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HYPNOSIS INDUCES A CHANGED COMPOSITION OF BRAIN OSCILLATIONS IN EEG: A CASE STUDY

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Abstract

Cognitive functions associated with the frontal lobes of the brain may be specifically involved in hypnosis. Thus, the frontal area of the brain has recently been of great interest when searching for neural changes associated with hypnosis. We tested the hypothesis that EEG during pure hypnosis would differ from the normal non-hypnotic EEG especially above the frontal area of the brain. The composition of brain oscillations was examined in a broad frequency band (1–30 Hz) in the electroencephalogram (EEG) of a single virtuoso subject. Data was collected in two independent data collection periods separated by one year. The 'hypnotic' and 'non-hypnotic' conditions were repeated multiple times during each data acquisition session. We found that pure hypnosis induced reorganization in the composition of brain oscillations especially in prefrontal and right occipital EEG channels. Additionally, hypnosis was characterized by consistent right-side-dominance asymmetry. In the prefrontal EEG channels the composition of brain oscillations included spectral patterns during hypnosis that were completely different from those observed during non-hypnosis. Furthermore, the EEG spectral patterns observed overall during the hypnotic condition did not return to the pre-hypnotic baseline EEG immediately when hypnosis was terminated. This suggests that for the brain, the return to a normal neurophysiological baseline condition after hypnosis is a time-consuming process. The present results suggest that pure hypnosis is characterized by an increase in alertness and heightened attention, reflected as cognitive and neuronal activation. Taken together, the present data provide support for the hypothesis that in a very highly hypnotizable person (a hypnotic virtuoso) hypnosis as such may be accompanied by a changed pattern of neural activity in the brain.

Key words: adaptive classification, brain functions, electroencephalogram (EEG), hypnosis, short-term spectral patterns, theta/alpha/beta oscillations

Introduction

It remains unclear what happens in the brain during 'pure' hypnosis, that is, after the subject is given a hypnotic induction as such, without any further suggestions. According to one theoretical approach, this 'pure' hypnosis involves a change in brain function that serves as the special 'background state' of hypnosis. This background state is supposed to enable the altered experiences that will be produced by further suggestions, should such be given (Kallio and Revonsuo, 2003, 2005; see also Kirsch, 2005). Furthermore, the 'background state', if it exists as an empirical reality, should also have some objectively measurable neurophysiological correlates. Although many neurophysiological correlates associated with hypnosis have been reported in the literature (e.g. Gruzelier 1998, 2000, 2006; Egner, Jamieson and Gruzelier, 2005) none of the findings so far have been able to truly resolve the central theoretical debate in the field: the state non-state debate (Kallio and Revonsuo, 2003, 2005).

The existence of such a background state and its neural correlates remains one of the major dividing lines between the social cognitive theories of hypnosis and the state theories of hypnosis (Kallio and Revonsuo, 2003, 2005). Therefore, empirical research on this question could directly contribute to the theoretical understanding of the nature of hypnosis.

Changes in different EEG-frequencies have already been reported in association with hypnosis (for a review see Crawford and Gruzelier, 1992), however, it is difficult to compare different studies with each other because of methodological differences as well as different criteria when selecting subjects for experiments. These experiments have typically studied hypnosis in association with additional suggestions (e.g. pain reduction, hallucinations, etc.). They have not been directly designed to answer questions concerning the possible changes of pure hypnosis per se but are rather studying different phenomena in a hypnotic context or using hypnosis as an instrument for exploring other psychological processes and phenomena (see e.g. Oakley, 2006). Therefore, it is not surprising that consistent and reproducible neurophysiological evidence of possible neural changes associated with hypnosis per se, i.e. neutral hypnosis, does not exist.

Another methodological reason for the lack of consistent findings could be a problem associated with the way the data is typically analysed. The traditional protocol for analysing EEG data is based on averaging procedures from extended periods of time and/or broad fixed frequency bands for a specific lead. This practice makes the examination of the natural composition of brain oscillations rather difficult (for a discussion, see Fingelkurts et al., 2002, 2004, 2006a).

Our purpose in this experiment was to focus on exploring the nature of hypnosis itself (i.e. pure hypnosis) by using a design with only one independent variable involving two levels: non-hypnosis and hypnosis. The aim is to test the frontal hypothesis in general (e.g. Bowers, 1992; Crawford and Gruzelier, 1992; Woody and Bowers, 1994; Gruzelier, 1998, 2000) and the Altered State Theory of hypnosis (AST) by Kallio and Revonsuo (2003) in particular. In this experiment the guidelines suggested by Kallio and Revonsuo (2003) were followed in order to reduce the effects of confounding variables. First, hypnosis was induced and cancelled by a posthypnotic suggestion (a Finnish pseudoword) in order to rapidly change between the control (non-hypnosis) and experimental (hypnosis) condition. Second, we used a single case approach which is free from group averaging (Shallice, 1979; Barabasz and Barabasz, 1992). Third, the subject was a hypnotic virtuoso who had previously proved to respond well to a posthypnotic suggestion and who had also shown changes in mismatch negativity (MMN) component of auditory Event Related Potential (ERP) during hypnosis in a previous study (Kallio et al., 1999). Fourth, we used a novel design for EEG analysis in order to examine the natural composition of brain oscillations in the broad frequency band (1–30 Hz). This is a model-independent technique which pays regard to the nonstationarity of EEG, does not require prior knowledge of the underlying dynamics and it produces results which are easy to interpret in terms of their neurophysiological correlates.

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Our hypothesis was that some differences between non-hypnosis (control condition) and hypnosis (experimental condition) should occur especially in the frontal area of the brain and thus be most strongly reflected in scalp EEG at the electrode sites located directly above the frontal lobes.

Methods

Subject

The subject (T.S.-H.) was an experienced participant in hypnosis experiments (e.g. Kallio et al., 1999). She was a 39-year-old right-handed female office worker who also performs as a classical singer semi-professionally. She has scored the maximum of 12 points in SHSS-C (Weitzenhoffer and Hilgard, 1962) and displays all phenomena typically associated with very highly susceptible individuals (virtuosos), such as vivid hallucinations and amnesia. She furthermore instantly responds to a posthypnotic suggestion (e.g. a word or a sign) about 'entering hypnosis' which makes it possible to induce or cancel hypnosis without standard experimental induction procedures. T.S.-H. had no history of neurological or psychiatric illnesses and she gave her informed consent to participate in the study.

