2004), with disturbance of the frontal attentional control and of the executive system (Egner & Raz, 2007; Egner, Jamieson, & Gruzelier, 2005; Gruzelier, 2006; Kaiser, Barker, Haenschel, Baldeweg, & Gruzelier, 1997). There is currently increasing interest in employing hypnosis as a tool in cognitive research (Casale et al., 2012; Lifshitz, Bonn, Fischer, Kashem, & Raz, 2013; Nemeth, Janacek, Polner, & Kovacs, 2013; Oakley, Deeley, & Halligan, 2007; Oakley & Halligan, 2009; Vanhaudenhuyse, Laureys, & Faymonville, 2014). In particular, the focused attention under hypnosis allows exploration of the long lasting effects of attention-amplified cognitive conditioning, that is, to explore how this conditioning—also called posthypnotic suggestion (PHS) (Barrios, 2001)—affects cognition.

PHS can have dramatic effects on cognition such as overriding the Stroop, the McGurk, and the flanker compatibility effects (Déry, Campbell, Lifshitz, & Raz, 2014; Iani, Ricci, Baroni, & Rubichi, 2009 ; Iani, Ricci, Gherri, & Rubichi, 2006; Lifshitz et al., 2013; Raz, Fan, & Posner, 2005; Raz et al., 2003; Raz, Shapiro, Fan, & Posner, 2002). To date, the research on the effect of PHS has mostly focused on inhibiting/cancelling cognitive effects (Barrios,

2001; Déry et al., 2014; Lifshitz et al., 2013; Oakley, & Halligan, 2009) and little is known about the ability of PHS to enhance cognition. This is essentially due to mixed early results (Barabasz, 1980; Gladfelter & Crasilneck, 1960; Hammer, 1954; Sakata & Anderson, 1970; Salzberg, & Depiano, 1980) coupled with some methodological issues (Barber, 1965; Jacobs & Salzberg, 1987). However, recent studies appear to be more promising for the potential use of PHS to enhance cognition, thus calling for further exploration of this issue (Appel, 1992; Carvalho, Mazzoni, Kirsch, Meo, & Santandrea, 2008; Cohen Kadosh, Henik, Catena, Walsh, & Fuentes, 2009; Iani et al., 2006; 2009; Lifshitz et al., 2013). For instance, Cohen and colleagues (2009) showed that PHS can be used to develop associative memories by reporting synesthetic-like PHS-induced performance in healthy individuals, and Lifshitz et al. (2013) reported two experiments suggesting that PHS can be employed to automatize cognition yielding to enhance performances at visual tasks of identifying the direction of moving geometric figures (clockwise or counterclockwise) or searching for a target item among distractors. In sum, the evidence of the ability of PHS to enhance cognition remains scarce and to some degree controversial. Furthermore, so far, the effect of hypnosis including PHS on learning processes has not been extensively explored (Nemeth et al., 2013). The purpose of the present study is to test behaviorally and neurophysiologically (with event-related potentials, ERP) if PHS can enhance an instance of implicit learning referred to as *sequential learning* (SL). SL can be defined as the ability to extract probabilities from a series of discrete elements and form expectations about upcoming events based on that information (Fiser & Aslin, 2001; Kirkham, Slemmer, & Johnson, 2002; Krogh, Vlach, & Johnson, 2013; Saffran 2003; Siegelman & Frost, 2015; Turk-Browne, Scholl, Johnson, & Chun, 2010).

Importantly, while assumed to occur outside of awareness as other implicit learning mechanisms, SL is known to be sensitive to top-down effects of attention and intention to learn (Daltrozzo & Conway, 2014). In line with Barrios's above-mentioned top-down model of PHS (Barrios, 2001) and neurophysiological evidence supporting such top-down effect of PHS (e.g., Raz et al., 2005; Takarada & Nozaki, 2014), we expected that a PHS designed to enhance SL would be able to amplify SL through a top-down effect by reinforcement of attention to the to-be-learned material and by stimulating motivation to learn.

The neurophysiological exploration of the effect of PHS on SL was motivated by the expected sensitivity of ERP to top-down effects, including those of PHS. Indeed, ERP, including ERP correlates of SL, are known to be sensitive to the level of attention and intention to learn (Daltrozzo & Conway, 2014). Furthermore, this neurophysiological approach (combined with a behavioral assessment) fits within an increasing recent line of research that explores the relationships between hypnosis and cognition through the use of neuroimaging techniques such as fMRI and PET (Casale et al., 2012), electroencephalography (Hinterberger, Schoner, Halsband, 2011; Lee et al., 2007; Vaitl et al., 2005), and ERP (Casiglia et al., 2010; Raz et al., 2005; Terhune, Cardeña, & Lindgren, 2010).

One experimental task that has been useful to test SL with ERPs is that used by Jost, Conway, Purdy, Walk, and Hendricks (2015). In this variation of the standard oddball paradigm (Squires, Squires, & Hillyard, 1975), participants were presented with sequences

of visual, nonlinguistic stimuli (colored circles; randomly assigned between-participants) containing a “standard” stimulus (i.e., that was presented repeatedly) and a set of four different “deviant” stimuli. These deviants belonged to one of two different categories: predictor or target. The participants were asked to respond to the target deviants by pressing a button. Participants were not told that the other type of deviants—the predictor deviants—would precede the target with one of three different levels of fixed contingent probability in relation to the target (i.e., “high,” “low,” and “null” predictability with 90%, 20%, and 0% probabilities, respectively). With exposure to the three predictor-target probabilities, participants learned these statistical associations and could use them to predict the occurrence of the target. Jost et al. (2015) reported a late positive ERP component that increased with predictor-target probability. That is, the ERP component displayed the greatest amplitude for the “high” compared to the “low” or “null” predictors and hence was interpreted as an ERP index of SL. These authors proposed that this late positivity was a P300, an ERP component reflecting stimulus evaluation-based decision or categorization processes as well as memory updating of contextual representations (for a review, see Polich, 2007). However, given the late latency of the ERP effect reported by Jost et al. (2015), an alternative interpretation could be that they found a modulation of the P600 component. (Note that Coulson, King, and Kutas, 1998, have suggested that the P300 and P600 may actually be the same ERP component, but see Frisch, Kotz, von Cramon, and Friederici, 2003).

In the present study, the statistical structure of input sequences provided to participants was similar to the one used by Jost et al. (2015). Therefore, we expected to find a similar late positivity that increases target predictability, i.e., with predictor-target statistical contingency, being therefore an index of SL. Hence, our operational definition of SL at the neurophysiological level was a centro-parietal late positive ERP effect (between experimental “Predictability” conditions with varying predictor-target statistical contingency). In addition, similar to most behavioral studies of SL such as serial reaction time tasks (Nissen & Bullemer, 1987), our operational definition of SL at the behavioral level was defined by participants’ response time (RT) on the SL task with faster RT to targets as predictability (predictor-target statistical contingency) increases (i.e., fastest RT when the target is highly predictable, i.e., follows the “high predictability” predictor than when the target is less predictable, i.e., follows the “low predictability” predictor).

