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Cortex Functional Connectivity as a Neurophysiological Correlate of Hypnosis: an EEG Case Study

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Abstract

Cortex functional connectivity associated with hypnosis was investigated in a single highly hypnotizable subject in a normal baseline condition and under neutral hypnosis during two sessions separated by a year. After the hypnotic induction, but without further suggestions as compared to the baseline condition, all studied parameters of local and remote functional connectivity were significantly changed. The significant differences between hypnosis and the baseline condition were observable (to different extent) in five studied independent frequency bands (delta, theta, alpha, beta, and gamma). The results were consistent and stable after one year. Based on these findings we conclude that alteration in functional connectivity of the brain may be regarded as a neuronal correlate of hypnosis (at least in very highly hypnotizable subjects) in which separate cognitive modules and subsystems may be temporarily incapable of communicating with each other normally.

Descriptors: consciousness; structural (operational) synchrony; frequency bands; EEG segmentation; local/remote synchronization; hypnotizability; hypnosis; hypnotic virtuoso; suggestibility; metastability

Abbreviations: ASC – Altered State of Consciousness; SHSS-C – Stanford Hypnotic Susceptibility Scale, form C; H – Hypnosis; NH – Nonhypnosis; B – Baseline; RTP – Rapid Transition Processes; A – Average amplitude within EEG segment; L – Average length of EEG segments; V – Coefficient of amplitude variability within EEG segments; AR – Average amplitude relation among adjacent EEG segments; S – Average steepness among adjacent EEG segments; ISS – Index of Structural Synchrony; OS – Operational Synchrony; SS – Structurally Synchrony.

1. Introduction

Apparently the most crucial theoretical issue in association with hypnosis has been the debate about the possible involvement of an altered state of consciousness (ASC) in hypnosis. The involvement of an ASC would imply that hypnosis leads to an objectively measurable change in brain function that can not be explained by ordinary psychological mechanisms (such as role playing, expectation, or selective attention). There is some evidence showing that in a very highly susceptible subject, pure hypnosis (or neutral hypnosis; Edmonston, 1979) without any further suggestions can give rise to an altered way of information processing in the early, preattentive level of auditory processing (Kallio et al., 1999). This kind of result lends support to the *state* view of hypnosis (Spiegel, 1991; Gruzelier, 2000; Weitzenhoffer, 2000) because it is difficult to explain by referring to social-psychological concepts (the opposing, *non state* view of hypnosis) such as implicit or explicit expectations (Kirsch, 2000) or compliance (Wagstaff, 1981).

If there is an ASC involved in hypnosis, EEG during hypnosis should provide incontestable evidence for it. However, previous studies have failed to uncover an unambiguous physiological marker of hypnosis. For a long time hypnosis was thought to be associated with EEG alpha frequencies, but it has not been possible to replicate this finding reliably (Perlini & Spanos, 1991). One often reported EEG finding has been that highly susceptible individuals possess more theta activity (3-7 Hz), either in baseline (Galbraith et al., 1970) or during both hypnosis and baseline (Sabourin et al., 1990; Freeman et al., 2000). However, these findings have not been consistently replicated either. For example, Williams and Gruzelier (2001) did not find any correlation between theta and susceptibility/hypnosis; and Graffin et al. (1995) found a decrease of theta activity for highly susceptible subjects during hypnosis. These highly inconsistent observations suggest that there are no systematically reproducible patterns of readily observable EEG changes specifically associated with hypnosis. One explanation for this may be that the experimental designs used in different studies vary widely. Furthermore, only very few studies (if any) have ever been designed specifically to explore the neural correlates of *pure* hypnosis; i.e. the neurocognitive changes brought about by the hypnotic induction as such, without any additional tasks or suggestions given to the subjects.

According to Kallio and Revonsuo (2003), if hypnosis constitutes an altered background state of consciousness different from the normal baseline state of wakefulness, then the hypnotic induction should lead (at least in the very highly susceptible subjects or “virtuosos”) to changes in the background brain mechanisms modulating or realizing the phenomenal contents of consciousness. Due to these changes, there should be a predisposition for the mechanisms of subjective experience to process and represent available information in an altered manner, so that if specific suggestions are given by the hypnotist, then the resulting conscious experience of the subject will misrepresent reality in some way, allowing, e.g. hallucinations instead of an accurate perception of reality (Kallio & Revonsuo, 2003). Such unusual patterns of experience may be due to the functional dissociations in the cognitive system such that separate cognitive modules and subsystems may be temporarily incapable of communicating with each other normally (Hilgard, 1986; Bowers, 1992; Crawford & Gruzelier, 1992; Gruzelier, 1998, 2000; Woody & Bowers, 1994).

If one accepts the thesis that every event or change at the mental (or cognitive) level must be accompanied by a corresponding change at the neural level (mind-brain supervenience; Kim, 1998), then it follows that if hypnosis involves a change in psychological or cognitive mechanisms, there must be a corresponding alteration taking place at the neural level. Furthermore, if change on the neural level involves changes in the communication between different functional modules in the brain, then they should be associated with changes in the underlying EEG activity (synchrony between different brain areas, see reviews Fingelkurts & Fingelkurts, 2001, 2004, 2006). Thus, local and remote *functional brain connectivity* measured by EEG may be regarded as a putative neuronal correlate of hypnosis. To our knowledge there have been no previous studies that have explored the local and remote functional cortex connectivity in the 'pure' altered background state of hypnosis. Hypnosis research is usually done in the context of studying certain suggested behaviors (Raz et al., 2002) or tasks but rarely explicitly in the study of pure hypnosis. As an example see the unpublished experiment of Kaiser (briefly reported in Gruzelier, 1998) and the study of Egner et al. (2005).

As has been suggested by Kallio and Revonsuo (2003), in the individuals referred to as 'hypnotic virtuosos,' the 'hypnotic' phenomena are manifested in their clearest form and are not easily confused with any other phenomena (such as simple compliance or faking). This view is close to the one already presented by Weitzenhoffer (2000) who has pointed out that in order to study the hypnotic state per se, one should focus attention on 'ultraresponsive' or 'ultrasuggestible' individuals. However, true virtuosos are very rare and group studies on virtuosos may not be feasible for practical reasons, therefore the case-study approach could be utilized at early stages of research.

When a virtuoso is used as a subject, the assumed 'altered background state' of hypnosis should be produced by means of an extremely brief induction. The use of a brief induction would minimize the need for lengthy suggestions of relaxation, drowsiness, etc. which are typically used in a hypnotic induction. No additional suggestions aiming to change the phenomenal contents of consciousness should be given; only the ‘pure’ or ‘neutral’ hypnosis as such. In the control (baseline/nonhypnotic) condition, the procedure should be identical apart from the hypnotic induction. If reliable differences in cortex functional connectivity indexed by EEG structural synchrony (Kaplan et al., 1997, 2005; for the review, see Fingelkurts et al., 2005) between these two different experimental conditions can be found, then there would be empirical support for the view that pure hypnosis as such involves changes in brain function.