Procedure

The EEG acquisitions were carried out in two sessions between 10 am and 1 pm with a one-year interval in between. Following electrode placement and instrument calibration, the subject was seated in a comfortable chair in a dimmed room and the experimental procedure was explained. To reduce muscle artefacts in the EEG signal, the subject was instructed to assume a comfortable position, to avoid movement, and to relax her jaw muscles. The subject had previously been given a posthypnotic suggestion about entering hypnosis or waking when hearing the experimenter say certain Finnish pseudowords. During the experiment, hypnosis was induced and cancelled with this technique. The only instruction given to the subject was to focus on a LED-light in front of her (about 2 metres distance) and avoid unnecessary eye movements.

Each session started with two minutes of EEG data acquisition (baseline condition) while the subject sat in a comfortable chair and had her eyes open and focused on the LED-light. After this baseline recording the hypnotist sat behind the subject and gave her instructions to just continue to focus on the LED-light in front of her and relax. This was followed by three EEG acquisition blocks where hypnosis and non-hypnosis followed each other being induced by a posthypnotic suggestion. Each block consisted of 3–4 hypnosis and non-hypnosis periods lasting about 2 minutes/period (2 mins of hypnosis, 2 mins of non-hypnosis, 2 mins of hypnosis, etc). The three blocks (each lasting about 10 minutes) were separated by a break of about 5 minutes in normal waking state while the subject could stretch herself. This was done to avoid fatigue and help the subject to feel more comfortable. The sequence of hypnotic and non-hypnotic conditions was varied so that each condition started the blocks equally often. The hypnosis and non-hypnosis periods within the blocks varied also +/−30 seconds in order to prevent the subject from anticipating the change. While the hypnotist gave the posthypnotic suggestion (either to enter hypnosis or to 'wake'), he simultaneously pressed a button delivering a code to EEG-data. Thus, it was possible later to locate the exact time for the beginning and the end for hypnosis and non-hypnosis periods. The subject had her eyes open during the whole procedure.

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Data acquisition

EEG data acquisition was performed in a magnetically and electrically shielded room at the Centre for Cognitive Neuroscience, University of Turku. Spontaneous electrical brain activity was recorded with a 20-channel EEG data acquisition system (NeuroScan 386, Acquire 4.0 and SynAmps) with a frequency band of 0.05 to 100 Hz (sampling rate 500 Hz). EEG was recorded with an electrode cap according to the International 10/20 extended system and the nose electrode was used as reference. The impedance of each electrode was monitored with an impedance meter prior to data collection; this was always below 5 kΩ. Vertical and horizontal electro-oculograms were recorded. The presence of an adequate signal was determined by visually checking each raw signal on the computer screen.

Data processing

EEG epochs containing artefacts (amplitude >80 μV) due to eye blinks, significant muscle activity, and movements were automatically removed. In addition the data was visually scanned for conspicuous large artefacts which were manually removed. Subsequently, the EEG streams free from artefacts were split into 3 distinct groups:

1) Baseline condition: the first 2 minutes from each session was used to establish a baseline. This data was recorded *before* any hypnotic conditions were induced.
2) Non-hypnotic condition: the data recorded during normal waking conditions *following a hypnotic condition*, i.e. during these non-hypnotic periods the subject had just been 'woken' from hypnosis.
3) Hypnotic condition: the data recorded during the hypnotic conditions.

Further data processing was performed separately for each one-minute portion of the signal for each condition. Due to the technical requirements of the tools which were later used to process the data, EEGs from 20 electrodes ($Fp_{1/2}$ $F_{7/8}$, F_Z, $F_{3/4}$, $T_{3/4}$, $C_{3/4}$, C_Z, $T_{5/6}$, P_Z, $P_{3/4}$, O_Z, $O_{1/2}$) were analysed with a converted sampling rate of 128 Hz.

After re-sampling and prior to calculation of power spectra, each EEG signal was bandpass filtered using the 1–30 Hz frequency range. This frequency range was chosen because approximately 98% of spectral power lies within these limits (Thatcher, 2001). Thus, individual power spectra were calculated in the range of 1–30 Hz with 0.5-Hz resolution (60 values), using FFT with a 2-sec Hanning window shifted by 50 samples (0.39-sec) for each channel of one-minute EEG. According to previous studies, these values have proved to be most effective for revealing oscillatory patterns from the signal (Levy, 1987; see details in Fingelkurts et al., 2006b).

As a result, the total number of individual spectral patterns (SP) for each channel of 1-min EEG was 149 (Figure 1). These SPs formed the multitude of the objects for further classification procedure. The compositions of brain oscillations (in terms of SPs) were estimated with the help of a probability-classification analysis of the short-term EEG SPs. Considering that a detailed description of this analysis has been previously published elsewhere (Fingelkurts et al., 2003), here we are highlighting only the most important steps. In short, this analysis was undertaken in two stages (see Figure 1).

During the first stage, sequential single SPs were adaptively classified in each channel of 1-min EEG using a set of standard SPs (n = 32, for SP description, see Figure 3). As the result of this classification, each current SP was labelled according to the index of the class to which it belongs. Hence, each EEG signal was reduced to a sequence of individually classified SPs (Figure 1).

