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# SOURCE LOCATIONS OF EEG FREQUENCY BANDS DURING HYPNOTIC ARM LEVITATION: A PILOT STUDY

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## Abstract

Intracerebral model source locations of three major electroencephalogram (EEG) frequency bands between 1.5 Hz and 30 Hz were compared in a pilot study with four subjects while their left arm was kept raised after prompted, willful initiation versus after hypnotic suggestion of arm levitation. Source locations of inhibitory activity (delta–theta EEG frequency band) were more posterior ($p<0.04$), and sources of routine functioning activity (alpha EEG frequency band, mainly alpha1) were more anterior ($p<0.10$) in the brain during the hypnotic than control condition. Comparison of the source location changes during hypnosis with reported findings after eye-opening (attention) and during sleep onset suggests that hypnosis cannot exclusively be positioned on a scale from lowered vigilance to attention, but has an electrophysiological profile of its own.

**Key words**: arm levitation, EEG frequency bands, EEG source localization, hypnosis

## Introduction

What is different in brain electric activity during hypnosis as compared to no hypnosis? In general, such comparisons are confounded by the problem that hypnosis conditions are inherently associated with suggestions of subjective states, such as relaxation, excitation, sleep, happiness, painlessness etc. Similarly, induction might work with very divergent internal states, from enhanced attention to enhanced inattention. It appears that a clean comparison is possible during willfully initiated motor activity versus hypnotically initiated motor activity. Other suggested conditions either cannot be self-induced by willful decisions (for example, sleep) or – without suggestions – would require extensive training (for example, sadness, happiness) if self-inducible at all, and it would be difficult to ensure that a successful non-hypnotic suggestion of a subjective condition (for example, an emotion) does not involve hypnotic components.

In the present pilot study the difference in brain activity between a willful and a hypnotic motor condition was explored, that is, whilst subjects kept their arm raised after prompted self-initiation and whilst subjects kept their arm raised during arm levitation under hypnosis. Brain activity was assessed for each of the three major electroencephalogram (EEG) frequency bands by the intracerebral location of the EEG single-source model computed in the frequency domain (Lehmann and Michel, 1990). The various EEG frequency bands are known to represent different brain functions, from inhibitory (slow EEG frequencies) to routine performance (medium frequencies) to excitatory (fast frequencies).

Left arm manipulations were concentrated upon because right hemispheric functions are known to be more easily accessible to hypnotic manipulations (Sackeim, 1982; Gruzelier, Brow, Perry, Rhonder and Thomas, 1984). During the recordings, the hypnotist was seated to the left of the subject. Since therefore, fully symmetric comparisons between left and right arm procedures would not be possible, comparisons on the left–right axis were omitted and data analysis was restricted to source changes along the anterior–posterior and superior–inferior brain axes.

## Method

Four subjects (three females, one male; age range 31–43 years) participated in the study, each in one session. The hypnotist is a practising psychiatrist and hypnotherapist. The volunteers, who were known to the hypnotist as highly hypnotizable subjects, were recruited from the hypnotist's clients. All subjects were right-handed after Chapman and Chapman (1987). The study was accepted by the hospital Ethics Committee and subjects gave their written consent after having been informed about the experimental procedure.

Preceding the sessions with the four subjects, an additional subject was recorded in an extended pilot experiment to familiarize the hypnotist with the setting and to rehearse the laboratory procedures. After this, it was agreed to perform hypnotic levitations with the left arm as the core objective of the study, to be repeated if possible, whereas other suggestions (such as finger movement, right arm levitation, both arm levitations) would be of secondary importance.

The laboratory instrument room and the recording chamber were shown to subjects and the procedure was explained in detail while 27 electrodes were attached to them with electrode paste at Fp1/2, Fpz, F7/8, F3/4, Fz, Fc1/2, T7/8, C3/4, Cz, Cp1/2, P7/8, P3/4, Pz, Po3/4, O1/2 and Oz of the modified combinatorial nomenclature (anonymous, 1994); Cz was used as recording reference. In addition, three electrodes were attached at the lateral canthi and below the left eye for EOG recordings.