Given that the literature reports consistently variations of performance of several cognitive mechanisms according to hypnotic susceptibility (HS) or hypnotizability (Gruzelier, 1996; Iani et al., 2009) including Stroop effect inhibition through PHS in high but not in low susceptible participants (Raz et al., 2002, 2005), we measured the HS construct with the Stanford Hypnotic Susceptibility Scale, Form C (SHSS:C, Weitzenhoffer & Hilgard, 1962) and included this measure as a covariate of our statistical analyses.

We predicted that, compared to suggestion in the normal wake state, PHS would enhance SL and this would be evidenced with our behavioral (RT) and neurophysiological (ERP) indices of SL.

Method

In this between-subject design, participants were first assessed for their hypnotizability with the SHSS:C and then received a suggestion (see “Suggestion” section below) to enhance SL either under hypnosis (test group) or under normal wake state (control group). Then, all participants were assessed for their general level of selective attention with a Flanker task (Eriksen & Eriksen, 1974), completed a SL task while ERPs were recorded, and were reassessed for selective attention. Finally, participants were administered two IQ tests: the Block Design (BD) and the Matrix Reasoning (MR) subsets of the Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler, 2011).

Hypnotizability Measure

The SHSS:C assesses the hypnotizability of adult participants with 13 items of increasing difficulty. In addition to motor items, the scale contains cognitive suggestions, including hallucination and age regression. The SHSS:C has come to serve as the gold standard against which all other hypnotizability scales are compared (Kihlstrom, 1985; Woody & Barnier, 2008). Participants were administered the SHSS:C by JD. The mean HS in the test and control groups (see “Participants” section below) are presented in Table 1.

General Level of Selective Attention

To control for possible variations in the general level of selective attention across participants, we measured the performance on a Flanker task (Eriksen & Eriksen, 1974; Shalev & Tsai, 2003), which was collected immediately before and after the SL task. The Flanker task is a visual-search task measuring a person’s ability to detect relevant information in the midst of irrelevant information (Eriksen & Eriksen, 1974). This task is commonly used to test response inhibition and selective attention (Casey et al., 2000; Fenske & Eastwood, 2003; Hübner, Steinhauser, & Lehle, 2010; Lavie, Hirst, de Fockert, & Viding, 2004). It comprises a central target (e.g., ‘<’) flanked by nontarget stimuli, which either match the direction of the target in half of the trials (congruent stimuli; e.g., ‘<<<<<<’) or are in the opposite direction of the target in the rest of the trials (incongruent stimuli; e.g., ‘>>>>>>’). A directional response (left or right) is assigned to the target stimulus. Response times for incongruent trials are typically longer than for congruent trials—a difference known as the flanker effect (Eriksen & Eriksen, 1974). The Flanker task allows the testing of how well attention is restricted to a particular object or location (Fenske & Eastwood, 2003) and thus can be used as a measure of selective attention (Lavie et al., 2004). Participants were required to give a speeded left- or right-hand response to indicate the direction of the target. The number of correct button-press responses with the left and right hand was counterbalanced across congruent and incongruent experimental conditions. A new trial was presented immediately after the participant’s response. Flanker effect scores were computed for accurate trials only by subtracting mean response times for incongruent trials from mean response times for congruent trials. For each participant we averaged their Flanker effect before and after the SL task. The mean Flanker effects in the test and control groups (see “Participants” section below) are presented in Table 1.

General Cognitive Performance

Following the second assessment of the Flanker task, participants were assessed for their general cognitive performance with two IQ tests: the Block Design (BD) and the Matrix Reasoning (MR) subsets of the Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler, 2011). The BD subtest broadly measures spatial perception including spatial visualization ability in conjunction with motor skill, abstract visual perception, and problem-solving capabilities. In this task, the participant is presented with a complete unidimensional pattern along with a set of blocks that are colored on each side. Participants must use hand movements to rearrange these blocks to match the pattern, within a certain time frame. Accuracy and speed in completing the task are both used to score each item. The MR subtest provides estimates of nonverbal abstract problem solving and inductive and spatial reasoning. In this task, the participant views an incomplete object matrix and has to logically complete it, using any of the various options presented. The mean BD and MR raw scores in the test and control groups (see “Participants” section below) are presented in Table 1.

Participants

Thirty participants (16 females, $M = 24.2$ years, $SD = 8.4$) from Georgia State University participated in the study to receive class credit. Participants reported no language, cognitive, neurological, or psychological deficits. All were native English speakers and all (except 1 left-handed and 4 ambidextrous) were right-handed according to the Edinburg Handedness Inventory (Oldfield, 1971). All participants provided written informed consent to the study, which was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the local Ethics Committee (the Institutional Review Board of Georgia State University).

Following the administration of the SHSS:C, participants received a suggestion (see “Suggestion” section below) to enhance SL either under hypnosis (test group, $n = 15$) or under normal wake state (control group, $n = 15$). Participants were assigned to the test or the control group in a counterbalanced order. These groups did not significantly differ according to age, SHSS:C score, general selective attention according to the Flanker effect, or IQ according to the BD or MR scores (Table 1).

Suggestion

The administrated suggestion to enhance SL was derived from the one used by Iani et al. (2009):

Soon you will be ready to play a computer game. In this computer game you will hear some sounds in front of a computer screen. To play, you will have to press a button to only one of these sounds. This specific sound will be the **target sound**. You will press the button very easily and quickly when you hear the **target sound**. Just before the presentation of the **target sound**, you will hear other sounds that will make it very easy for you to guess when you will hear the **target sound**. When you will hear the **target sound** you will press the button very easily and quickly. Your interest will be captured like a magnet by the sounds before the **target sound** because they will help you so much to predict when you will hear the **target sound**.

These sounds will help you to know when you have to quickly press the button. You will have to press a button only when you hear the **target sound** but all other sounds will strongly help you to know when the **target sound** will occur. Your attention will be completely absorbed by the order in which the other sounds occur. This order will let you know very easily when you will hear the **target sound** and have to press the button very quickly. Your attention will be completely captured by how these other sounds unfold in time, because this pattern of sounds will tell you very accurately when the **target sound** will occur and thus when you will have to press the button very quickly. Any other information will appear as irrelevant and meaningless. You will be able to attend to the sounds and their pattern in time only and to press the button very quickly when you hear the **target sound**. It will be very easy and automatic. Each time you hear the **target sound**, your index finger will press the button in a fast and automatic way. Your index finger will press the button very quickly when you hear the **target sound** because you will be able to predict when the **target sound** will come from the pattern of the other sounds that will completely capture your attention. Nothing will disturb you, and you will be able to play this game easily and effortlessly.

The test group received the instructions of the SHSS:C for hypnotic induction. Once under hypnosis, participants received the above suggestion and then were woken up from hypnosis using the SHSS:C procedure. This procedure lasted approximately 20 minutes. The control group was first assessed with a test of receptive vocabulary lasting approximately 20 minutes (the "Peabody Picture Vocabulary Test IV," Dunn & Dunn, 2007) and then received the above suggestion under normal wake state. Both groups were then requested to perform a first session of the Flanker task (see above section "General Level of Selective Attention") before being administered the SL task.