2. Methods

2.1. Subject

The subject (T.S.-H.) was a 39-year-old right-handed female office worker who is also a semi-professional classical singer. She is an experienced subject and had previously participated in hypnosis experiments (Kallio et al., 1999), and was thus well acquainted with the laboratory procedures and EEG registration. In a scale measuring hypnotic susceptibility (Stanford Hypnotic Susceptibility Scale, form C (SHSS-C); Weitzenhoffer & Hilgard, 1962), T.S.-H. scored the maximum of 12 points. She displayed all the subjective phenomena typically associated with very highly susceptible individuals, such as vivid visual and acoustic hallucinations and an immediate re-entry into hypnosis when a previously implanted posthypnotic suggestion was applied. T.S.-H. had no history of neurological illnesses. She gave her informed consent to participate in the study.

2.2. Procedure

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 her. The EEG acquisition sessions took place at the same time of the day (between 10 am and 1 pm). To reduce muscle artifacts in the EEG signal, the subject was instructed to assume a comfortable position and to avoid movement.

The subject was tested for hypnotizability one day before the experiments took place in order to make sure that she still meets the criteria for a hypnotic virtuoso. During this preliminary session the subject was tested for a positive and negative hallucination which she passed. In addition two posthypnotic suggestions were implanted. One pseudoword was implanted to trigger hypnosis (i.e. whenever this word would later be uttered by the hypnotist, it would have the same effect as an ordinary hypnotic induction) and another pseudoword was implanted to cancel hypnosis (and to trigger the return of the baseline state). The aim of this procedure was to minimize the length of the hypnotic induction and the cancellation of hypnosis during the forthcoming experiment where hypnosis was then induced and cancelled with this technique. An identical procedure has been used with this same subject previously (see Kallio et al. 1999). Before the experiment began the subject was given instructions to sit in an arm chair, look at a dim LED-light in front of her and just relax. There were no additional tasks whatsoever.

2.3. EEG recording

EEG recordings were performed in a magnetically and electrically shielded room at the Centre for Cognitive Neuroscience, University of Turku. Electric spontaneous 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.

The EEG recordings were carried out during two separate sessions with a one-year interval. During each session the first and last two minutes of EEG were recorded (baseline recording, hereafter B) while the subject sat in a comfortable chair and had her eyes open and focused on a LED-light in front of her (about 2 meters) and was instructed to relax. This was followed by 2 minutes of EEG recording while the subject had her eyes closed. The closed eyes condition was not part of the experimental analysis, however it was done as a part of the standard (clinical) procedure to check the default mode of brain activity at rest (Gusnard & Raichle, 2001). After this the hypnotist sat behind the subject and repeated the instructions about looking at the light and relaxing. This was followed by three blocks where hypnosis and non-hypnosis followed each other. Each switch was induced by the hypnotist uttering the relevant pseudoword that had been implanted as a posthypnotic suggestion to either trigger or to cancel hypnosis. Each block consisted of 3-4 periods of hypnosis (hereafter H) and non-hypnosis (hereafter NH) lasting about 2 minutes/period (2 min of H, 2 min of NH, 2 min of H, etc). The six blocks (each lasting about 10 minutes) where 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 H and NH was varied so that both started the blocks equally often. The H and NH periods inside 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 or to cancel hypnosis), 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 H and NH periods.

2.4. Data processing

EEG epochs containing artifacts due to eye blinks, significant muscle activity, and movements were automatically removed. Full EEG streams free from artifacts were split into 2 distinct groups: 'B' and 'H.' Further data processing was performed separately for each 1-min portion of the signal and the groups. 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 analyzed with a converted sampling rate of 128 Hz.

After resampling and prior to the nonparametric adaptive segmentation procedure, each EEG signal was bandpass filtered with third order Butterworth filter in the delta (1-3 Hz), theta (4-6 Hz), alpha (7-13 Hz), beta (15-25 Hz), and gamma (35-45 Hz) frequency bands. In the case of scalp EEG, it has been observed that different frequency bands are associated with different functional processes (for review see Stam et al., 2003; Basar et al., 2004).

2.5. Estimation of the local functional interrelations

Local functional interrelations were estimated in two stages. At the *first stage*, the adaptive level segmentation of local EEGs was performed. Each 1-min EEG filtered in five frequency bands (delta, theta, alpha, beta, and gamma) was segmented using the method of identification of rapid transition processes (RTP) in the EEG amplitude (*RTPseg* tool). For the detailed description see Fingelkurts et al. (2006). RTPs are the markers of boundaries between quasi-stationary segments in EEG. This method is based on the automatic selection of level-conditions in accordance with a given level of the probability of "false alarms" and carrying out simultaneous screening of all EEG channels (for details, see Kaplan et al., 2005; see also Fingelkurts et al., 2003a,b).

The following steps are taken to estimate RTPs: 1) Comparisons are made between ongoing EEG amplitude absolute values averaged in two windows (first window << second window), both starting from the first data point. 2) If the absolute maximum of the averaged amplitude values in the small window exceeds the averaged amplitude values in the large window, according to the threshold of "false alarms" (the Student criteria) – its time instant becomes the preliminary estimate of the RTP. 3) Using additional statistical analysis the preliminary RTP is verified and assumed to be actual. 4) Then, each of the windows shifts by one data point from the actual RTP, and the procedure is repeated. With this technique, the sequence of RTPs with statistically proven ($P<0.05$, Student *t*-test) time coordinates has been determined for each EEG channel individually for each 1-min epoch. The theoretical concepts behind this analysis are described elsewhere (Kaplan, 1998; Kaplan & Shishkin, 2000; Fingelkurts et al., 2005).

At the *second stage*, after quasi-stationary segments (indexed by RTPs) were obtained, several characteristics (attributes) of segments (Kaplan & Borisov, 2003) were calculated. These attributes reflect different aspects of local processes in the cortex and thus permit assessing the mesolevel description of cortex interactions (interactions within transient neuronal assemblies) through large-scale EEG estimates (Fingelkurts et al., 2004). The attributes are:

1. *Average amplitude* (A) within each segment (μV) – as generally agreed, indicates mainly the volume or size of neuronal population: indeed, the more neurons recruited into assembly through local synchronization of their activity, the higher will be the amplitude of corresponding to this assembly oscillations in the EEG (Nunez, 2000; Klimesch et al., 2005).
2. *Average length* (L) of segments (msec) – illustrates the functional life span of neuronal population or the duration of operations produced by this population: since the transient neuronal assembly functions during a particular time interval, this period is reflected in EEG as a stabilized interval of quasi-stationary activity (Fell et al., 2000; Fingelkurts et al., 2004).
3. *Coefficient of amplitude variability* (V) within segments (%) – shows the stability of local neuronal synchronization within a neuronal population or assembly (Truccolo et al., 2002).
4. *Average amplitude relation* (AR) among adjacent segments (%) – indicates the neuronal assembly behavior – growth (recruiting of new neurons) or distraction (functional elimination of neurons) (Kaplan & Borisov, 2003).
5. *Average steepness* (S) among adjacent segments (estimated in the close area of RTP) (%) – shows the speed of neuronal population growth or detraction (Kaplan & Borisov, 2003).