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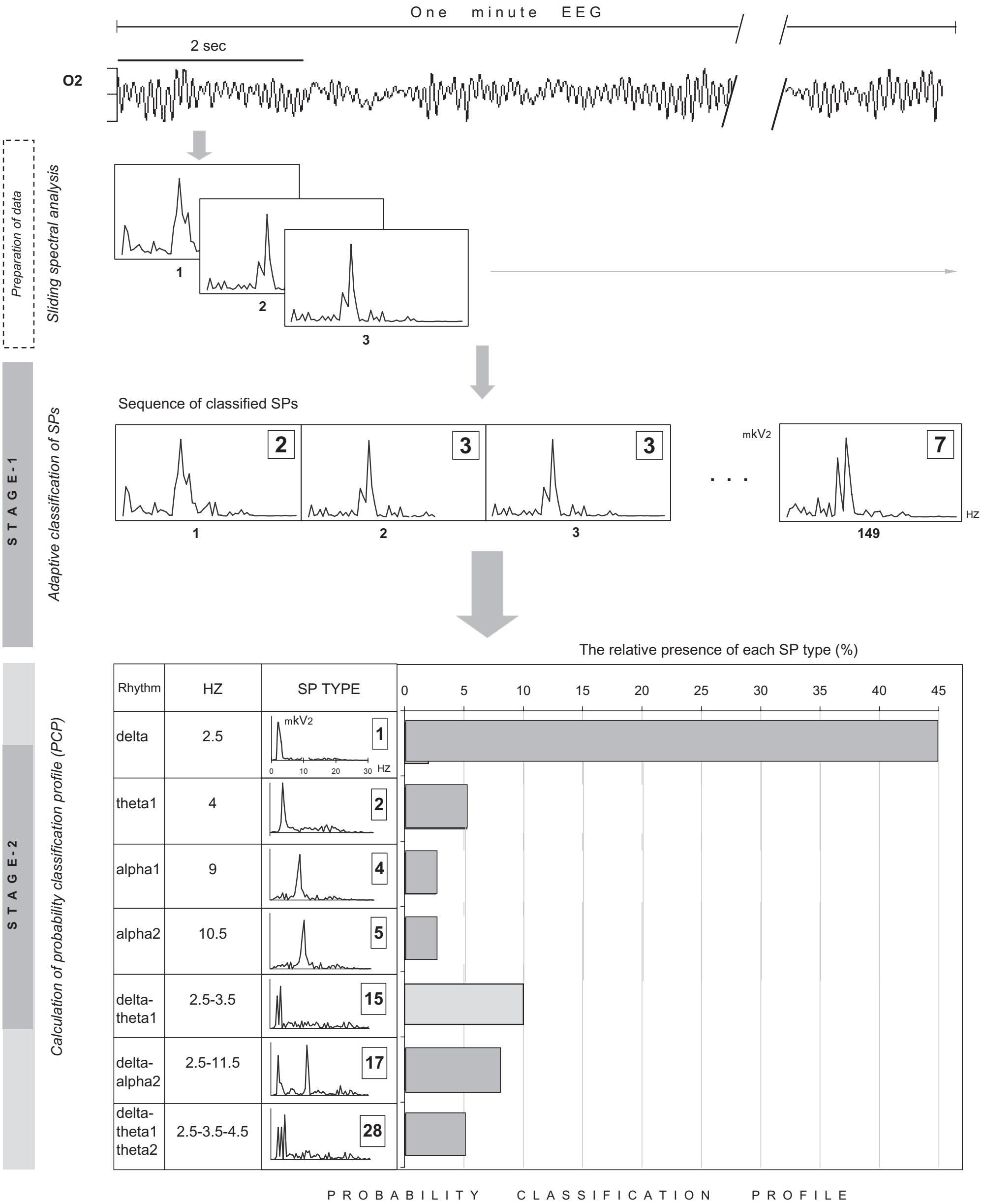

Figure 1. The scheme of the data processing. Sliding spectral analysis, adaptive classification of spectral patterns (SP) and calculation of the probability-classification profiles (PCP) were conducted separately for each channel of 1-min EEG (modified from Fingelkurts et al., 2006a). Grey small numbers under each SP represent the running numbers from 1 to 149. The numbers in the square represent the labels – types of classified SPs (1–32). Column 'Hz' represents the main dominant peak(s) in particular SP. Presented PCP illustrates the composition and percentage ratio of brain oscillations in O_2 EEG for virtuoso subject during neutral hypnosis.

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At the second stage, probability-classification profile (PCP) of SPs for each channel of 1-min EEG was calculated (Figure 1). PCP was calculated by taking the relative number of cases of an SP type as a percentage of the total amount of all SPs within each EEG channel – presented as the histogram of relative presence of each SP type (Fingelkurts et al., 2003a). PCPs were averaged across 22 (for hypnotic condition), 13 (for non-hypnotic condition), and 4 (for baseline condition) 1-min EEG signals separately for each EEG channel. It was expected that these PCPs would make it possible to illustrate in detail (in SP description) the composition of brain oscillations and their percentage ratio.

Index of *non-homogeneity of classification profile* (NHCP) was estimated as a ratio of the number of SP types detected in a given 1-min EEG to the total number in the standard set (32 standard SPs = 100%). This index indicates how many different SP types participate in PCP.

In addition conventional spectral patterns were calculated by the averaging all (n = 149) individual SPs within each EEG channel separately for each condition.

Since the main results were reproduced in retest examination after one year (Figure 2, $r = 0.81–0.95$), the entire data was combined for further analysis. Only results which were reproduced in first, second and combined analysis sessions are presented in this paper as the most robust.

Statistics

In order to reveal any statistically significant differences in the relative presence of each SP type in PCPs between any two conditions, the paired Wilcoxon t-test was used separately for each type of SPs presented in the PCPs. Statistical significance was assumed where $P < 0.05$ (only statistically significant values are displayed). Since we intended to assess each variable in its own right, no Bonferroni correction was applied (for the problems associated with Bonferroni adjustments, see Rothman, 1990; Perneger, 1998).

However, in the case where we compared three groups ('baseline,' 'non-hypnosis,' and 'hypnosis') a Bonferroni correction was made in order to control for repeated observations of the same measures. $P_{corrected}$ is the value required to keep the number of false positives at $P = 5\%$.

An asymmetry score was computed by estimating a statistically significant difference between SP type's relative presence in PCP for all sites that have symmetrical left and right locations (O^1 and O^2, and so on).

Results

General description of EEG for hypnotic, non-hypnotic, and baseline conditions

For hypnotic, non-hypnotic, and baseline conditions all EEG channels were characterized by the same 4–5 SP types dominant in the PCPs (Figure 3), however, all these conditions differed significantly from each other according to the probability estimation of the occurrence of these SP types in PCPs (Table 1). The comparative analysis of PCPs for different conditions showed that there were no particular types of EEG SPs associated exclusively with hypnosis, i.e. all SP types that were present during hypnosis could be seen at least in some electrode during baseline. At the same time, Fp_1 and Fp_2 EEG channels had unique SP description during the hypnotic condition when