Sequential Learning Task

In the SL task (Figure 1), participants listen to a series of white noise sounds of various durations. The order of presentation of these sounds of various durations follows sequential statistical rules similar to those used in Jost et al. (2015). Stimuli were presented with a 1000ms interstimulus interval. Participants were instructed to press a button as quickly as possible when a given "target" sound (a 50ms white noise sound) was presented. There was first a training session. The instructions of the training session were as follows:

First we are going to do some practice trials. You are going to hear sounds of various durations. The **target sound** is the shortest sound of all of these. Please listen carefully to the **target sound** by pressing the button. [button pressure - target sound presented]. Your task is to press the button as quick as possible only when you hear the **target sound**. Press the button when ready. [Experimenter stay by the participant and make sure that the participant press the button to the target and only to the target. If the participant do not perform the task correctly, the instructions are provided again and the training session is performed again.]

After the training session, the following instructionS (for the test session) are given to the participant:

In this experiment, you will hear short and long sounds. Your job is to press the button as quickly as you can when you hear the **target sound**, which is the shortest sound of all of these. Please listen carefully to the **target sound** by pressing the button. [button pressure - target sound presented]. Your job is to press the button as quickly as you can when you hear the **target sound**. Do your best not to press the button for any other sounds. If you understand these instructions, press the button to continue.

Unbeknownst to the participants, the sequence of sounds of various durations followed a set of fixed statistical regularities (see Figure 1). For each participant, in addition to the target stimulus, one of the stimuli was pseudo-randomly chosen as a “standard” stimulus, one as a “high predictability” (HP) predictor, one as a “medium predictability” (MP) predictor, and one as a “low predictability” (LP) predictor from among a set of five white noise sounds of 200ms, 400ms, 600ms, 800ms, and 1000ms. The interval of 200ms between these durations was expected to allow for easy duration discrimination (Rammsayer, 2014). All white sounds were generated with Praat (version 5.3.84 using the RandomGauss function; Boersma, & Weenink, 2015), were root-mean-squared normalized, and were amplified with Adobe Audition CS5.5 (version 4.0) to be presented through loudspeakers at a sound level of 66 dBA according to a sound level meter (model 407732 of Extech Instruments in the 125ms response time and 35 to 100 dB range acquisition modes).

During each trial the standard stimulus was repeated a pseudorandom number of times. Next, one of the three (HP, MP, or LP) predictors was presented, each with a one-third probability of occurrence. The HP predictor was followed by the target in 80% of the trials and by the standard in 20% of the trials. The MP predictor was followed by the target in 50% of the trials and by the standard in 50% of the trials. The LP predictor was followed by the target in 20% of the trials and by the standard in 80% of the trials. Each trial concluded with a second series of standards of a random length.

For each predictability condition (HP, MP, and LP) there were 50 trials for a total of 150 trials divided among five blocks of 30 trials. All trials were randomly ordered across the three predictability conditions (HP, MP, and LP) in a continuous fashion such that the participant was unable to distinguish one trial from another. A break lasting a minimum of 30 seconds was given between each block. Stimuli were presented on a Dell Optiplex 755 computer running E-Prime version 2.0.8.90.

Electroencephalography Acquisition

While the participant performed the SL task, the electroencephalograph (EEG) was recorded from 256 scalp electrodes using an Electrical Geodesic Inc. sensor net (Figure 2) and was preprocessed using Net Station version 4.3.1 with subsequent processing using custom scripts written in MATLAB (version R2012b 8.0.0783, MathWorks) and the EEGLAB toolbox (version 10.2.2.2.4a; Delorme & Makeig, 2004). Active electrode impedances were kept below 50 k Ω . The EEG was acquired with a 0.1 to 100 Hz band-pass filter at 250 Hz with vertex reference and then re-referenced to the average reference, resampled to 256 Hz (to allow filtering with Fast Fourier Transformation), and low-pass filtered at 30 Hz. Participants were instructed to refrain from blinking throughout the experiment. Eye blink

artifacts were corrected by independent component analysis. Other remaining artifacts were removed manually. This procedure removed 13.6% of the trials [HP: $M = 12.7\%$, $SD = 13.2$; MP: $M = 14.0\%$, $SD = 13.4$; LP: $M = 14.0\%$, $SD = 13.4$; $F(2,58) = 1.19$, $p = .312$, $N = 30$; Friedman test: $F = 1.212$, $p = .546$, $N = 30$]. The continuous EEG was segmented into epochs -200ms to $+1000\text{ms}$ with respect to the predictor onset. ERPs were baseline-corrected at 200ms prestimulus. Separate ERPs were computed for each participant, predictability condition, and electrode. All experimental sessions were conducted in a 132 square foot double-walled, sound-deadened acoustic chamber.

Statistical Procedures

Single trial response times (RT) of the SL task to target stimuli following the HP, MP, and LP predictors and individual EEG means in time-windows time-locked to the predictors (defined after Bonferroni-corrected preliminary analyses in consecutive 50-ms time-windows, Schirmer & Kotz, 2003) were analyzed with linear mixed models (LMM) following the method used by Daltrozzo et al. (in press).

The LMMs were conducted using the *lmer()* function from *lme4* library in R version 3.2.0 (Bates, Maechler, & Bolker, 2009). The LMM is a more general model than the ANOVA, allowing analysis of continuous independent variables (e.g., a hypnotizability score). This statistical approach is becoming more frequently applied in EEG/ERP research (Bagiella, Sloan, & Heitjan, 2000; Davidson & Indefrey, 2007; Moratti, Clementz, Gao, Ortiz, & Keil, 2007; Newman, Tremblay, Nichols, Neville, & Ullman, 2012; Pritchett et al., 2010; Wierda, van Rijn, Taatgen, & Martens, 2010) as recommended by Bagiella et al. (2007) and Newman et al. (2012) because it offers several advantages over traditional AN(C)OVA models, such as richer modeling of (multiple, crossed, and/or nested) random effects (e.g., to identify and account for differences in the data that are specific to variation for each participant), analyses of unbalanced designs, analyses with missing data, and analyses of data with nonsphericity issues without the need for additional corrections such as Greenhouse-Geisser or Huynh-Feldt (Bagiella et al., 2000).

The LMM statistical model we used to analyze ERPs was similar to the one applied by Daltrozzo et al. (*In Press*) with fixed effects defined by the full factorial design that included the Predictability condition (HP, MP, and LP) with Group (control or test), mean-centered HS, and region of interest (ROI, Figure 2) and with intercept by-ROI and intercept by-participant as random factors. The ROI definition followed Daltrozzo et al. (*In Press*). The 9 levels of the ROI factor were defined in the LMM as follows: 1:LAN, 2:LCn, 3:LPo, 4:FRz, 5:CNz, 6:POz, 7:RAn, 8:RCn, 9:RPo.

To correct for the incompatibility between the additive nature of the LMM (and ANOVA models) and the multiplicative nature of interactions that could yield incorrect significant (i.e., Type I error) interactions involving ROI, McCarthy and Wood (1985) developed a correction by EEG mean scaling (see also Dien & Santuzzi, 2005). In every condition, for each participant, mean EEG amplitudes are scaled by the square root of the sum of the squared mean EEG amplitudes, i.e., $X_{ij} / \sqrt{\sum (X_{ij}^2)}$, where X_{ij} is the EEG mean amplitude for participant i in condition j . If the scalp ROI by condition interaction remains significant after rescaling, this allows for more confidence in the authenticity of the interaction, under certain

conditions (Urbach & Kutas, 2002, 2006). RTs were analyzed with the same LMM model but without the ROI factor.