2.6. Estimation of the remote functional connectivity

Remote functional connectivity was estimated by calculation of the index of EEG structural synchrony. The index of structural synchrony (ISS) was estimated through synchronization of rapid transition processes (RTP) between different EEG channels (*RTPsyn* tool). Details can be found in Fingelkurts et al. (2006). This measure reveals functional (operational) interrelationships between cortical sites which differ from those measured by correlation, coherence and phase analysis (Kaplan et al. 2005; Fingelkurts et al., 2005). As the details of this technique are beyond the scope of this paper, we will only concentrate on some essential aspects. In brief, each RTP in the reference EEG channel (the channel with the minimal number of RTPs from any pair of EEG channels) was surrounded by a short “window” (ms). Any RTP from another (test) channel was considered to coincide if it fell within this window. The ISS for pairs of EEG channels can be estimated using this procedure and a particular mathematical formalism (for details, see Kaplan et al., 2005; Fingelkurts et al., 2003a,b). The ISS tends towards zero where there is no synchronization between the EEG segments and has positive or negative values where such synchronization exists. Positive values indicate ‘active’ coupling of EEG segments (synchronization of EEG segments are observed significantly more often than expected by chance; $P<0.05$, random shuffling, computer simulation), whereas negative values mark ‘active’ decoupling of segments (synchronization of EEG segments are observed significantly less than expected by chance; $P<0.05$, random shuffling, computer simulation). From a qualitative perspective, the coupling of EEG segments corresponds to the phenomenon of synchronization of brain operations (operational synchrony, OS) (Kaplan et al., 1997; Fingelkurts & Fingelkurts, 2001; 2004; 2006).

2.7. Statistics

1. Concerning the validity of data from one subject, the best way to obtain the robustness of the results is to check them for homogeneity: it means that the rules governing the changes in the resulted values are the same throughout the whole or several experiment(s). Testing may be accomplished in several ways: when the subject underwent the same experiment with the same instructions twice after some prolonged time interval (the test-retest reliability); or by splitting whole data into two or more parts and analyzing these separately. Homogeneity can be assumed when all sub-parts yield the same result (Martin & Bateson, 1993). This would mean that the data is robust. In the present study, the test-retest reliability (with the one year time interval) testifies that the values were systematically obtained for the subject (for each the same condition) and they were consistently different between hypnosis and baseline. This testifies that the results cannot be the result of chance because “by definition chance findings do not replicate” (Duffy et al. 1994, p. XI). Since the main results were reproduced in the retest examination after one year and after data from both sessions have been combined (Table 1 and Table 2), only reproducible results are presented here. Additionally, in this paper we only compare the data between baseline recording B (the recording which preceded and finalized the presentation of the blocks) and

hypnosis (H). This is because the NH data turned out to be intermediate between B and H (so-called carryover effect), although still differing significantly from both B and H. One potential drawback should be noted: since there was averaging of data from pre-hypnosis and post-hypnosis baseline conditions, the post-hypnotic recording may be confounded by carryover effects from the H condition. However, at the moment there is no knowledge about possible duration of such effects to setup the optimal time for the post-hypnotic baseline recording. In any case these effects (if present) should make the difference effects between B and H conditions smaller, not larger and, therefore, the presented significant results are valid.

Table 1. Pearson correlations between the EEG segment attributes in first and second (after one year) sessions of EEG registration and in first+second and either first or second sessions. Data presented for each EEG segment attribute separately for five frequency bands.

DELTA

EEG segment attributes	1Sx2S		S(1+2)xS1		S(1+2)xS2	
	rr	*p*	*rr*	*p*	*rr*	*p*
Amplitude	0.9	< 0.001	0.99	< 0.001	0.9	< 0.001
Length	0.89	< 0.001	0.9	< 0.001	0.9	< 0.001
Amplitude Variability	0.88	< 0.001	0.89	< 0.001	0.9	< 0.001
Amplitude Relations	0.7	< 0.001	0.75	< 0.001	0.79	< 0.001
Steepness	0.78	< 0.001	0.8	< 0.001	0.8	< 0.001

THETA

EEG segment attributes	1Sx2S		S(1+2)xS1		S(1+2)xS2	
	rr	*p*	*rr*	*p*	*rr*	*p*
Amplitude	0.77	< 0.001	0.8	< 0.001	0.85	< 0.001
Length	0.78	< 0.001	0.8	< 0.001	0.87	< 0.001
Amplitude Variability	0.8	< 0.001	0.89	< 0.001	0.88	< 0.001
Amplitude Relations	0.7	< 0.001	0.8	< 0.001	0.81	< 0.001
Steepness	0.78	< 0.001	0.82	< 0.001	0.8	< 0.001

ALPHA

EEG segment attributes	1Sx2S		S(1+2)xS1		S(1+2)xS2	
	rr	*p*	*rr*	*p*	*rr*	*p*
Amplitude	0.8	< 0.001	0.89	< 0.001	0.88	< 0.001
Length	0.8	< 0.001	0.9	< 0.001	0.89	< 0.001
Amplitude Variability	0.83	< 0.001	0.89	< 0.001	0.88	< 0.001
Amplitude Relations	0.7	< 0.001	0.78	< 0.001	0.79	< 0.001
Steepness	0.79	< 0.001	0.8	< 0.001	0.84	< 0.001

BETA

EEG segment attributes	1Sx2S		S(1+2)xS1		S(1+2)xS2	
	rr	*p*	*rr*	*p*	*rr*	*p*
Amplitude	0.9	< 0.001	0.99	< 0.001	0.9	< 0.001
Length	0.9	< 0.001	0.9	< 0.001	0.9	< 0.001
Amplitude Variability	0.89	< 0.001	0.9	< 0.001	0.9	< 0.001
Amplitude Relations	0.79	< 0.001	0.8	< 0.001	0.82	< 0.001
Steepness	0.8	< 0.001	0.88	< 0.001	0.87	< 0.001

GAMMA

EEG segment attributes	1Sx2S		S(1+2)xS1		S(1+2)xS2	
	rr	*p*	*rr*	*p*	*rr*	*p*
Amplitude	0.78	< 0.001	0.8	< 0.001	0.87	< 0.001
Length	0.79	< 0.001	0.84	< 0.001	0.88	< 0.001
Amplitude Variability	0.87	< 0.001	0.89	< 0.001	0.88	< 0.001
Amplitude Relations	0.77	< 0.001	0.8	< 0.001	0.8	< 0.001
Steepness	0.79	< 0.001	0.82	< 0.001	0.8	< 0.001

1S, first session of EEG registration; 2S, second session of EEG registration (one year later).

2. Segment attributes were averaged across all 1-min EEG epochs within each frequency band separately for each EEG channel and condition ('B' vs. 'H'). As in the previous work (Kaplan et al., 2002; Kaplan & Borisov, 2003; Fingelkurts et al., 2004), the comparison of the same segment attributes between different conditions was performed using paired Wilcoxon *t*-test.