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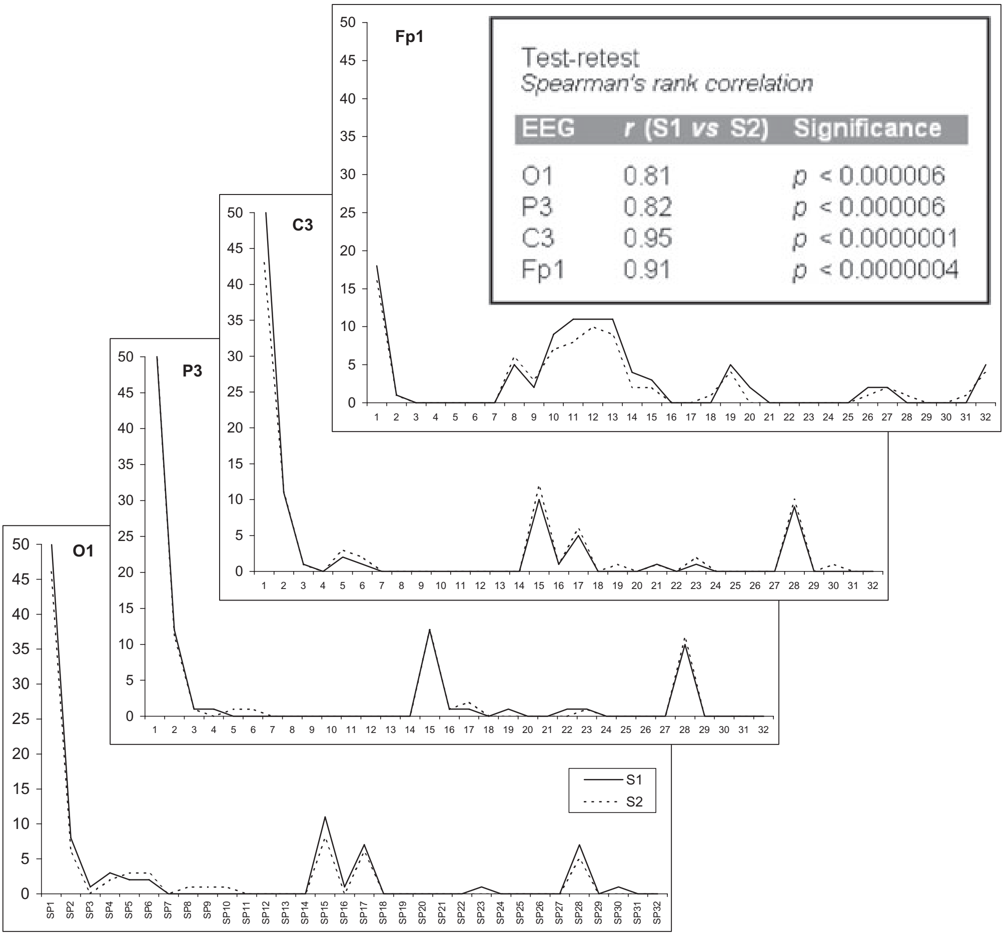

Figure 2. Test-retest reliability of hypnosis effect (with one year in-between two sessions) and probability-classification profiles for the first and second sessions (S_1 and S_2 correspondently). Data averaged across 10 one-minute EEGs for the 1st session and 12 one-minute EEGs for the 2nd session.
O_1 = occipital, P_3 = parietal, C_3 = central, and Fp_1 = prefrontal EEG channels placed at the left hemisphere of the brain. The *X*-axis displays the labels (numbers) of the standard spectral patterns (SP) from 1 to 32. The *Y*-axis displays the share of the corresponding SPs in the percentage from the total number of the classified SPs. A line graphic was chosen instead of a bar for the ease of comparison. (Note that *X*-axis consists of 32 discrete values, all the in-between values are meaningless).

compared with the baseline condition. In these electrodes seven out of seventeen (the total amount of SPs found in these channels) SP types were only present during hypnosis (Table 2).

The composition of brain oscillations included delta, theta$_1$, delta-theta$_1$, delta-theta$_1$-theta$_2$, and delta-alpha$_2$. These brain oscillations composed 18 SP types observed in EEG. In general, the spatial distribution of these brain oscillations was smoothed: only a trend for an increase of alpha- and decrease of delta- and theta-rhythmic EEG segments in frontal-to-occipital direction was observed.

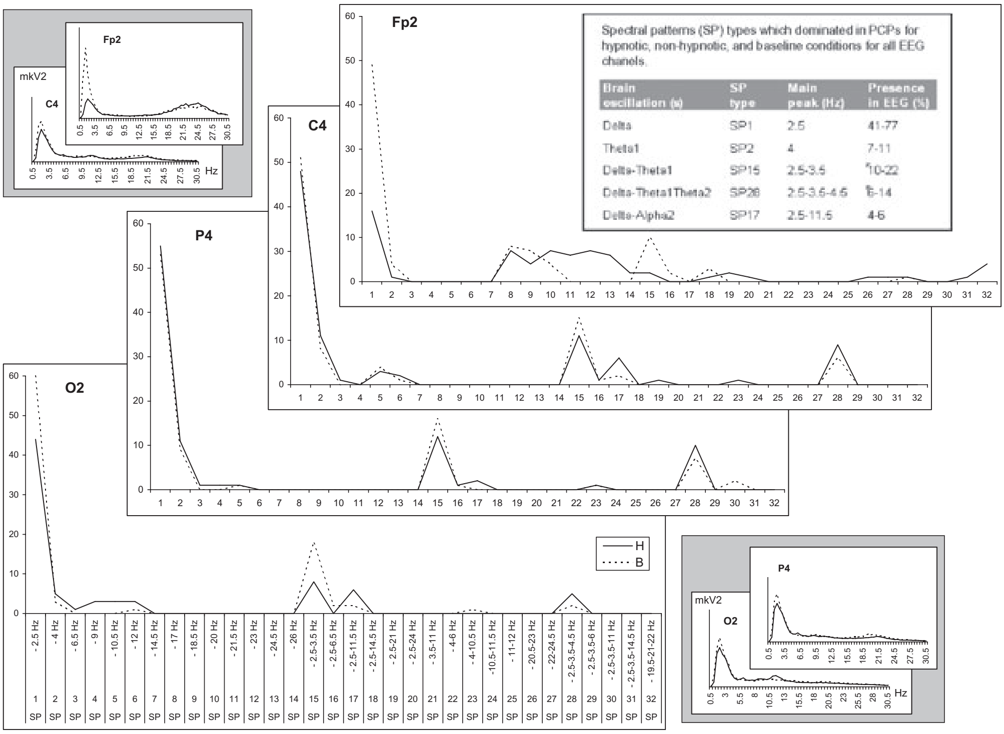

Figure 3. Probability-classification profiles and spectral patterns (SP) dominant in EEG during hypnotic, non-hypnotic, and baseline conditions. Data averaged across 22 one-minute EEGs for hypnosis, 13 one-minute EEGs for non-hypnosis, and 4 one-minute EEGs for baseline conditions (joint first and second sessions). Grey insertions represent mean power spectra (conventional spectral analysis).
O_2 = occipital, P_4 = parietal, C_4 = central, and Fp_2 = prefrontal EEG channels placed at the right hemisphere of the brain; H = hypnotic condition, B = baseline condition. The *X*-axis displays the labels (numbers) of the standard SP from 1 to 32 and their main frequency peaks. The *Y*-axis displays the share of the corresponding SPs in the percentage from the total number of the classified SPs. A line graphic was chosen instead of a bar for the ease of comparison. (Note that *X*-axis consists of 32 discrete values, all the in-between values are meaningless).