Results

Response Times

The applied LMMs for the analysis of the RTs are described in Table 2 and Table 3. The LMM showed an interaction between Predictability (HP, MP, and LP) and Group (control versus test) [$F(3, 74) = 4.28$; $p = .008$]. For the control group, posthoc tests indicated faster responses to the target following the HP predictor ($M = 409\text{ms}$, $SD = 115$) compared to the LP ($M = 457\text{ms}$, $SD = 67$; $p = .010$) predictors and following the MP ($M = 416\text{ms}$, $SD = 92$) compared to the LP predictor ($p = .014$) but no significant difference between RTs to MP and HP ($p = .981$). For the test group, post hoc tests indicated that the trends for faster responses to the target following the HP predictor ($M = 408\text{ms}$, $SD = 63$) compared to the MP ($M = 432\text{ms}$, $SD = 71$) and LP ($M = 425\text{ms}$, $SD = 58$) predictors did not significance ($p = .441$ and $p = .288$, respectively). There was also no significant difference between RTs to MP and LP ($p = .124$).

In addition, there was a significant interaction between predictability, group, and mean-centered HS, $F(3, 74) = 3.46$; $p = .020$, indicating that whereas in the control group HS did not affect SL according RTs (RT to LP condition minus RT to HP conditions), this SL RT effect increased with HS in the test group (Figure 3).

In sum, these behavioral results indicate that with exposure, participants (at least in the control group and in participants with high HS of the test group) were able to extract the statistical structure embedded within the sequences as reflected by quicker responses to the target when following a HP predictor than when following a LP predictor. This behavioral measure of SL appeared to be related to the HS in the test group (but not in the control group) with larger SL RT effects associated with higher HS.

Event-Related Potentials

Figure 4 and Figure 5 display for the control and test groups, respectively, the grand averaged ERPs time-locked to the three predictors (HP, MP, and LP) at the nine regions of interest used for topographic analyses. Visual inspection suggests a larger centro-parietal (POz) late positivity between approximately 500ms and 1000ms as predictor predictability increases in the control group, replicating the general effect observed by Jost et al. (2015). This ERP effect is reduced in the test group with the late centro-parietal positivity being almost as large in the LP and MP conditions as in the HP condition.

The applied LMMs for the analysis of the ERPs are described in Table 2, Table 4, and Table 5. The LMM on the mean amplitude ERPs time-locked to the predictors between 500ms and 650ms revealed an interaction between Predictability, Group, mean-centered HS, and ROI, $F(3, 12037) = 28.25$; $p < .001$, as depicted on Figure 6 and Figure 7. This interactions remained significant after McCarthy and Wood (1985) correction, $F(3, 12037) = 87.99$; $p < .001$. Figure 6 and Figure 7 indicate that the relationship between the centro-parietal SL ERP effects and HS was different between the control and the test groups. Specifically, Figure 6

reveals the expected increased late centro-parietal ROI (POz) positivity between LP and HP in the control group but only for the highly suggestible participants. For the weakly suggestible participants, the ERP effect was in the opposite direction. This ERP component modulation with increased HS was stronger in the MP compared to the HP condition. Figure 7 reveals that in the test group, the late centro-parietal ROI (POz) positivity was virtually unchanged between LP and HP while in the MP condition this ERP component decreased with higher HS. This later effect was even more important on the late right-parietal ROI (RPo) positivity.

The LMM on the mean amplitude ERPs time-locked to the predictors between 700ms and 950ms revealed an interaction between Predictability, Group, mean-centered HS, and ROI [$F(3, 12037) = 29.85$; $p < .001$] as depicted on Figure 8 and Figure 9. This interactions remained significant after McCarthy and Wood (1985) correction [$F(3, 12037) = 38.40$; $p < .001$]. Figure 8 and Figure 9 indicate that the relationship between the centro-parietal SL ERP effects and HS was different between the control and the test groups. Specifically, Figure 8 reveals the expected increased late centro-parietal ROI (POz) positivity between LP and HP in the control group but only for the highly suggestible participants. For the weakly suggestible participants, the ERP effect was in the opposite direction. This ERP component modulation with increased HS was similar in the MP compared to the HP condition. Figure 9 reveals that in the test group, the late centro-parietal ROI (POz) positivity was virtually unchanged between LP and HP while in the MP condition this ERP component decreased with higher HS. This later effect was even more important on the late right-parietal ROI (RPo) positivity.

In sum, these neurophysiological results indicate that participants were able to extract the statistical structure embedded within the sequences because the late parietal ERP responses differed across levels of the Predictability conditions. Importantly, the modulation of the late centro-parietal (POz) and right-parietal (RPo) ERP with target Predictability and hypnotizability was clearly different between the control and the test groups, indicating a strong effect of presenting the suggestion (see “Suggestion” section in Methods) either in the normal wake state (control group) or under hypnosis (test group) but this strong effect of PHS was not associated with the expected effect given the content of the suggestion, that is enhancing SL.

Discussion

The aim of this study was to investigate whether implicit learning could be enhanced by posthypnotic suggestion (PHS). For this purpose, we used an instance of implicit learning known as sequential learning (SL). SL was recorded with a modified oddball paradigm based on Jost et al. (2015) wherein the participant is asked to press a button to the presence of a target from among the presentation of ‘standard’ as well as predictor stimuli. As expected from earlier SL studies (Daltrozzo et al., in press; Jost et al., 2015), in the control group—who received the suggestion (see “Suggestion” section in the Methods) to enhance SL prior to the SL task in the normal wake state—RTs to the target were shorter when the target was in the “high predictability” (HP) compared to when the target was in the “low predictability” (LP) condition and this behavioral (response time) SL effect was

accompanied by an SL ERP effect (i.e., a larger late centro-parietal positive component in HP compared to LP). While we predicted that in the test group, the PHS would enhance these behavioral and neurophysiological SL effects, the results showed no enhancement. Instead, in low susceptible participants, the RT effect was in the opposite direction (i.e., RTs faster to LP compared to HP) and the SL ERP effect was unexpectedly right-lateralized. High susceptible participants displayed a similar SL RT effect as the control group together with a right-lateralized SL ERP effect in the opposite direction compared to expectation (i.e., a larger late positivity to LP compared to HP). Importantly, these RT and ERP SL effects differed dramatically between the test and control groups indicating that the PHS had a strong effect on SL. However, these behavioral and neurophysiological data did not support the prediction of SL enhancement according to our PHS. We discuss below these results in details.

Behavioral and Neurophysiological Correlates of Statistical Learning in the Control Group

The behavioral data demonstrated that SL occurred as indicated by a SL RT effect: faster RTs to the target when it was highly predictable by the preceding stimulus (i.e., when the target followed the predictor with a 80% probability in the “HP condition”) compared to RTs to the target when it was less predictable by the preceding stimulus (i.e., when the target followed the predictor with a 20% probability in the “LP condition”). The size of this SL RT effect was 48ms, which is in the typical range of RT effects previously reported in the SL literature (e.g., Baldwin & Kutas 1997; Eimer, Goschke, Schlaghecken, & Stürmer, 1996; Ferdinand, Mecklinger, & Kray, 2008).