3. The differences in the number and strength of structurally synchronized (SS) EEG patterns between B and H conditions were assessed using the paired Wilcoxon *t*-test as in the majority of the functional connectivity studies (for an overview see Rappelsberger, 1998; Weiss & Rappelsberger, 2000). All SS pair EEG patterns within each frequency band were divided into nine categories ($\text{short}_{\text{left/right}}$, $\text{short}_{\text{anterior/posterior}}$, $\text{long}_{\text{left/right}}$, $\text{long}_{\text{anterior/posterior}}$, $\text{long}_{\text{interhemispheric}}$)

Table 2. Pearson correlations between the number/strength of functional connections in first and second (after one year) sessions of EEG registration and in first+second and either first or second sessions. Data presented for each category of EEG functional connections separately for five frequency bands.

DELTA

Number of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.89	< 0.001	0.8	< 0.001	0.9	< 0.001
Short right	0.99	< 0.001	0.99	< 0.001	0.92	< 0.001
Short anterior	0.87	< 0.001	1	< 0.001	0.89	< 0.001
Short posterior	0.79	< 0.001	0.85	< 0.001	0.9	< 0.001
Long left	0.9	< 0.001	0.99	< 0.001	0.9	< 0.001
Long right	0.89	< 0.001	0.9	< 0.001	1	< 0.001
Long anterior	0.9	< 0.001	0.84	< 0.001	0.88	< 0.001
Long posterior	0.87	< 0.001	0.86	< 0.001	0.96	< 0.001
Long interhemispheric	0.89	< 0.001	1	< 0.001	0.99	< 0.001

Strength of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.77	< 0.001	0.83	< 0.001	0.8	< 0.001
Short right	0.69	< 0.001	0.79	< 0.001	0.84	< 0.001
Short anterior	0.82	< 0.001	0.9	< 0.001	0.9	< 0.001
Short posterior	0.76	< 0.001	0.79	< 0.001	0.82	< 0.001
Long left	0.8	< 0.001	0.9	< 0.001	0.86	< 0.001
Long right	0.9	< 0.001	0.85	< 0.001	0.89	< 0.001
Long anterior	0.85	< 0.001	0.92	< 0.001	0.91	< 0.001
Long posterior	0.8	< 0.001	0.9	< 0.001	0.87	< 0.001
Long interhemispheric	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

THETA

Number of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.79	< 0.001	0.89	< 0.001	0.88	< 0.001
Short right	0.89	< 0.001	0.99	< 0.001	0.9	< 0.001
Short anterior	0.85	< 0.001	0.89	< 0.001	1	< 0.001
Short posterior	0.73	< 0.001	0.83	< 0.001	0.83	< 0.001
Long left	0.86	< 0.001	0.91	< 0.001	0.97	< 0.001
Long right	0.81	< 0.001	0.9	< 0.001	0.9	< 0.001
Long anterior	0.9	< 0.001	1	< 0.001	1	< 0.001
Long posterior	0.89	< 0.001	0.89	< 0.001	0.9	< 0.001
Long interhemispheric	0.85	< 0.001	0.95	< 0.001	0.91	< 0.001

Strength of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.79	< 0.001	0.85	< 0.001	0.8	< 0.001
Short right	0.88	< 0.001	0.9	< 0.001	0.8	< 0.001
Short anterior	0.9	< 0.001	0.93	< 0.001	0.9	< 0.001
Short posterior	0.78	< 0.001	0.8	< 0.001	0.87	< 0.001
Long left	0.89	< 0.001	0.9	< 0.001	0.9	< 0.001
Long right	0.8	< 0.001	0.89	< 0.001	0.9	< 0.001
Long anterior	0.8	< 0.001	0.89	< 0.001	0.89	< 0.001
Long posterior	0.8	< 0.001	0.9	< 0.001	0.8	< 0.001
Long interhemispheric	0.75	< 0.001	0.82	< 0.001	0.8	< 0.001

ALPHA

Number of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.82	< 0.001	0.9	< 0.001	0.89	< 0.001
Short right	0.89	< 0.001	0.9	< 0.001	1	< 0.001
Short anterior	0.86	< 0.001	0.85	< 0.001	0.89	< 0.001
Short posterior	0.79	< 0.001	0.8	< 0.001	0.89	< 0.001
Long left	0.9	< 0.001	0.9	< 0.001	1	< 0.001
Long right	0.9	< 0.001	0.9	< 0.001	1	< 0.001
Long anterior	0.79	< 0.001	0.8	< 0.001	0.89	< 0.001
Long posterior	0.8	< 0.001	0.8	< 0.001	0.9	< 0.001
Long interhemispheric	0.7	< 0.001	0.8	< 0.001	0.9	< 0.001

Strength of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.7	< 0.001	0.86	< 0.001	0.85	< 0.001
Short right	0.7	< 0.001	0.8	< 0.001	0.8	< 0.001
Short anterior	0.8	< 0.001	0.86	< 0.001	0.86	< 0.001
Short posterior	0.68	< 0.001	0.7	< 0.001	0.78	< 0.001
Long left	0.7	< 0.001	0.8	< 0.001	0.82	< 0.001
Long right	0.8	< 0.001	0.85	< 0.001	0.8	< 0.001
Long anterior	0.89	< 0.001	0.9	< 0.001	0.9	< 0.001
Long posterior	0.89	< 0.001	0.89	< 0.001	0.88	< 0.001
Long interhemispheric	0.7	< 0.001	0.75	< 0.001	0.8	< 0.001

BETA

Number of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.89	< 0.001	0.89	< 0.001	0.89	< 0.001
Short right	0.9	< 0.001	0.9	< 0.001	0.9	< 0.001
Short anterior	0.88	< 0.001	0.89	< 0.001	1	< 0.001
Short posterior	0.79	< 0.001	0.8	< 0.001	0.89	< 0.001
Long left	0.8	< 0.001	0.89	< 0.001	0.9	< 0.001
Long right	0.8	< 0.001	0.89	< 0.001	0.9	< 0.001
Long anterior	0.8	< 0.001	0.9	< 0.001	1	< 0.001
Long posterior	0.89	< 0.001	0.89	< 0.001	0.9	< 0.001
Long interhemispheric	0.89	< 0.001	0.9	< 0.001	0.99	< 0.001

Strength of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.78	< 0.001	0.8	< 0.001	0.85	< 0.001
Short right	0.8	< 0.001	0.9	< 0.001	0.89	< 0.001
Short anterior	0.8	< 0.001	0.9	< 0.001	0.89	< 0.001
Short posterior	0.7	< 0.001	0.8	< 0.001	0.79	< 0.001
Long left	0.9	< 0.001	0.99	< 0.001	1	< 0.001
Long right	0.7	< 0.001	0.8	< 0.001	0.9	< 0.001
Long anterior	0.8	< 0.001	0.89	< 0.001	1	< 0.001
Long posterior	0.8	< 0.001	0.89	< 0.001	1	< 0.001
Long interhemispheric	0.79	< 0.001	0.83	< 0.001	0.81	< 0.001