Characteristics of hypnosis-induced EEG changes

In general, hypnosis affected all EEG channels: there was not a single EEG channel without statistically significant differences in the relative presence of at least 11% of SP types in PCPs between hypnotic, non-hypnotic, and baseline conditions. At the same time, different EEG channels were characterized by different number of SP types, which demonstrated statistically significant differences in their relative presence in PCPs, thus indicating the magnitude of the effect of hypnosis. Frontal (Fp_1, Fp_2) and right occipital (O_2) EEG channels were maximally affected by hypnosis – the number of SP types which demonstrated a statistically significant difference in their relative presence in PCPs between hypnotic, non-hypnotic, and baseline conditions reached in these areas up to 89% from all observed SP types. A minimum number of SP types (up to 11%) which demonstrated a statistically significant difference in their relative presence in PCPs between hypnotic, non-hypnotic, and baseline conditions was observed in the mid frontal (F_Z) and right parietal (P_4) EEG channels.

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Table 1. Spectral pattern types which demonstrated statistically significant ($P_{corrected} < 0.02 - P_{corrected} < 0.0001$) difference between hypnotic, non-hypnotic, and baseline conditions
Data averaged across 22 (for hypnotic condition), 13 (for non-hypnotic condition), and 4 (for baseline condition) 1-min EEGs

Brain oscillation (s)	SP type	Main peak (Hz)	EEG channels (%)	Topological distribution
B < NH < H				
Theta3	SP3	6.5	70	distributed across all brain lobes
Delta-theta3	SP16	2.5–6.5	30	distributed across majority of brain lobes
Delta-theta1-theta2	SP28	2.5–3.5–4.5	25	distributed across occipital, parietal, and temporal brain areas
Delta-alpha2	SP17	2.5–11.5	45	distributed across majority of brain lobes
Theta2-alpha2	SP23	4–10.5	40	distributed across parietal, central, temporal, and frontal brain areas
	SP4	9	50	distributed across majority of brain lobes
Alpha	SP5	10.5	20	distributed across occipital areas
	SP6	12	20	distributed across occipital areas
Delta-beta2	SP19	2.5–21	30	distributed across central, temporal, and frontal brain areas
B > NH > H				
Delta	SP1	2.5	25	distributed across frontal areas
Delta-theta1	SP15	2.5–3.5	35	distributed across occipital, parietal, and frontal brain areas

H – Hypnotic condition; NH – Non-hypnotic condition; B – Baseline condition; SP – spectral pattern; 'Brain oscillation' column represents the brain oscillations which contribute the most into a particular SP.
'SP type' column represents the labels of spectral pattern types; 'Main peak' column represents frequency of the main peaks for each SP type; 'EEG channels' column represents number of EEG channels where given SP type demonstrated statistically significant difference in its relative presence in PCPs between hypnotic, non-hypnotic, and baseline conditions; 'Topological distribution' column represents brain areas, where the effect was found.

At the same time, all observed SP types ($n = 18$) revealed statistically significant difference in its relative presence in PCPs between hypnotic, non-hypnotic, and baseline conditions in at least 5% of EEG channels.

Comparative analysis of the PCPs demonstrated that EEG during the hypnotic condition was characterized by a larger percentage of delta-theta- [SP16 (main peaks at 2.5 and 6.5 Hz), SP28 (2.5–3.5–4.5 Hz)], theta$_3$- [SP3 (6.5 Hz)], delta-alpha$_2$- [SP17 (2.5–11.5 Hz)], theta-alpha$_2$- [SP23 (4–10.5 Hz)], alpha- [SP4 (9 Hz), SP5 (10.5 Hz), SP6 (12 Hz)], and delta-beta$_2$- [SP19 (2.5–21 Hz)] rhythmic segments, and by a smaller percentage of delta- [SP1 (2.5)], delta-theta$_1$- [SP15 (2.5–3.5 Hz)] rhythmic segments when compared with baseline condition ($P_{corrected} < 0.02 - P_{corrected} < 0.0001$ for different EEG channels and SPs; Table 1). The non-hypnotic condition demonstrated intermediate values between hypnotic and baseline conditions, which differed significantly from both hypnotic and baseline conditions. Note that the majority of SP types presented in Table 1 are not dominant in EEG (see Figure 3).

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Table 2. Spectral pattern types which demonstrated statistically significant ($P_{corrected} < 0.02 - P_{corrected} < 0.0001$) difference between hypnotic, non-hypnotic, and baseline conditions in Fp1 and Fp2 EEG channels
Data averaged across 22 (for hypnotic condition), 13 (for non-hypnotic condition), and 4 (for baseline condition) 1-min EEGs

SP	Frequency (Hz)	Brain oscillation	Fp1	Fp2
	H > NH > B			
9	18.5	beta1	+	–
10	20	beta1	+	–
11	21.5	beta2	+	+
12	23	beta2	+	+
13	**24.5**	**beta2**	+	+
14	**26**	**beta2**	+	–
20	**2.5–24**	**delta-beta2**	+	+
26	**20.5–23**	**beta2-beta2**	+	+
27	**22–24.5**	**beta2-beta2**	+	–
31	**2.5–3.5–14.5**	**delta-theta1-beta1**	+	–
32	**19.5–21–22**	**beta1-beta2-beta2**	+	+
	H < NH < B			
1	2.5	delta	+	+
2	4	theta2	+	+
3	6	theta3	+	–
15	2.5–3.5	delta-theta1	+	+
16	2.5–6.5	delta-theta3	–	+
28	2.5–3.5–4.5	delta-theta1-theta2	+	+

SP – Spectral patterns; PCP – Probability-classification profile; H – hypnosis; NH – Non-hypnosis; B – Baseline;
+ SP presence in PCP
– SP absence in PCP
Boldface indicates those spectral patterns which exist only during hypnosis.