SL was further confirmed with the ERP findings. Visual inspection of grand averages (Figure 4) in the present study suggests a larger centro-parietal (POz) positivity between 500ms and 1000ms in the HP compared to the LP condition. The SL ERP effect observed in the present study closely replicates the findings of Daltrozzo et al. (*In Press*) and Jost et al. (2015), who found a larger centro-parietal positivity in a similar time-window in a HP condition (predictor stimulus followed in 90% of the trials by the target) compared to a LP condition (predictor stimulus followed in 20% of the trials by the target). Given the similar design of the present study with those of Daltrozzo et al. (*In Press*) and Jost et al. (2015) this replication was expected. Jost et al. (2015) interpreted the larger late centro-parietal positivity to the HP compared to the LP condition as an indication that participants formed an association or mental “chunk” between the predictor and the target in the HP condition but not in the LP condition. This interpretation is consistent with previous suggestions that this ERP component reflects chunking processes (Verleger, 1988) and that chunking processes are an important aspect of implicit learning and SL in particular (Perruchet & Pacton, 2006). The proposal is that through tracking statistical contingencies, participants form chunks between highly associated stimuli, essentially treating the predictor stimulus in the HP condition at some level to be equivalent to the target itself.

In sum, the data of the control group indicate both behaviorally and neurophysiologically that SL occurred. The ERP effects were those expected, replicating results of similar SL experiments (Daltrozzo et al., *In Press*; Jost et al., 2015).

Effect of Posthypnotic Suggestion: Behavioral and Neurophysiological Correlates of Statistical Learning in the Test Group

The behavioral and neurophysiological SL effects displayed by the test group differ strikingly from those of the control group indicating a strong effect of PHS on SL. However, the effect of PHS was not the expected SL enhancement.

Unlike the control group who showed the expected SL RT effect (faster RT to HP compared to LP condition) in all participants, the test group responded differently according to HS. While the SL RT effect was similar between the high susceptible participants of the test group and the control group, low susceptible participants displayed a SL RT effect in the opposite direction compared to expectation (i.e., faster responses to targets in the LP compared to the HP condition). The literature indicates that although SL is assumed to reflect an instance of implicit learning, the underlying mechanisms of SL can be influenced by the intention to learn the statistical rules (Daltrozzo & Conway, 2014). One psychological trait of low susceptible participants is their ability to resist to suggestions (defend themselves against coercion), that is voluntarily refrain from following the suggestions sometime even to the extent of intentionally doing the exact opposite of what the suggestion is requesting (Jones & Spanos, 1982; Lynn, Weekes, Rhue, & Snodgrass, 1985; Spanos & Bodorik, 1977). This effect in the opposite direction compared to the intent of the suggestion in low susceptible participants has been referred to as the “Negative Subject Effect” by Spanos and Bodorick (1977). One possibility is that the opposite SL RT effect found in the low susceptible participants reflects the intention of the participants to learn or behave in the opposite direction as requested by the PHS. While the negative subject effect was not indexed by RTs in the control group, it was detected by this behavioral measure in the test group. This dissociation suggests that participants’ resistance to coercion was more pronounced when suggested under hypnosis (test group) compared to normal wake state (control group).

PHS had also a strong effect on the ERP correlate of SL. While the control group showed the expected centro-parietal larger late positivity to the HP compared to the LP condition, the test group showed a right-lateralized SL ERP effect. Even though the test group was awakened from hypnosis before performing the SL task, it is possible that the hypnotic state had carried on effects during the SL task. Since there is accumulated evidence that hypnosis can entrain right-lateralized activation (Behbahani & Nasrabadi, 2015; Gruzelier, 1996), the right-lateralization of the SL ERP effect in the test group could be an after effect of the hypnosis session.

In the low susceptible participants, this SL ERP effect was in the expected direction (i.e., larger positivity to the HP compared to the LP condition) as in the control group and previous studies using a similar SL paradigm (Daltrozzo et al., in press; Jost et al., 2015). Unexpectedly, in the high susceptible participant, the SL ERP effect was in the opposite direction (i.e., larger positivity to the LP compared to the HP condition). This reversal may be a correlate of a low confidence in the participants’ predictions of the target due to a difference between the actual task difficulty and the task difficulty expected from the PHS that stressed: “Just before the presentation of the **target sound**, you will hear other sounds

that will make it very easy for you to guess when you will hear the **target sound**.” Indeed, there is accumulated evidence showing that the late positive component depends on the participants’ level of confidence (Woodruff, Hayama, & Rugg, 2006; Yu & Rugg, 2010), here of the predictor stimulus supposedly making it “easy” to predict the target. As indicated earlier (see previous section of the Discussion), in the present paradigm, SL is expected to be observed by a chunking/learning process occurring in the HP condition but not in the LP condition. Thus, it is only in the HP condition that learning and hence effects of confidence in the prediction of the target are expected to occur and modulate the late positive component. The literature indicates that the amplitude of the late positive component increases with confidence. Therefore, the lack of confidence in the prediction of the target in the HP condition is expected to decrease the amplitude of the late positive component. This would result in a SL ERP effect in the opposite direction to expectation because the late positive component would be attenuated in the HP condition (due to a lack of confidence in the target prediction) while no such attenuation would occur in the LP condition.

General Discussion

In sum, the behavioral and the neurophysiological data of the test group provide a strong evidence of an effect of PHS on SL. Unlike our expectations, PHS did not enhance SL. Instead, the data showed that the effect of the PHS was: (1) to invert, inhibit, or leave unaffected the SL effect observed with RTs in low, medium, and high susceptible participants, indicating a resistance to coercion in the low susceptible participants; and (2) to interfere with the participants’ confidence in predicting the targets according to the ERP data.

Our discussion of ERP effects reported in this study focused mostly on those observed at the centro-parietal cortical site because our ERP operational definition of SL was at this scalp location (see Introduction), however ERP effects between HP, MP, and LP were found also at other locations including the frontal area. These other effects could have driven our reported interaction between the SL ERP effect, participants’ group, and hypnotizability. With a very similar paradigm, Jost et al. (2015) reported also large frontal ERP effects between various target predictability conditions. There are several possible (competing or complementary) interpretations for the source(s) of these frontal ERP effects, e.g., the modulations of a contingent negative variation (Walter, Cooper, Aldridge, McCallum, & Winter, 1964) or a slow negative wave (Lang & Kotchoubey, 2000) or the opposite scalp projection of a dipole source (oriented along the frontal to centro-parietal direction) of the SL ERP effect. These issues are discussed more extensively in Daltrozzo and Conway (2014).