GAMMA

Number of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.74	< 0.001	0.9	< 0.001	0.8	< 0.001
Short right	0.78	< 0.001	0.8	< 0.001	0.86	< 0.001
Short anterior	0.81	< 0.001	0.87	< 0.001	0.86	< 0.001
Short posterior	0.79	< 0.001	0.8	< 0.001	0.82	< 0.001
Long left	0.89	< 0.001	0.9	< 0.001	1	< 0.001
Long right	0.9	< 0.001	1	< 0.001	1	< 0.001
Long anterior	0.8	< 0.001	0.8	< 0.001	0.88	< 0.001
Long posterior	0.8	< 0.001	0.89	< 0.001	0.9	< 0.001
Long interhemispheric	0.7	< 0.001	0.8	< 0.001	0.81	< 0.001

Strength of connections	1Sx2S		S(1+2)xS1		S(1+2)xS2	
Category	*rr*	*p*	*rr*	*p*	*rr*	*p*
Short left	0.72	< 0.001	0.8	< 0.001	0.85	< 0.001
Short right	0.69	< 0.001	0.7	< 0.001	0.76	< 0.001
Short anterior	0.82	< 0.001	0.88	< 0.001	0.89	< 0.001
Short posterior	0.68	< 0.001	0.78	< 0.001	0.79	< 0.001
Long left	0.69	< 0.001	0.7	< 0.001	0.8	< 0.001
Long right	0.78	< 0.001	0.8	< 0.001	0.8	< 0.001
Long anterior	0.9	< 0.001	0.9	< 0.001	0.9	< 0.001
Long posterior	0.8	< 0.001	0.89	< 0.001	0.82	< 0.001
Long interhemispheric	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

1S, first session of EEG registration; 2S, second session of EEG registration (one year later).

separately for all 5 frequency bands. Pairs of EEG electrodes which have one or more electrodes between the ‘members’ of the pair were classified as long-range connections (according to Weiss & Rappelsberger, 2000). Since the absolute number of possible SS EEG pairs within each category was different, the percentage of the number of SS EEG pairs was calculated.

4. Separate computer maps of the ISS values were created for each 1-minute EEG for each frequency band. The problem of multiple comparisons between maps cannot easily be overcome due to the large number of electrode pairs (Rappelsberger & Petsche, 1988) in the SS maps. This problem is common to all studies which require multiple comparisons between maps (Weiss & Rappelsberger, 2000; Razoumnikova, 2000). The comparisons that have been made should therefore be considered descriptive rather than confirmatory (Stein et al., 1999). To have valid results and as we have done in our previous work (Fingelkurts et al., 2003a,b, 2004, 2006), all pair combinations of EEG channels exhibiting statistically proven SS ($P<0.05$) were ranged in accordance with their rate of occurrence within all analyzed 1-min EEG epochs. Only the most frequently found combinations (not less than 85% occurrence in all epochs) for the same condition (B or H) were analyzed further. As it has been shown (Fingelkurts et al., 2006; Appendix E) such an analysis enables us to overcome the problem of multiple comparisons.

3. Results

3.1. Changes of EEG segment attributes as a function of hypnosis

Average amplitude (A) of EEG segments decreased significantly for all frequency bands (exception was theta band) under hypnosis ($P<0.05$-0.001) when compared with the baseline condition (Fig. 1). This decrease affected almost all EEG locations and was maximal for delta, beta, and gamma frequency bands. The increase of A ($P<0.05$) was observed only in the occipital cortex areas for the theta and alpha frequency oscillations. Average length (L) of EEG segments mostly increased by hypnosis ($P<0.05$-0.01) for delta, theta, alpha, and beta bands; and decreased ($P<0.05$-0.001) for the gamma frequency oscillations. Note, that for the delta frequency band a strong decrease in the L values was observed under hypnosis ($P<0.001$) in frontal areas when compared with the baseline condition (Fig. 1).

The coefficient of amplitude variability (V) within EEG segments increased significantly with hypnosis ($P<0.05$-0.001) mainly for the delta, beta, and gamma frequency bands; and decreased ($P<0.05$-0.01) for both alpha and theta frequencies (Fig. 1). Average amplitude relation (AR) among adjacent EEG segments increased significantly during hypnosis ($P<0.05$-0.001) mainly for the delta, theta, alpha, and gamma frequency bands. At the same time, AR

mostly decreased with hypnosis when compared with the baseline (*P*<0.05) for the beta frequency band.

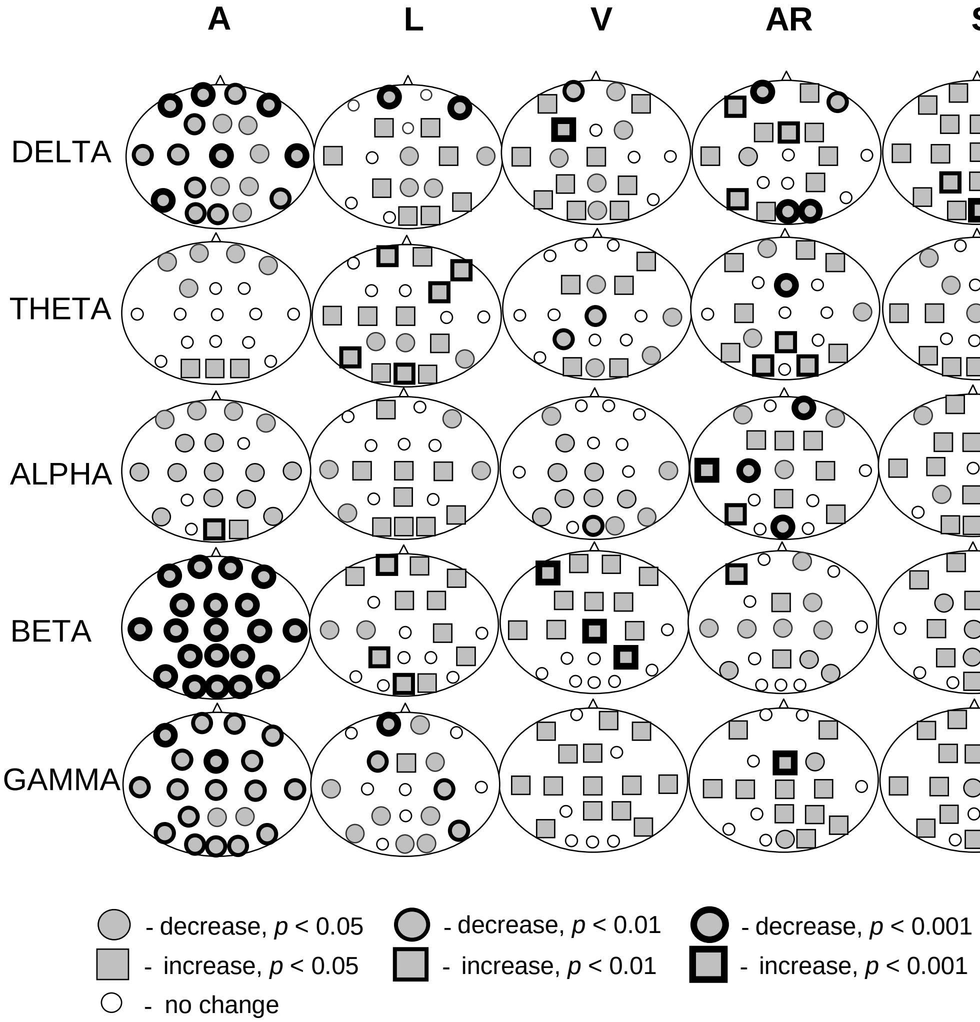

Figure 1. The maps of hypnosis-induced changes (after the Wilcoxon filtering) of EEG segment attributes. Corresponding data presented separately for five frequency bands and for comparison: hypnosis *vs* baseline. EEG labels: first level of electrodes from the top and from the left – Fp_1, Fp_2; second – F_7, F_8; third – F_3, F_Z, F_4; forth – T_3, C_3, C_Z, C_4, T_4; fifth – P_3, P_Z, P_4, sixth – T_5, O_1, O_Z, O_2, T_6. *A* – Average amplitude within segments (μV); *L* – Average length of segments (msec); *V* – Coefficient of amplitude variability within segments (%); *AR* – Average amplitude relation among adjacent segments (%); *S* – Average steepness among adjacent segments (estimated in the close area of RTP) (%).