Subjects were seated comfortably on a chair with padded armrests in a sound-, light- and electrically shielded recording chamber at a small round table with a microphone and an intercom for communication with the adjacent instrument room where the experimenter observed the recording scene via on-line video. A video recording of the entire session was taped via an additional camera. EEG data and eye movements were recorded continuously, using a 64-channel recording system (M&I Company, Prague, Czechia) with 0.5–70 Hz bandpass and 250 samples/s per channel.

### *Experimental protocol*

The present report concerns two experimental conditions:

- Whilst the left arm was willfully held in a raised position (control condition).
- Whilst the left arm was held in a raised position under hypnosis.

Part 1
Using the intercom, the experimenter asked subjects to open and close their eyes for a resting EEG recording. Thereafter, subjects were asked – with eyes closed – to raise their left arm and to hold it elevated at about shoulder height until told to let it down, as discussed before the recording, for one minute.

Part 2
The hypnotist entered the chamber and sat down on a chair to the subject's left, at an angle of about 130°. After induction of hypnosis, including eye closure, the hypnotist began the specific suggestions, among them the suggestion of left arm levitation. Part 2 lasted between 38 and 44 minutes. After termination of hypnosis, the hypnotist left the chamber.

Part 3
Part 1 was repeated.

*Data conditioning and analysis*
The recordings during control arm raising and hypnotic arm levitation were carefully reviewed off-line in data epochs of two seconds, excluding those with eye movement, head movement and muscle artifacts. Epochs during which the hypnotist spoke were also excluded from analysis. The available data epochs during the willful (control) and hypnotic raised-arm conditions are listed in Table 1.

Data were downsampled to 128 samples/s. For each epoch, the frequency domain source locations were computed by use of the fast Fourier transform (FFT) dipole approximation (Lehmann and Michel, 1990) which entered, for each FFT frequency point (at 0.5-Hz intervals), the FFT results of all channels into a sine–cosine diagram, projected the entries orthogonally onto the axis of the first principal component of the cloud of entries and read out the distances between the projected entries as microvolt gradients of a potential distribution map.

This map was subjected to conventional single-source dipole modelling (three-shell head model) that resulted in the model source localization on the three brain axes (anterior–posterior, left–right and superior–inferior) and in the strength of the model source. The model sources were located (mm) in a standard head of 78 mm radius, referred to zero at 10% above the zero point of the 10/20 EEG electrode system; positive values in the anterior and upward direction. The anterior–posterior and superior–inferior location values and the strength values were analysed further. All values were averaged over the FFT frequency points for each of the following three frequency bands: delta–theta (1.5–8 Hz); alpha (8.5–12 Hz); and beta (12.5–30 Hz). For each subject and for both conditions, the location and strength values of each band were averaged over epochs.

The model source locations of the three bands on the anterior–posterior and superior–inferior brain axes, and the strength values were compared between the two conditions with exploratory statistics, by use of paired Student's *t*-tests. Two-tailed *p*-values are reported.

Before applying Student's *t*-test statistics to any measurements, they were tested for deviation from the normal distribution by use of the procedure by Lilliefors (1967) and the Shapiro–Wilk's W-test (Shapiro, Wilk and Chen, 1968). No significant deviations were found with both tests.

**Table 1.** Number of recording runs/subject number of the available two-second EEG data epochs and results in the two experimental conditions*

| | Available material | | | | Relevant results: Mean locations across epochs and their differences (hypnosis minus control) on the anterior–posterior brain axis (in mm) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left arm levitation during hypnosis | | Left arm raised as control | | Delta–Theta frequency band | | | Alpha frequency band | | |
| Subject | Runs | Data epochs | Runs | Data epochs | Hypnosis | Control | Difference ($p < 0.04$) | Hypnosis | Control | Difference ($p < 0.1$) |
| 1 | 1 | 25 | 2 | 34 | 12.5 | 15.6 | –3.1 | –8.6 | –12.1 | 3.5 |
| 2 | 2 | 42 | 2 | 29 | –4.9 | 9.1 | –14.0 | –43.1 | –44.6 | 1.5 |
| 3 | 2 | 36 | 2 | 35 | 8.4 | 14.7 | –6.3 | –13.9 | –19.6 | 5.7 |
| 4 | 1 | 58 | 2 | 41 | 6.3 | 17.6 | –11.3 | –10.0 | –10.4 | 0.4 |
| Mean | 1.5 | 40.3 | 2 | 34.8 | 5.6 | 14.3 | –8.7 | –18.9 | –21.7 | 2.8 |
| SD | 0.6 | 13.8 | 0 | 4.9 | 7.4 | 3.7 | 4.9 | 16.3 | 15.8 | 2.3 |