The lack of a strong quantitative variation in the expected direction from the PHS is at odds with the dramatic effects of PHS previously reported in the literature such as for instance the cancellation of one of the strongest psychological effects, namely the Stroop effect (Lifshitz et al., 2013). But as mentioned earlier, the strong effects of PHS have essentially shown inhibitory/cancellation effects, not enhancing effects. The evidence reported here suggests that PHS may not be able to enhance a cognitive ability as much as it is able to cancel it. However, it is possible that the lack of learning enhancement was due to the use of a

suboptimal PHS. According to Barrios' model (Barrios, 2001), a PHS is efficient only if it is able to create a higher-order "cognitive-cognitive" conditioning resulting from the pairing of two cognitive stimuli through the suggestion. In our experiment, the participants were not previously exposed to the stimuli of the SL task at the time that the PHS was administered. Furthermore, these stimuli were most likely unfamiliar to participants as sounds of white noise of various durations are not common environmental sounds. The PHS was expected to create a cognitive stimulus associated to the meaning of the word "target sound" that was mentioned again in the instructions provided to perform the SL task. However, given the lack of familiarity with the target sound at the time the PHS administration, references to the target sound may have evoked only a minor meaning to the participants, resulting in a weak cognitive stimulus and thus a weak "cognitive-cognitive" conditioning. Even though our PHS may have been suboptimal and could have been improved (for instance by presenting the predictor and the target sounds during the administration of the PHS to enhance "cognitive-cognitive" conditioning), the PHS was still effective in the present study as indicated by the clear difference between the data of the test and the control groups. Overall, the results suggest that PHS cannot be used to enhance implicit learning mechanisms. Rather, consistently with previous research, PHS can inhibit or modify qualitatively (e.g., invert the direction of) such learning mechanisms.

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Figure 1: Sample sequence of white noise sounds of various durationa.

HP: “High Predictability” predictor, MP: “Medium Predictability” predictor, LP: “Low Predictability” predictor, T: Target, S: Standard. For each participant, HP, MP, LP, and S were pseudo-randomly assigned to one of five white noise sounds of 200ms, 400ms, 600ms, 800ms, and 1000ms.. T was a 50ms white noise sound.

Figure 2: 256 Electrical Geodesic Inc. sensor net for EEG recordings and the nine regions of interest.

left (LAn), middle (FRz), and right anterior (RAn); left (LCn), middle (CNz), and right central (RCn); and left (LPo), middle (POz), and right posterior (RPo) regions used for topographic analyses.

Figure 3: Response Time against Predictability and Hypnotizability.

LP: “Low Predictability” condition, MP: “Medium Predictability” condition, HP: “High Predictability” condition, HS: mean-centered hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSS:C, Weitzenhoffer & Hilgard, 1962).

Figure 4: Grand averaged ERPs of the control group.

N=15 participants; Nine regions of interest (see Figure 2); Grand averaged ERPs in response to the HP (solid thick lines), MP (solid thin lines), and LP (dotted thin lines) predictors (positivity upward in microvolts; time in seconds).

Figure 5: Grand averaged ERPs of the test group.

N=15 participants; Nine regions of interest (see Figure 2); Grand averaged ERPs in response to the HP (solid thick lines), MP (solid thin lines), and LP (dotted thin lines) predictors (positivity upward in microvolts; time in seconds).

Figure 6: Predictability Condition × Hypnotizability interaction for each ROI in the Control Group.

The x-axis is the mean-centered hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSS:C, Weitzenhoffer & Hilgard, 1962), and the y-axis is the LMM estimated ERP mean amplitude between 500ms and 650ms post predictor onset (positivity upward in microvolts). The thick solid line is the simple effect of the mean-centered hypnotizability in the “High Predictability” condition (HP, predictor followed in 80% of the trials by the target). The thin solid line is the simple effect of the mean-centered hypnotizability in the “Medium Predictability” condition (MP, predictor followed in 50% of the trials by the target). The broken line is the simple effect of the mean-centered hypnotizability in the “Low Predictability” condition (LP, predictor followed in 20% of the trials by the target).

Figure 7: Predictability Condition × Hypnotizability interaction for each ROI in the Test Group.

The x-axis is the mean-centered hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSS:C, Weitzenhoffer & Hilgard, 1962), and the y-axis is the LMM estimated ERP mean amplitude between 500ms and 650ms post predictor onset (positivity upward in microvolts). The thick solid line is the simple effect of the mean-centered hypnotizability in the “High Predictability” condition (HP, predictor followed in 80% of the trials by the target). The thin solid line is the simple effect of the mean-centered hypnotizability in the “Medium Predictability” condition (MP, predictor followed in 50% of the trials by the target). The broken line is the simple effect of the mean-centered hypnotizability in the “Low Predictability” condition (LP, predictor followed in 20% of the trials by the target).

Figure 8: Predictability Condition × Hypnotizability interaction for each ROI in the Control Group.

The x-axis is the mean-centered hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSS:C, Weitzenhoffer & Hilgard, 1962), and the y-axis is the LMM estimated ERP mean amplitude between 700ms and 950ms post predictor onset (positivity upward in microvolts). The thick solid line is the simple effect of the mean-centered hypnotizability in the “High Predictability” condition (HP, predictor followed in 80% of the trials by the target). The thin solid line is the simple effect of the mean-centered hypnotizability in the “Medium Predictability” condition (MP, predictor followed in 50% of the trials by the target). The broken line is the simple effect of the mean-centered hypnotizability in the “Low Predictability” condition (LP, predictor followed in 20% of the trials by the target).

Figure 9: Predictability Condition × Hypnotizability interaction for each ROI in the Test Group.

The x-axis is the mean-centered hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSS:C, Weitzenhoffer & Hilgard, 1962), and the y-axis is the LMM estimated ERP mean amplitude between 700ms and 950ms post predictor onset (positivity upward in microvolts). The thick solid line is the simple effect of the mean-centered hypnotizability in the “High Predictability” condition (HP, predictor followed in 80% of the trials by the target). The thin solid line is the simple effect of the mean-centered hypnotizability in the “Medium Predictability” condition (MP, predictor followed in 50% of the trials by the target). The broken line is the simple effect of the mean-centered hypnotizability in the “Low Predictability” condition (LP, predictor followed in 20% of the trials by the target).

Table 1:
Comparison between the control and test groups on age, hypnotizability, general selective attention, and general cognitive performance.

SHSSC: hypnotizability according to the Stanford hypnotic susceptibility scale form C (SHSSC, Weitzenhoffer & Hilgard, 1962); Flanker Effect: general level of selective attention according to the mean Flanker effect (Eriksen & Eriksen, 1974) assessed before and after the SL task (see Methods); Block Design and the Matrix Reasoning raw scores of subsets of the WASI-II. Means are compared with the two-tailed Mann-Whitney test.

	Control Group		Test Group		Mann-Whitney Test	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>U</i>	<i>p</i>
Age	22.33	3.15	26.07	13.00	112.50	0.983
SHSSC	7.53	2.20	8.20	2.96	89.50	0.346
Flanker Effect	54.53	57.39	29.53	25.05	98.50	0.575
Block Design	39.27	10.26	33.00	11.35	72.50	0.101
Matrix Reasoning	19.27	2.99	18.80	4.46	111.00	0.967

Table 2:
Description of the linear mixed models.