Average steepness (*S*) among adjacent EEG segments increased significantly during hypnosis (*P*<0.05-0.001) in a majority of cortical areas for all frequency bands (Fig. 1).

3.2. The number of structurally synchronized EEG pairs during hypnosis

Figure 2 (B) illustrates the number of structurally synchronized (SS) EEGs registered from different cortical areas (estimated by an index of structural synchrony, ISS) during hypnosis and the baseline condition for the five frequency bands. The number of SS EEG pairs was significantly less (*P*<0.05) during hypnosis than during the baseline for $\text{short}_{\text{anterior}}$ and $\text{long}_{\text{left}}$ functional connections in all frequency bands except the theta frequency range. Delta frequency band exhibited total decrease in the number of functional connections in vast majority of categories. However, the number of $\text{short}_{\text{left}}$ and $\text{long}_{\text{left}}$ SS EEG pairs for the theta frequency band and $\text{short}_{\text{posterior}}$ SS EEG pairs for the beta frequency band increased significantly (*P*<0.05) during hypnosis.

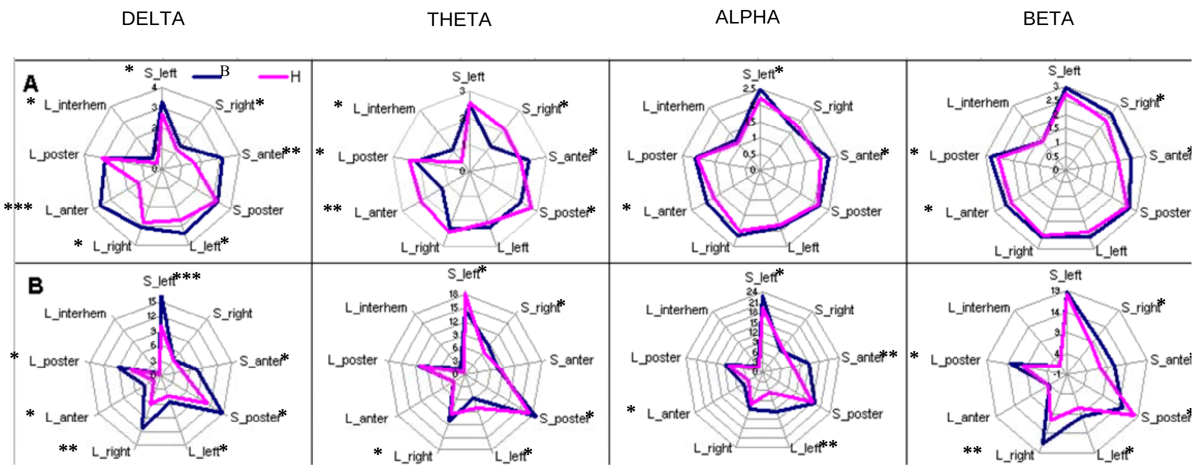

Figure 2. The number (B) and strength (A) of structurally synchronized (SS) EEG pairs (indexed by the index of structural synchrony) for each of the nine categories in hypnosis and baseline separately for five frequency bands. The radian-axis displays the labels of the categories for EEG pair connection. The median-axis displays the percentage from the maximum number of the EEG pair connections within each category (bottom row), and displays the average values of ISS for EEG pair connections within each category (top row). A polar representation of the data was chosen instead of a bar for the ease of comparison.
B – baseline condition; H – hypnosis condition. * – *P*<0.05, ** – *P*<0.01, *** – *P*<0.001.

3.3. The strength of the structurally synchronized EEG pairs during hypnosis

The strength of the structurally synchronized EEG pairs can be estimated by the values of the index of structural synchrony (ISS): the higher this value is, the stronger the synchrony between the pairs. The main finding was the absence of negative values of ISS in all obtained combinations of EEG channels for all frequency bands (delta, theta, alpha, beta, and gamma).

Figure 2 (A) illustrates the mean values of ISS for the nine SS EEG pair categories during hypnosis when comparing with the baseline condition separately for the five EEG frequency bands. The ISS values were significantly lower during hypnosis than in baseline practically in all categories ($P<0.05–0.001$ for different categories) and in all frequency bands, except theta (Fig. 2, A).

The lowest values of ISS during hypnosis were found in all frequency bands except theta for $\text{short}_{\text{anterior}}$ and for $\text{long}_{\text{anterior}}$ categories ($P<0.05–0.001$).

3.4. EEG structural synchrony (functional connectivity) in hypnosis condition

To assess the principal topological picture of EEG structural synchrony (SS), all pair-wise combinations of EEG channels exhibiting statistically proven SS ($P<0.05$) were ranged in accordance to their rate of occurrence within all analyzed 1-min EEG epochs. Only the most frequently found combinations (not less than 85% occurrence in all epochs) were analyzed further.

Figure 3 displays the reliable statistically significant ($P<0.05$) ISS values mapped onto brain schemata as connecting lines between corresponding EEG sites during hypnosis and during the baseline for the five frequency bands. Figure 3 indicates that maps of synchronized cortical areas (indexed by ISS) differed during hypnosis and during the baseline condition. Anterior cortical areas lose their active functional connections with other cortical areas in hypnosis. This was the case for all frequency bands. Additionally, during hypnosis one extremely specific and strong new functional connection appeared (O_2-T_5) in all frequency bands (Fig. 3). This functional connection was absent in the baseline condition as well as in open and closed eyes functional probes. During hypnosis, beta activity was characterized by the largest number of unique and specific functional connections, whereas the gamma activity had the least number of synchronized cortical areas.