Conventional 'energetic' estimation (mean spectral power) of the hypnosis-related EEG spectral changes revealed a simplified 'picture': decreased power in the delta (1.5–2.5 Hz) and increased power in the beta (16.5–30 Hz) activity only in Fp_1 and Fp_2 EEG channels during hypnotic condition when compared with the baseline condition ($P < 0.01$; see insertions in Figure 3).

Fp_1 and Fp_2 EEG channels showed a unique type of SPs during hypnosis (they were only present during this condition in Fp_1 and Fp_2) and had the largest hypnosis effect (the number of SP types which demonstrated a statistically significant difference in their relative presence in PCPs; Table 2). EEGs in Fp_1 and Fp_2 during the hypnotic condition were characterized by a larger percentage of delta-beta-, delta-theta$_1$-beta-, and beta-rhythmic segments, and by a smaller percentage of delta-, theta-, and delta-theta- rhythmic segments when compared with the baseline condition ($P_{corrected} < 0.02 - P_{corrected} < 0.0001$ for different SPs; Table 2). The non-hypnotic condition demonstrated also intermediate values between hypnotic and baseline conditions, which differed statistically significantly from both hypnotic and baseline conditions. A majority of the beta-rhythmic

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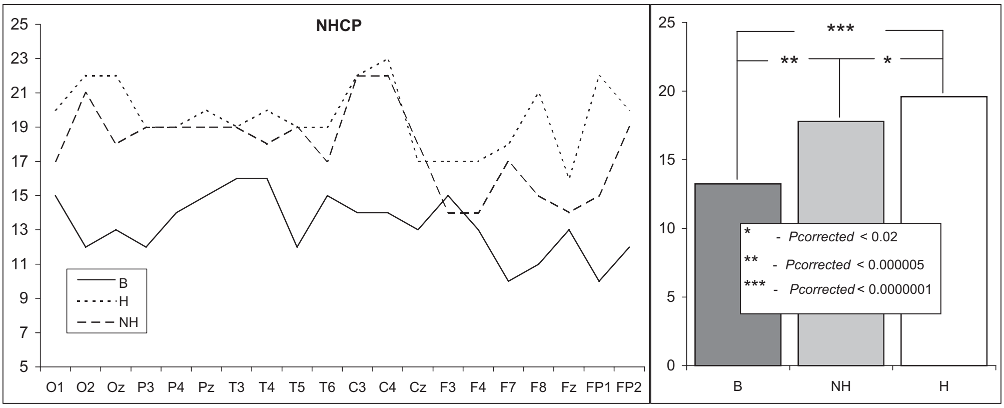

Figure 4. Index of non-homogeneity of classification profile (NHCP) for each EEG channel separately and averaged across all EEG channels ($n = 20$). NHCP was estimated as a ratio of the number of spectral pattern (SP) types detected in a given one-min EEG to the total number in the standard set (32 standard SPs = 100%). This index indicates how many different SP types participate in probability-classification profile. Data averaged across 22 one-minute EEGs for hypnosis, 13 one-minute EEGs for non-hypnosis, and 4 one-minute EEGs for baseline conditions (joint first and second sessions). H = hypnotic condition, NH = non-hypnotic condition, B = baseline condition.

segments existed in the EEG only during the hypnotic condition (Table 2). Control for the possible influence of myogram on the EEG in Fp_1 and Fp_2 channels demonstrated that the increase in the amount of beta brain oscillations was not due to myogram, because voluntary constriction of forehead muscles resulted in the increase in delta and polyrhythmic activity, but not in beta activity.

The number of SP types (measured as NHCP) which described EEG (all channels) was the largest during the hypnotic condition ($P_{corrected} < 0.02 - P_{corrected} < 0.0000001$ for different EEG channels; Figure 4). Again, the non-hypnotic condition demonstrated intermediate values between hypnotic and baseline conditions, which differed significantly from both of them.

Interhemispheric asymmetry in the EEG during hypnotic and baseline conditions

In general, for both hypnotic and baseline conditions, statistically significant ($P < 0.05 - P < 0.0001$ for different pairs) interhemispheric asymmetry (indexed by relative presence of SPs in PCPs) was observed in all homologous EEG-channel pairs ($n = 8$) for at least 6% of SP types. At the same time, a majority of the observed SP types showed statistically significant ($P < 0.05 - P < 0.0001$ for different SPs) interhemispheric asymmetry in their relative presence in PCPs for at least 12% of EEG-channel pairs.

During the hypnotic condition occipital, temporal, and frontal homologous EEG-channel pairs demonstrated statistically significant differences ($P < 0.05 - P < 0.0001$ for different pairs) for the most SP types (up to 50%). Whereas during the baseline condition, occipital, parietal, and frontal homologous EEG-channel pairs demonstrated statistically significant ($P < 0.05 - P < 0.0001$ for different pairs) differences for the largest number of SP types (up to 28%, much smaller than during hypnosis). Hypnosis was characterized by more EEG-channel pairs with right-side-dominance asymmetry than with left-side-dominance asymmetry ($P < 0.05$), whereas the baseline condition did not have consistent dominance.

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Discussion

General

We found support for the hypothesis that pure hypnosis is accompanied by a different pattern of brain oscillations (in terms of their probability) compared to a non-hypnotic condition. Furthermore, the data show that this changed pattern does not return to a normal baseline level directly after the subject had been 'woken' from hypnosis. The oscillation pattern in a non-hypnotic condition, observed directly after the hypnotic induction had been cancelled, appeared to be somewhere in the middle ground between the hypnosis and the original baseline condition that was not contaminated by prior hypnosis as it was applied first in the whole session, before any hypnotic conditions were induced.

To summarize briefly, the main results observed in the present study were:

1) Hypnosis changed the total amount of the time (percentage of EEG segments) that particular types of brain oscillations were observed, rather than their amplitude or power.
2) Hypnosis induced considerable reorganization in the composition of brain oscillations in EEG.
3) The types of SPs during hypnosis were not different types of SPs from those found during baseline. However, in Fp_1 and Fp_2 electrodes, seven out of seventeen SP types were only present during hypnosis.
4) The observed changes did not involve the dominant types of SPs. Therefore, the global and dominating patterns of EEG do not undergo radical changes during hypnosis. Instead, the changed patterns represent non-dominant spectral patterns in the EEG, and the changes detected are specific in terms of their spectral composition and the site of measurement or brain area.