Model specification is using the R syntax. AIC: Akaike information criterion; BIC: Bayesian information criterion; LL: log-likelihood value; EEG mean: individual mean amplitude ERPs time-locked to the predictors in time window 500ms-650ms or 700ms-950ms; Predictability: Predictability condition (“High Predictability”, HP; “Low Predictability”, LP); HS: mean-centered hypnotizability according to the SHSS:C; ROI: region of interest (Figure 2). Models m1, m2, and m3 are detailed in Table 3, Table 4, and Table 5, respectively.

Model	Model Specifications	df	AIC	BIC	LL	Deviance
Behavioral Data						
m1	RT ~ Predictability + Predictability:Group + Predictability:HS + Predictability:Group:HS + (1 Participant)	14	10147	10226	−5059	10119
Neurophysiological Data						
500ms-650ms						
m2	EEG mean ~ Predictability + Predictability:ROI + Predictability:Group + Predictability:HS + Predictability:Group:ROI + Predictability:HS:ROI + Predictability:Group:HS + Predictability:Group:HS:ROI + (1 ROI) + (1 Participant)	27	34863	35063	−17405	34809
700ms-950ms						
m3	EEG mean ~ Predictability + Predictability:ROI + Predictability:Group + Predictability:HS + Predictability:Group:ROI + Predictability:HS:ROI + Predictability:Group:HS + Predictability:Group:HS:ROI + (1 ROI) + (1 Participant)	27	37278	37478	−18612	37224

Table 3:
Detailed description of models m1.

Fixed and random effects of m1 model of Table 1. LP: “Low Predictability” condition; MP: “Medium Predictability” condition; HP: “High Predictability” condition; HS: mean-centered hypnotizability according to the SHSS:C.

Model m1			
Fixed Effects	Estimate	SE	p
Intercept	17.81	1.79	0.000
MP	−1.569	1.02	0.1244
HP	−1.031	0.971	0.2883
LP:TestGroup	1.711	2.317	0.4647
MP:TestGroup	5.354	2.146	0.0184
HP:TestGroup	4.803	2.105	0.0305
LP:HS	3.279	1.785	0.0738
MP:HS	4.306	1.658	0.0145
HP:HS	3.03	1.63	0.0737
LP:TestGroup:HS	−2.371	2.227	0.2933
MP:TestGroup:HS	−5.29	2.066	0.0158
HP:TestGroup:HS	−4.518	2.029	0.0343
Random Effects	SD		
Participant	1.645		
Residual	2.812		

Table 4:

Detailed description of model m2.

Fixed and random effects of m2 model of Table 1. LP: “Low Predictability” condition; MP: “Medium Predictability” condition; HP: “High Predictability” condition; HS: mean-centered hypnotizability according to the SHSS:C; ROI: region of interest 9 levels (LAn, LCn, LPo, FRz, CNz, POz, RAn, RCn, RPo, Figure 2) with LAn as reference level.

Model m2			
Fixed Effects	Estimate	SE	p
Intercept	−0.6835	1.0220	0.927
MP	0.4825	0.0933	0.000
HP	0.1988	0.0933	0.033
LP:LCn	0.5917	1.4420	0.944
MP:LCn	0.3900	1.4420	0.958
HP:LCn	0.3961	1.4420	0.957
LP:LPo	1.3300	1.4420	0.916
MP:LPo	0.6781	1.4420	0.940
HP:LPo	0.6952	1.4420	0.939
LP:FRz	−0.5795	1.4420	0.945
MP:FRz	−0.2485	1.4420	0.970
HP:FRz	−0.6001	1.4420	0.944
LP:CNz	−0.0098	1.4420	0.999
MP:CNz	−0.0476	1.4420	0.994
HP:CNz	−0.1190	1.4420	0.985
LP:POz	1.1980	1.4420	0.920
MP:POz	0.5380	1.4420	0.948
HP:POz	0.3440	1.4420	0.961
LP:RAn	0.1751	1.4420	0.978
MP:RAn	0.1413	1.4420	0.982
HP:RAn	0.2007	1.4420	0.975
LP:RCn	0.9022	1.4420	0.930
MP:RCn	0.3631	1.4420	0.960
HP:RCn	0.6867	1.4420	0.939

Model m2			
Fixed Effects	Estimate	SE	p
LP:RPo	1.2640	1.4420	0.918
MP:RPo	0.4415	1.4420	0.954
HP:RPo	1.0030	1.4420	0.926
LP:TestGroup	0.5655	0.1397	0.000
MP:TestGroup	0.1691	0.1397	0.230
HP:TestGroup	0.3656	0.1397	0.011
LP:HS	-0.0549	0.0435	0.212
MP:HS	0.2026	0.0435	0.000
HP:HS	0.0761	0.0435	0.085
LP:LCn:TestGroup	-0.4415	0.1322	0.001
MP:LCn:TestGroup	-0.4920	0.1322	0.000
HP:LCn:TestGroup	-0.2768	0.1322	0.036
LP:LPo:TestGroup	-1.1820	0.1322	0.000
MP:LPo:TestGroup	-0.8593	0.1322	0.000
HP:LPo:TestGroup	-0.5792	0.1322	0.000
LP:FRz:TestGroup	0.5836	0.1322	0.000
MP:FRz:TestGroup	0.2147	0.1322	0.104
HP:FRz:TestGroup	0.4383	0.1322	0.001
LP:CNz:TestGroup	0.0228	0.1322	0.863
MP:CNz:TestGroup	-0.0185	0.1322	0.889
HP:CNz:TestGroup	0.1761	0.1322	0.183
LP:POz:TestGroup	-1.1670	0.1322	0.000
MP:POz:TestGroup	-0.6182	0.1322	0.000
HP:POz:TestGroup	-0.1343	0.1322	0.309
LP:RAn:TestGroup	0.0125	0.1322	0.925
MP:RAn:TestGroup	-0.1397	0.1322	0.291
HP:RAn:TestGroup	-0.0920	0.1322	0.487
LP:RCn:TestGroup	-0.6731	0.1322	0.000
MP:RCn:TestGroup	-0.2585	0.1322	0.051
HP:RCn:TestGroup	-0.4156	0.1322	0.002

Model m2			
Fixed Effects	Estimate	SE	p
LP:RPo:TestGroup	-1.1860	0.1322	0.000
MP:RPo:TestGroup	-0.1343	0.1322	0.310
HP:RPo:TestGroup	-0.7668	0.1322	0.000
LP:LCn:HS	0.0482	0.0261	0.065
MP:LCn:HS	0.0279	0.0261	0.285
HP:LCn:HS	-0.0027	0.0261	0.917
LP:LPo:HS	0.0355	0.0263	0.176
MP:LPo:HS	0.0425	0.0263	0.106
HP:LPo:HS	-0.0155	0.0263	0.555
LP:FRz:HS	0.0309	0.0266	0.245
MP:FRz:HS	-0.0101	0.0266	0.704
HP:FRz:HS	0.0686	0.0266	0.010
LP:CNz:HS	-0.0245	0.0270	0.364
MP:CNz:HS	0.0003	0.0270	0.990
HP:CNz:HS	0.0158	0.0270	0.558
LP:POz:HS	0.0403	0.0275	0.142
MP:POz:HS	0.0396	0.0275	0.149
HP:POz:HS	0.0311	0.0275	0.259
LP:RAn:HS	0.1378	0.0281	9E-07
MP:RAn:HS	0.0077	0.0281	0.785
HP:RAn:HS	0.0458	0.0281	0.103
LP:RCn:HS	0.1173	0.0288	5E-05
MP:RCn:HS	0.0163	0.0288	0.571
HP:RCn:HS	0.0112	0.0288	0.697
LP:RPo:HS	0.1313	0.0296	9E-06
MP:RPo:HS	0.0211	0.0296	0.475
HP:RPo:HS	0.0856	0.0296	0.004
LP:TestGroup:HS	-0.0300	0.0510	0.559
MP:TestGroup:HS	-0.2300	0.0510	4E-05
HP:TestGroup:HS	-0.1038	0.0510	0.047