* With the four subjects: left arm levitated in hypnosis and left arm raised willfully as control (there was one control run before and one after the hypnosis runs in all subjects). Listed are the relevant source locations (in mm: zero at 10% above the zero point of the 10/20 EEG electrode system; anterior=positive values) and their differences (location during hypnosis condition minus location during control condition for each subject) that yielded $p$-values <0.10 in the three examined frequency bands; such values were found in the delta–theta and alpha bands, in both bands on the anterior–posterior brain axis.

## Results

The exploratory statistics yielded $p$ values <0.10 of location differences on the anterior–posterior brain axis for two of the three frequency bands. On the superior–inferior brain axis, the location differences between conditions did not reach $p<0.10$.

Table 1 displays the relevant results on the anterior–posterior brain axis. The Student's $t$-tests yielded $p<0.04$ for the delta–theta frequency band and $p<0.10$ for the alpha band. The model source locations in the slow-frequency band of delta–theta were more posterior during the hypnotic condition than during the control condition before and after hypnosis. The opposite was observed for the alpha band where the model source was more anterior in the hypnotic than in the control condition. For both differences, the directions of the mean location differences were the same in all four subjects, as shown in Table 1. When subdividing the tested wide bands of delta–theta and alpha into the factor analysis-based EEG frequency sub-bands (Kubicki, Herrmann, Fichte and Freund, 1979) of 1.5–6 Hz (delta), 6.5–8 Hz (theta), 8.5–10 Hz (alpha1) and 10.5–12 Hz (alpha2), Student's $t$-test statistics demonstrated that delta ($p = 0.055$) as well as theta ($p = 0.044$) and alpha1 ($p = 0.10$), but not alpha2 contributed to these results. Exploratory analysis of the beta sub-bands showed anteriorization ($p = 0.013$) for beta1 (12.5–18 Hz) in the hypnotic condition.

When comparing the model source locations of the delta–theta and alpha bands during the control conditions before and after the hypnosis condition, no significant differences across subjects were found (paired Student's $t$-tests). The mean ($n = 4$) location differences (post-hypnosis minus pre-hypnosis) were 1.6 mm (standard deviation (SD) 5.7; $p>0.6$) and –4.0 mm (SD 4.6; $p = 0.18$), respectively, for the delta–theta and alpha band.

The strength values of the model sources for the three frequency bands did not differ between conditions.

## Discussion

The locations of the intracerebral model sources of brain electric activity in the three major EEG frequency bands were compared whilst the left arm of subjects was in a willfully raised position and whilst it was levitated during hypnosis. The source location of the slow EEG frequency band 'delta–theta' (which reflects inhibitory brain functions) was clearly more posterior in the hypnotic than in the control condition; the opposite, a more anterior location in the hypnotic condition, was found as statistical tendency for the source of the medium EEG frequency band 'alpha' (which reflects routine performance functions). Sub-band examination specified that delta, theta and alpha1 contributed crucially to the results, but not alpha2.

A sequence effect, that is, an effect of progressing time during the entire session can be excluded very clearly for delta–theta, since the two parts of the control condition preceding and following hypnosis did not show different source locations: after hypnosis, the measure returned to the pre-hypnosis value. The differences for alpha were similarly not significant, but larger.

On the other hand, since the two parts of the control condition were much shorter than the hypnosis condition, elapsed time within the pre-hypnosis, during-hypnosis and post-hypnosis recordings is an uncontrolled factor. Yet, if a time-dependent property, such as increasing relaxation or attention, played a role, it is not expected that this is reset completely after the end of hypnosis – unless it is an inherent part of hypnosis. In general, there is no straightforward, perfect control condition for hypnosis (omitting the impossible case where the hypnotist reads the induction and suggestion text without actually hypnotizing the subject): given equal time for control and hypnosis, subjects' activity, task or non-task (relaxation, attention, emotional load etc.) during the control condition would test only a specific, pre-selected factor as possible cause of hypnosis effects.

The source models' global strengths of the activity in the three EEG frequency bands studied did not differ between conditions. But, since this measure of global source strength does not reflect topographic differences, compensating local differences of scalp EEG power cannot be excluded.