Although hypnosis affected all EEG channels, the largest effects of hypnosis were observed at right occipital electrode (O_2) and electrodes above the prefrontal cortex (Fp_1 and Fp_2). This finding is consistent with studies stressing the importance of prefrontal and right occipital brain areas in search of neural changes associated with hypnosis (Kaiser et al., 1997; De Pascalis et al., 1998; Gruzelier, 1998, 1999, 2000, 2006; Rainville et al., 1999).

The data were also analysed using the traditional mean power spectrum which showed that hypnosis decreased delta activity and increased beta activity in the frontal area (electrodes Fp_1 and Fp_2). The reason for these rather modest findings using the traditional EEG spectral analysis method can be explained by the fact that hypnosis affected only some of the non-dominant types of EEG SPs. The main part of EEG individual segments, as has been shown, contributes constantly to the EEG classification profile, which explains why hypnosis does not bring about any radical changes when using traditional mean power spectrum. In the traditional spectral analysis, the spectral patterns altered during hypnosis are covered by the much more prominent and more powerful spectral components of EEG, which remain largely unchanged across the hypnosis–non-hypnosis manipulation.

Prefrontal cortex

Fp_1 and Fp_2 EEG channels demonstrated a unique SP description during the hypnotic condition when compared with non-hypnotic and baseline conditions. The majority of

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the beta-rhythmic segments appeared in the EEG only during the hypnotic condition. Such a unique composition of brain oscillations in prefrontal cortex during hypnosis is in harmony with the previously presented theoretical views and empirical findings that point to the particular importance of this region for hypnosis (Gruzelier, 1998, 2000, 2006).

In contrast to the classical hypofrontality hypothesis of hypnosis (for a review, see Dietrich, 2003), or selective lateralized frontal inhibitory effects (Gruzelier 1998, 2000, 2006), however, the present results rather indicate an increase in the percentage of beta-rhythmic EEG segments in Fp_1 and Fp_2 EEG channels during hypnosis. Therefore an increase in the percentage of beta-rhythmic EEG segments rather points to an increase in alertness (Knyazeva and Vil'davski, 1986; Bouyer et al., 1987; Bonnet and Arand, 2001), or to a heightened state of attention (Murthy and Fetz, 1992), not an inhibition of frontal functions. Our results can rather be interpreted as reflecting a state of cognitive (Ray and Cole, 1985) and neuronal (Porjesz et al., 2002) activation.

Thus, our data are in line with the earlier results reported by Kallio et al. (1999, 2001) that hypnosis is not associated with a generalized inhibition of frontal lobe functions. Considering that the frontal lobes are extensively involved in attentional networks (Stuss et al., 1994) the present data support the relevance of the attentional system for hypnosis and hypnotic susceptibility (Crawford et. al., 1993; Crawford, 1994; Kallio et al., 1999, 2001).

Interhemispheric asymmetry in the EEG during hypnosis

Even though both conditions demonstrated interhemispheric asymmetry, the hypnotic condition demonstrated more asymmetric brain activity than the baseline condition. Moreover, only hypnosis was characterized by a consistent right-side-dominance asymmetry. Such findings are in harmony with the work of Dimond (1979), Gruzelier (1988, 1999), De Pascalis (1998), and Crawford, Clarke, Kitner-Triolo (1996). The right hemisphere has been suggested to be an important mediator of hypnosis (for the review, see Kallio and Revonsuo, 2003). Note that the present data on interhemispheric asymmetry revealed right-side-dominance asymmetry during hypnosis, but these data however say nothing about the activity/inactivity of the brain hemispheres.

Taken together, the present case study data have provided support for the hypothesis that neutral hypnosis may lead to a changed pattern of neural activity in the brain. This result is furthermore supported by the fact that the EEG-data from the same sessions were analysed by using another method which revealed changes in the functional connectivity during hypnosis (Fingelkurts et al., 2007). The result that some inertia may occur after a period of hypnosis can have some clinical consequences as well (for a similar finding see Williams and Gruzelier 2001). It raises the possibility that at least some of the very highly hypnotizable individuals may not be in their normal baseline state directly after the hypnotic intervention and may need to be informed about this fact.

However, since we only presented the results of a single case it is too early to conclude anything concerning hypnosis in general or even concerning other hypnotic virtuosos. Further studies are now needed in order to see if similar results can be obtained with other virtuosos. Furthermore, an interesting theoretical question is if comparable changes can be seen (in various amounts) in association with hypnosis more generally (or even in association with other manipulations, such as deep relaxation or meditation) or whether such changes are only restricted to pure hypnosis and hypnotic virtuosos.

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References

Barabasz A, Barabasz M (1992) Research designs and considerations. Recent research and future directions. In: E Fromm, M Nash (eds) Contemporary Hypnosis Research. New York: Guilford Press, 173–200.

Bonnet MH, Arand DL (2001) Impact of activity and arousal upon spectral EEG parameters. Physiology and Behaviour 74: 291–8.

Bouyer JJ, Montaron MF, Vahnee JM, Albert MP, Rougeul A (1987) Anatomical localization of cortical beta rhythms in cat. Neuroscience 22: 863–9.

Bowers KS (1992) Imagination and dissociation in hypnotic responding. International Journal of Clinical and Experimental Hypnosis 40: 253–75.

Crawford HJ (1994) Brain dynamics and hypnosis: attentional and disattentional processes. International Journal of Clinical and Experimental Hypnosis 42: 204–32.

Crawford HJ, Brown AM, Moon CE (1993) Sustained attentional and disattentional abilities: differences between low and high hypnotizable persons. Journal of Abnormal Psychology 102: 534–43.

Crawford HJ, Clarke S, Kitner-Triolo M (1996) Self-generated happy and sad emotions in low and highly hypnotizable persons during waking and hypnosis: laterality and regional EEG activity differences. International Journal of Psychophysiology 24: 239–66.

Crawford HJ, Gruzelier JH (1992) A midstream view of the neuropsychophysiology of hypnosis: recent research and future directions. In: E Fromm, M Nash (eds) Contemporary Hypnosis Research. New York: Guilford Press, 227–66.

De Pascalis V, Ray WJ, Tranquillo I, D'Amico D (1998) EEG activity and heart rate during recall of emotional events in hypnosis: relationships with hypnotizability and suggestibility. International Journal of Psychophysiology 29: 255–75.

Dietrich A (2003) Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. Conscious and Cognition 12: 231–56.

Dimond SJ (1979) Performance by Split Brain Humans on Lateralized Vigilance Tests. Cortex 15: 43–50.