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Model m2			
Fixed Effects	Estimate	SE	p
LP:ControlGroup:HS:ROI	−0.0075	0.0050	0.129
MP:ControlGroup:HS:ROI	−0.0412	0.0050	2E-16
HP:ControlGroup:HS:ROI	−0.0183	0.0050	2E-04
Random Effects			
SD			
Participant	0.2818		
ROI	1.0172		
Residual	0.9826		

Table 5:

Detailed description of model m3.

Fixed and random effects of m3 model of Table 1. LP: “Low Predictability” condition; MP: “Medium Predictability” condition; HP: “High Predictability” condition; HS: mean-centered hypnotizability according to the SHSS:C; ROI: region of interest 9 levels (LAn, LCn, LPo, FRz, CNz, POz, RAn, RCn, RPo, Figure 2) with LAn as reference level.

Model m3			
Fixed Effects	Estimate	SE	p
Intercept	-0.8959	1.0580	0.910
MP	0.6746	0.1027	0.000
HP	0.3643	0.1027	0.000
LP:LCn	1.0300	1.4930	0.919
MP:LCn	0.3749	1.4930	0.956
HP:LCn	0.6336	1.4930	0.938
LP:LPo	1.8950	1.4930	0.894
MP:LPo	0.8114	1.4930	0.928
HP:LPo	1.0960	1.4930	0.916
LP:FRz	-0.5596	1.4930	0.942
MP:FRz	-0.3255	1.4930	0.961
HP:FRz	-0.7136	1.4930	0.933
LP:CNz	0.3665	1.4930	0.957
MP:CNz	-0.1223	1.4930	0.984
HP:CNz	0.0320	1.4930	0.996
LP:POz	1.7860	1.4930	0.897
MP:POz	0.5435	1.4930	0.943
HP:POz	0.6471	1.4930	0.937
LP:RAn	0.2722	1.4930	0.966
MP:RAn	-0.1345	1.4930	0.982
HP:RAn	-0.0469	1.4930	0.994
LP:RCn	1.0910	1.4930	0.916
MP:RCn	0.1521	1.4930	0.980
HP:RCn	0.6317	1.4930	0.938

Model m3			
Fixed Effects	Estimate	SE	p
LP:RPo	1.4050	1.4930	0.906
MP:RPo	0.5181	1.4930	0.945
HP:RPo	1.0930	1.4930	0.916
LP:TestGroup	0.5225	0.1358	0.000
MP:TestGroup	0.1338	0.1358	0.326
HP:TestGroup	0.0013	0.1358	0.993
LP:HS	-0.1248	0.0415	0.003
MP:HS	0.1940	0.0415	0.000
HP:HS	0.1145	0.0415	0.007
LP:LCn:TestGroup	-0.7146	0.1455	0.000
MP:LCn:TestGroup	-0.4197	0.1455	0.004
HP:LCn:TestGroup	-0.3470	0.1455	0.017
LP:LPo:TestGroup	-1.4090	0.1455	< 2E-16
MP:LPo:TestGroup	-0.8316	0.1455	0.000
HP:LPo:TestGroup	-0.4755	0.1455	0.001
LP:FRz:TestGroup	0.5979	0.1455	0.000
MP:FRz:TestGroup	0.3297	0.1455	0.023
HP:FRz:TestGroup	0.3991	0.1455	0.006
LP:CNz:TestGroup	0.0046	0.1455	0.975
MP:CNz:TestGroup	0.1033	0.1455	0.478
HP:CNz:TestGroup	0.0459	0.1455	0.752
LP:POz:TestGroup	-1.2030	0.1455	< 2E-16
MP:POz:TestGroup	-0.3978	0.1455	0.006
HP:POz:TestGroup	-0.0352	0.1455	0.809
LP:RAn:TestGroup	-0.0234	0.1455	0.872
MP:RAn:TestGroup	0.1337	0.1455	0.358
HP:RAn:TestGroup	0.4869	0.1455	0.001
LP:RCn:TestGroup	-0.6094	0.1455	0.000
MP:RCn:TestGroup	-0.0435	0.1455	0.765
HP:RCn:TestGroup	0.1162	0.1455	0.425

Model m3			
Fixed Effects	Estimate	SE	p
LP:RPo:TestGroup	-0.8738	0.1455	0.000
MP:RPo:TestGroup	-0.1223	0.1455	0.401
HP:RPo:TestGroup	-0.1907	0.1455	0.190
LP:LCn:HS	0.0997	0.0287	0.001
MP:LCn:HS	0.0262	0.0287	0.362
HP:LCn:HS	0.0406	0.0287	0.158
LP:LPO:HS	0.1688	0.0289	0.000
MP:LPO:HS	0.0324	0.0289	0.262
HP:LPO:HS	0.0270	0.0289	0.351
LP:FRz:HS	-0.0453	0.0292	0.121
MP:FRz:HS	0.0143	0.0292	0.626
HP:FRz:HS	0.0738	0.0292	0.012
LP:CNz:HS	-0.0850	0.0297	0.004
MP:CNz:HS	0.0221	0.0297	0.457
HP:CNz:HS	0.0127	0.0297	0.669
LP:POz:HS	0.0375	0.0303	0.21545
MP:POz:HS	0.0193	0.0303	0.52465
HP:POz:HS	0.0913	0.0303	0.00256
LP:RAn:HS	0.1078	0.0309	0.0005
MP:RAn:HS	0.0289	0.0309	0.35008
HP:RAn:HS	0.0550	0.0309	0.07537
LP:RCn:HS	0.1011	0.0317	0.00145
MP:RCn:HS	0.0392	0.0317	0.2171
HP:RCn:HS	0.0414	0.0317	0.19144
LP:RPo:HS	0.1820	0.0326	2.4E-08
MP:RPo:HS	0.0188	0.0326	0.56492
HP:RPo:HS	0.1158	0.0326	0.00038
LP:TestGroup:HS	0.0471	0.0476	0.32645
MP:TestGroup:HS	-0.2209	0.0476	1.6E-05
HP:TestGroup:HS	-0.1583	0.0476	0.00142

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Model m3			
Fixed Effects	Estimate	SE	p
LP:ControlGroup:HS:ROI	−0.0185	0.0055	0.0007
MP:ControlGroup:HS:ROI	−0.0402	0.0055	1.8E-13
HP:ControlGroup:HS:ROI	−0.0266	0.0055	1.1E-06
Random Effects			
SD			
Participant	0.2403		
ROI	1.0533		
Residual	1.0817		