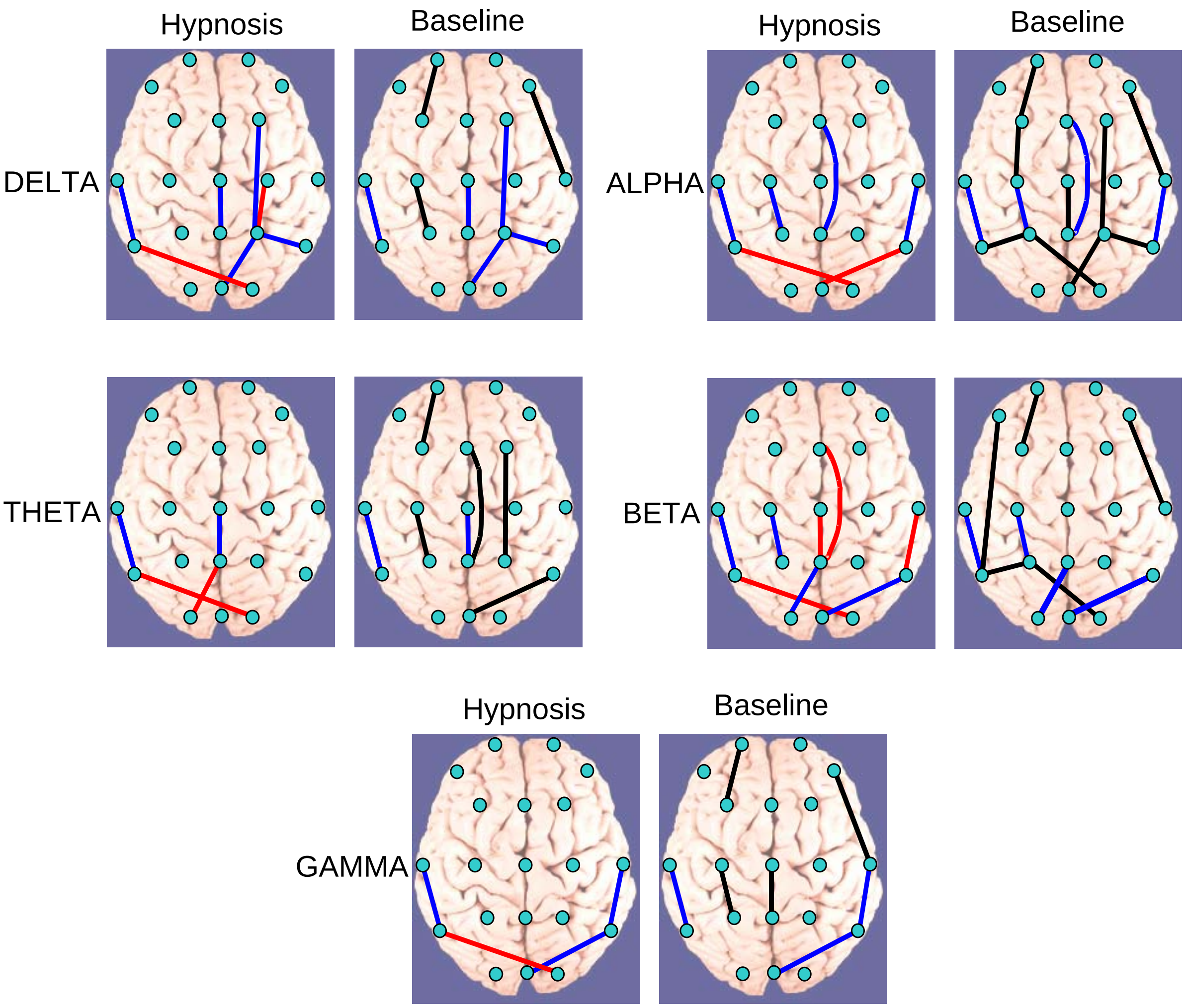

Figure 3. The stable statistically significant (*P*<0.05) values of Index of Structural Synchrony (ISS) in hypnosis and baseline conditions for all frequency bands. The ISS values which occur more than in 85% of repetitions across all epochs are mapped onto schematic brain maps as connecting lines between the EEG channels involved. Blue lines indicate connections which are the same during both conditions; red and black lines indicate connections specific for hypnosis and baseline conditions respectively. EEG labels are the same as at the Figure 1.

4. Discussion

We found evidence that the local and remote cortex functional connectivity was altered in a highly susceptible subject (virtuoso). During pure hypnosis (pure hypnosis; Edmonston, 1979) as compared to the baseline condition of consciousness, all studied parameters of functional connectivity were significantly changed during hypnosis. The differences between hypnosis and the baseline condition were observable (to a different extent) in all studied frequency bands and were replicated in this single subject one year after the first data acquisition (Table 1 and Table 2).

4.1. Local functional connectivity

As envisioned in the methods section, different attributes of obtained EEG quasi-stationary segments illuminate different characteristics of neuronal assemblies (Kaplan & Borisov, 2003). Together these attributes reflect and enable the detailed investigation of the intrinsic nature of local (mesolevel) interactions in the neocortex (Fingelkurts et al., 2004).

We found in the present case study that the individual attributes of cortex neuronal assemblies were sensitive to the changes in the experiment conditions (Fig. 1). Delta-, beta-, and gamma-generated neuronal assemblies (in the whole cortex) were characterized by decreased size (A attribute) and decreased stability (V attribute), being indicative of an increased independence of brain processes (effort to maintain a state of alertness) in the hypnotic condition. Many neuronal assemblies with distributed parallel processing are active, in agreement with the general understanding, when mental activation (in particular attention) takes place (Mesulam, 1990; Nunez, 2000). This idea is in line with the results derived from a study on EEG complexity (Isotani et al., 2001), where increased EEG dimensional complexity was found in high hypnotizables, which was interpreted as an increased independence of information processing, notable during overall mental activation or workload (Pritchard & Duke, 1992; Molle et al., 1996). This was in contrast to the theta- and alpha-generated neuronal assemblies, which exhibited an increase in their size (mostly in the occipital cortex areas) and stability during hypnosis. At the cortical level, generators of the alpha rhythm are likely to be the distal parts of the dendrites of pyramidal cells (Steriade et al., 1990) and according to Burgess and Gruzelier (2000) alpha oscillations might be important for a hippocampally dependent large-scale integration of information across brain areas distributed over temporal, fronto-parietal, and occipital regions. Theta also has been proposed to play a role in the transfer of information between the hippocampus and the neocortex (Buzsaki, 1996; Tesche & Karhu, 2000) and to reflect the intensification of attentional processes (Klimesch, 1999). It is thus possible that large alpha- and theta-generated neuronal populations, which in the present case study appeared during hypnosis, indicate that the subject was not only more relaxed, but also more facilitated to process information than in the baseline condition.

It is interesting that the functional life span (*L* attribute) of all (apart from the gamma-generated) neuronal assemblies was prolonged during hypnosis (Fig. 1). However, the delta-generated neuronal assemblies demonstrated significant shortening of their life span in hypnosis, but only in the frontal areas. With regard to our previous study (Fingelkurts et al., 2003a) where it was shown that the *L* attribute correlated strongly with reaction times (index of a speed of brain operations), we may speculate that prolongation of life span of neuronal assemblies during hypnosis for the studied virtuoso reflects the prolongation of brain operations and slowing down of cognitive processing. Indeed, during hypnosis the sense of time is usually shifted from external to internal events. Consequently, the sensation of time passing is stretched because internal events are subjectively slowed (Von Kirchenheim & Persinger, 1991; Naish, 2001). This subjective experience is reflected in the behavioral responses: in some studies, hypnosis has led to prolonged reaction times in highly hypnotizable subjects (e.g., Sheehan et al., 1988; see also Kallio et al., 2001). These results are also consistent with the study of Nordby et al. (1999), who similarly found a nonsignificant trend indicating that high hypnotizables had longer reaction times than low hypnotizables. At the same time, in the present case study brain operations within the gamma frequency range were shortened, thus indicating the possible intensification of narrowly focused attention which is associated with 40-Hz EEG activity during hypnosis (De Pascalis & Penna, 1990).