Egner T, Jamieson GA and Gruzelier JH (2005) Hyprosis decouples cognitive control from conflict monitoring processes of the frontal lobe. Neuro Image, 27, 269–978.

Fingelkurts AlA, Fingelkurts AnA, Krause CM, Sams M (2002) Probability interrelations between pre-/post-stimulus intervals and ERD/ERS during a memory task. Clinical Neurophysiology 13: 826–43.

Fingelkurts AlA, Fingelkurts AnA, Kaplan AYa (2003) The regularities of the discrete nature of multi-variability of EEG spectral patterns. International Journal of Psychophysiology 47: 23–41.

Fingelkurts AlA, Fingelkurts AnA, Kivisaari R, Pekkonen E, Ilmoniemi RJ, Kähkönen S (2004) The interplay of lorazepam-induced brain oscillations: microstructural electromagnetic study. Clinical Neurophysiology 115: 674–90.

Fingelkurts AlA, Fingelkurts AnA, Kaplan AYa (2006a) Stability, reliability and consistency of the compositions of brain oscillations. International Journal of Psychophysiology 59: 116–26.

Fingelkurts AlA, Fingelkurts AnA, Kaplan AYa (2006b) Interictal EEG as a physiological adaptation. Part I: Composition of brain oscillations in interictal EEG. Clinical Neurophysiology 117(1): 208–22.

Published by John Wiley & Sons, Ltd
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Fingelkurts AIA, Kallio S, Revonsuo A (2007) Cortex functional connectivity as a neurophysiological norrelate of hypnosis: an EEG case study. Neuropsychologia, 45(7): 1452–1462.

Gruzelier JH (1988) The Neuropsychology of Hypnosis. In: M Heap (ed.) Hypnosis: Current Clinical, Experimental and Forensic Practices. London: Croom Helm, 68–76.

Gruzelier JH (1998) A working model of the neurophysiology of hypnosis: a review of evidence. Contemporary Hypnosis 15: 3–21.

Gruzelier JH (1999) Hypnosis from a neurobiological perspective: A review of evidence and applications to improve immune function. Anales de psicología 15: 111–32. Servicio de Publicaciones de la Universidad de Murcia, Murcia (España).

Gruzelier JH (2000) Redefining hypnosis: theory, methods and integration. Contemporary Hypnosis 17: 51–70.

Gruzelier JH (2006) Frontal functions, connectivity and neural efficiency underpinning hypnosis and hypnotic susceptibility. Contemporary Hypnosis 23: 15–32.

Kaiser J, Barker R, Haenschel C, Baldeweg T, Gruzelier JH (1997) Hypnosis and event-related potential correlates of error processing in a Stroop-type paradigm: a test of the frontal hypothesis. International Journal of Psychophysiology 27: 215–22.

Kallio S, Revonsuo A (2005) Altering the state of the altered sate debate: reply to commentaries. Contemporary Hypnosis 22: 46–55.

Kallio S, Revonsuo A (2003) Hypnotic phenomena and altered states of consciousness: a multilevel framework of description and explanation. Contemporary Hypnosis 20: 111–64.

Kallio S, Revonsuo A, Lauerma H, Hämäläinen H, Lang H (1999) The MMN amplitude increases in hypnosis: a case study. NeuroReport 10: 3579–82.

Kallio S, Revonsuo A, Hämäläinen H, Markela J, Gruzelier JH (2001) Anterior brain functions and hypnosis: a test of the frontal hypothesis. International Journal of Clinical and Experimental Hypnosis 49: 95–108.

Kirsch I (2005) Empirical resolution of the altered state debate. Contemporary Hypnosis 22: 18–23.

Knyazeva MG, Vil'davskii VU (1986) Correspondence of spectral characteristics of EEG and regional blood circulation in 9–14-year-old children. Physiologija Cheloveka [Human Physiology] 12: 387–394.

Levy WJ (1987) Effect of epoch length on power spectrum analysis of the EEG. Anesthesiology 66: 489–95.

Murthy VN, Fetz EE (1992) Coherent 25- to 35-Hz oscillations in the sensorimotor cortex of awake behaving monkeys. Proceedings of the National Academy of Sciences US A 89: 5670–74.

Oakley D (2006) Hypnosis as a tool in research: experimental psychopathology. Contemporary Hypnosis 23: 3–14.

Perneger TV (1998) What is wrong with Bonferroni adjustments? British Medical Journal 136: 1236–8.

Porjesz B, Almasy L, Edenberg HJ, Wang K, Chorlian DB, Foroud T, Goate A, Rice JP, O'Connor SJ, Rohrbaugh J, Kuperman S, Bauer LO, Crowe RR, Schuckit MA, Hesselbrock V, Conneally PM, Tischfield JA, Li T-K, Reich T, Begleiter H (2002) Linkage disequilibrium between the beta frequency of the human EEG and a GABAA receptor gene locus. Proceedings of the National Academy of Sciences 99: 3729–33.

Rainville P, Hofbauer RK, Paus T, Duncan GH, Bushnell MC, Price DD (1999) Cerebral mechanisms of hypnotic induction and suggestion. Journal of Cognitive Neuroscience 11: 110–25.

Ray W, Cole H (1985) EEG alpha activity reflects attentional demands and beta activity reflects emotional and cognitive processes. Science 228: 750–2.

Rothman KJ (1990) No adjustments are needed for multiple comparisons. Epidemiology 1: 43–6.

Shallice T (1979) Case-study approach in neuropsychological research. Journal of Clinical Neuropsycholgy 1: 183–211.

DOI: 10.1002/ch

Stuss DT, Eskes GA, Foster JK (1994) Experimental neuropsychological studies of frontal lobe functions. In: F Boller, J Grafman (eds) Handbook of Neuropsychology. Amsterdam: Elsevier, 149–84.
Thatcher RW (2001) Normative EEG databases and EEG biofeedback. Journal of Neurotherapy 2: 1–29.
Weitzenhoffer AM, Hilgard ER (1962) Stanford Hypnotic Susceptibility Scale: Form C. Palo Alto, CA: Consulting Psychologists Press.
Williams JD, Gruzelier JH (2001) Differentiation of hypnosis and relaxation by analysis of narrow band theta and alpha frequencies. International Journal of Clinical and Experimental Hypnosis 49: 185–206.
Woody EZ, Bowers KS (1994) A frontal assault on dissociated control. In: SJ Lynn, JW Rhue (eds) Dissociation: Clinical and Theoretical Research Perspectives. New York: Guilford Press, 52–79.

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