The present analysis assessed the principal characteristics of the spatial configuration of EEG activity by tracking the locations of the single-source models of three major EEG frequency bands. A single-source model in the frequency domain can be thought of as the gravity centre of all simultaneous neuronal activity working at a particular frequency in the brain. Different locations of source models must have been caused by a different geometry of the active neuronal populations. Even though the actual differences of the localizations in millimeters were small (as usual in this analysis approach which concerns the gravity centres of very many individual generators), the observed differences clearly point to more anterior involvement of routine function processes and to more posterior involvement of inhibitory processes during hypnosis, the latter in line with reports of posterior (scalp-localized) delta and theta increase in hypnosis (Graffin, Ray and Lundy, 1995; Rainville, Hofbauer, Paus, Duncan, Bushnell and Price, 1999).

This finding is generally reminiscent of comparable location shifts of delta and alpha model source locations as reported after eye-opening in wakefulness (putative increase of attention), on the one hand, (Kondakor, Brandeis, Wackermann, Kochi, Koenig, Frei, Pascual-Marqui, Yagyu and Lehmann, 1997) and after sleep onset on the other, (Tsuno, Shigeta, Hyoki, Kinoshita and Lehmann, 1997), scalp-localized, posterior increase of delta in sleep (Hofle, Paus, Reutens, Fiset, Gotman, Evans and Jones, 1997). The executed motor behaviour would not exclude sleep (cf. 'sleep walking', Jacobson, Kales, Lehmann and Zweizig, 1965). However, detailed examination of the comparisons between the present results and the reports quoted above qualifies the similarities: delta and theta source models in hypnosis and sleep onset did show comparable, significant posteriorizations, but after eye-opening, delta posteriorization was non-significant and theta was even (non-significantly) anteriorized. Furthermore, the source models for the sub-bands of alpha1 and of alpha2 anteriorized after eye-opening as well as after sleep onset and during hypnosis, but whereas this change for alpha1 showed a $p$-value $<0.1$ in hypnosis, changes after eye-opening and after sleep onset were not significant, and contrarily, whilst this change for alpha2 was not significant after hypnosis, it was significant after eye-opening and after sleep onset. Hence, the profile of the source changes during hypnosis shares some characteristics with the profiles after eye-opening and after sleep onset, but also shows differences from either one. For delta–theta, hypnosis resembles sleep onset but eye-opening is different, whereas in the alpha sub-bands, eye-opening and sleep onset are comparable, but hypnosis is different. In this context it is interesting that the measures of EEG dimensionality increase with attention and after eye-opening

(Kondakor et al., 1997) and decrease in sleep. One type of such analyses (Global Omega Complexity, after Wackermann, 1999) was performed on the present data and yielded a decrease in hypnosis, but only at two-tailed $p<0.2$.

In conclusion, as hypnosis seems to share some electrophysiological features with lowered vigilance but other features with increased attention – although less closely – it is suggested that hypnosis cannot be positioned exclusively on a scale from lowered vigilance to attention, but has an electrophysiological profile of its own.

This pilot report further increases the large repertoire of EEG and ERP findings in hypnosis which cannot be reviewed here (see, for example, Crawford and Gruzelier, 1992; Gruzelier, 1996). A good reason for the variety of reported findings as mentioned above is the variety of studied hypnotic suggestions (Jasukaitis, Nouriani, Hugdahl and Spiegel, 1997; Barabasz, Barabasz, Jensen, Calvin, Trevisian and Warner, 1999; Rainville et al., 1999; Isotani, Tonaka, Lehmann, Pascual-Marqui, Kochi, Saito, Yagyu, Kinoshita and Sasada, 2001) and also the differences of effects between subject groups (such as high and low susceptibles) (Sabourin, Cutcomb, Crawford and Pribram, 1990; Crawford, Clarke and Kitner-Triolo, 1996). On the other hand, we are not aware of an EEG study using the raised-arm-paradigm, even though this is a procedure used widely during hypnosis induction.

The present pilot study introduced EEG source model localization as a further measure of hypnotic states. The results of this study should be tested in a larger population, more EEG dimensionality measures should be examined, and left–right comparisons should be included to clarify hemispheric differences (Gruzelier et al., 1984; Gruzelier, 1996; Jasukaitis et al., 1997; Barabasz et al., 1999).

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