The high speed (*S* attribute) of recruitment of new neurons into the delta-, theta-, alpha-, and gamma-generated neuronal assemblies and of elimination of neurons from the beta-generated assemblies (*AR* attribute) was observed during hypnosis in the studied virtuoso. This may be interpreted so that during hypnosis the shifts between brain operations are completed more dynamically and that there exists a transition to a more differential organization of functional relations in the cortex, where neuronal assemblies become more independent and are able to function as separate informational channels. We speculate that it may reflect the enhancement of the automated orienting mechanisms reported previously by Kallio et al. (1999).

Thus, findings on the dynamics of neuronal assembly attributes obtained in the present case study indicated that hypnosis gives rise to an altered local functional connectivity in the cortex (at least in the present virtuoso subject).

4.2. Remote functional connectivity

Remote functional connectivity in the present study refers to the estimation of the spatiotemporal synchronization of local microstates of neuronal assemblies and reflects the formation of metastable states (see review Fingelkurts & Fingelkurts, 2004; 2006). Metastability arises because intrinsic differences in activity between the neuronal assemblies are sufficiently large and they do their own job, while still retaining a tendency to be coordinated together (Kelso, 2002).

In the present case study we found that the number of remote functional connections among different cortical areas (estimated by an index of EEG structural synchrony, ISS) was significantly lower during hypnosis than during the baseline for most categories of functional connections in delta frequency band, and for $\text{short}_{\text{anterior}}$ and $\text{long}_{\text{left}}$ functional connections in all frequency bands except theta (Fig. 2 B). Such disruption in the functional synchrony among neuronal assemblies within distributed areas in anterior and left sections of the cortex is consistent with transient hypofrontality and left-hemisphere inhibition (e.g., Gruzelier, 2000), which has been deemed to be a condition of impaired information processing during hypnosis (Dietrich, 2003). Interestingly, a similar picture of disrupted functional connectivity (estimated by the same method of EEG structural synchrony) has been found in subjects with schizophrenic disorders (Borisov et al., 2005), whereas at the same time there is evidence that highly hypnotizable subjects share aspects of syndromes of the schizotypal personality (Jamieson & Gruzelier, 2001). The widespread low functional synchrony within delta frequency band found in the studied virtuoso may reflect increased vigilance and alertness (Harmony et al., 1996). Taking into account the proposal of Destexhe et al. (1998) that delta oscillations (dominant inhibitory effect) invade the entire network through a mutual interaction between cortex and thalamus, we speculate, based on our finding, that during neutral hypnosis the communication between cortex and thalamus in the studied virtuoso has been to some extent disrupted.

At the same time some cortical areas exhibited an increase in the number of functional connections during hypnosis. These were $\text{short}_{\text{left}}$ and $\text{long}_{\text{left}}$ functional connections for theta and $\text{short}_{\text{posterior}}$ connections for beta frequency bands (Fig. 2 B). Increased synchronicity within left and posterior sections of the cortex may be associated with enhanced fast habituation and selective attention (theta activity), and imagery processes (beta activity) (Basar et al., 2004).

It is interesting that the strength of remote functional connections among cortical areas was significantly lower for all categories of functional connections and for all studied frequency bands (except theta activity) in hypnosis when compared with baseline condition (Fig. 2 A). The weakest links were found for $\text{short}_{\text{anterior}}$ and $\text{long}_{\text{anterior}}$ categories of functional connections, supporting the hypofrontality theory (see review Gruzelier, 2000). These findings mark the importance of functional connections within the theta frequency band for hypnosis and simultaneously stress the weak communication among cortical areas at the other brain frequencies (at least for the studied virtuoso). This may explain such unusual subjective experiences during hypnosis as amnesia, timelessness, detachment from the self, a willingness to accept distortions of logic or reality, and the lack of initiative or willful movement (Dietrich, 2003).

4.3. Topological aspects of remote functional connectivity

The data of the present case study demonstrated that all-frequency-generated neuronal assemblies from the frontal areas (especially from the left hemisphere) lose active functional connections with the rest of the cortex during hypnosis (Fig. 3), thus supporting the hypofrontality theory (Gruzelier, 2000). The most representative and stable functional connection during hypnosis was found between right occipital and left low-temporal cortex areas in all frequency bands (Fig. 3), in spite of basic differences in their physiological reactivity and cognitive/functional meaning (Basar et al., 2004). This functional connection, being present exclusively during the hypnosis condition, may thus be considered to be characteristic of hypnosis, at least for the present virtuoso subject. Areas in the left temporal cortex have typically been related to the recognition, memory, and formation of semantics (Oliveri et al., 2004) as well as to high-level auditory processing (Poremba et al., 2003), while the right occipital area is usually associated with functions specialized in global visual form and low spatial frequency information, image recognition, and perception (Hellige, 1995). Usually the strong functional links between the appropriate parts of occipital and temporal cortices are developed when the source of the input to the brain is visual (Damasio et al., 1989; Tarkiainen et al., 1999). Theoretically it could be argued that the open eyes may be the reason. This is, however, not likely since the subject had her eyes open during baseline and non-hypnosis conditions as well, and yet this functional connection was absent. Thus, we may speculate that this strong functional link might be a neurocognitive marker of hypnosis. It might reflect the readiness of the hypnotic virtuoso to process verbal input (suggestions given by the hypnotist) so that the content of the input easily turns into a hallucinated reality in (visual) perception. This hypothesis should be further tested with other virtuoso subjects.

During hypnosis the largest number of specific cortex functional connections was found for the beta frequency band, whereas the gamma frequency range was characterized by the lowest number of functional connections (Fig. 3). These findings may indicate enhanced anticipation of the stimuli (beta frequency range) with a simultaneously diminished ability to engage attention (gamma frequency band) (Engel et al., 2001) in the studied virtuoso. A similar conclusion was achieved in a previous study using the same subject (Kallio et al., 1999). The authors interpreted the observed disconnection between the automatic orienting mechanisms and the focus of attention as a neurocognitive mechanism of *absorption*, also considered to be one of the main features of hypnosis.

5. Conclusion

Findings of local and remote cortex functional connectivity obtained in the present case study revealed significant differences between baseline and hypnotic conditions. In the highly susceptible subject (virtuoso), pure hypnosis without any further suggestions gave rise to an altered functional synchronicity in the electrophysiological activity of the brain. Thus, an altered brain functional connectivity may be regarded as a neuronal correlate of hypnosis. Still, it remains to be explored: a) if the discovered change in brain functional connectivity would be the same in other hypnotic virtuosos, b) what are the changes in the functional connectivity, shared by different subjects, that constitute a general neural correlate of pure hypnosis, and/or c) do such universally shared neural correlates of pure hypnosis exist at all, even in the virtuoso population? These questions remain to be explored by the future research on the neural correlates of hypnosis.

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