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EEG correlates of hypnotic susceptibility and hypnotic trance: spectral analysis and coherence

Michel E. Sabourin[1], Steven D. Cutcomb[2], Helen J. Crawford[3] and Karl Pribram[2,4]

[1] *Department of Psychology, University of Montreal, Montreal, Que. (Canada),* [2] *Neuropsychology Laboratories, Department of Psychology, Stanford University, Stanford, CA (U.S.A.),* [3] *Department of Psychology, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061 (U.S.A.) and* [4] *Center for Brain Research and Informational Sciences, Department of Psychology, Radford University, Radford, VA 24142 (U.S.A.)*

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EEG was recorded monopolarly at frontal (F3, F4), central (C3, C4) and occipital (O1, O2) derivations during A-B-A conditions of waking rest, hypnosis (rest, arm immobilization, mosquito hallucination, hypnotic dream), and waking rest. Stringently screened on several measures of hypnotic susceptibility, 12 very low hypnotizable and 12 very highly hypnotizable, right-handed undergraduate, subjects participated in one session. Evaluations were Fast-Fourier spectral analysis, EEG coherence between selected derivations and maximum spectral power within EEG bands. In eyes open and closed conditions in waking and hypnosis, highly hypnotizable subjects generated substantially more mean theta power than did low hypnotizable subjects at all occipital, central and frontal locations in almost all conditions of waking and hypnosis, with a larger difference in frontal locations. Both low and high hypnotizables showed increased mean theta power in hypnosis, suggesting an intensification of attentional processes and imagery enhancement. Mean alpha power was never a predictor of hypnotic susceptibility. Interactions with hypnotic susceptibility showed that highly susceptible subjects had more beta activity in the left than right hemispheres, while low susceptible subjects showed only weak asymmetry. No main effects for or interactions between waking/hypnosis and hypnotic level were found for coherence between derivations or maximum spectral power within theta, alpha and beta EEG bands.

INTRODUCTION

Current developments in EEG recording and analytic techniques permit a reexamination of the many attempts that have been made to identify electrocortical correlates of hypnosis (for review, see Crasilneck and Hall, 1959; Sarbin and Sable, 1979; Sabourin, 1982). These studies have examined (1) EEG frequency differences between low and highly hypnotizable individuals, and/or (2) EEG differences between waking and hypnosis conditions as moderated by hypnotic level. Overcoming many previous methodological limitations, the present study examined EEG frequency band differences in waking and hypnosis conditions in subjects stringently screened for low and high hypnotic susceptibility levels.

EEG DIFFERENCES BETWEEN LOW AND HIGH HYPNOTIZABLES

Alpha frequency differences

When electroencephalographic (EEG) alpha densities were being emphasized, several early studies reported that highly hypnotizable subjects

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Correspondence: M.E. Sabourin, Dept. of Psychology, University of Montreal, Montreal, Quebec, Canada.

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produced a higher proportion of occipital alpha waves (8–12 or 13 c/s) than those who were not susceptible to hypnosis (e.g. London et al., 1968; Bakan and Svorad, 1969; Engstrom et al., 1970a, b; Morgan et al., 1971, 1974; Ulett et al., 1972a; Edmonston, 1975; Barabasz, 1980, 1982), although other studies reported no such relationship (e.g. Edmonston and Grotevant, 1975; Meszaros and Banyai, 1975; Cooper and London, 1976; Dumas, 1977; Evans, 1979). When Evans (1979) found no relationships between alpha and hypnotic susceptibility as estimated by two different scales or by clinical diagnostic ratings, he concluded that the alpha/hypnotizability correlations were likely due to situational or methodological factors not related to hypnosis per se. While Dumas (1977) concluded that these correlations were due to subject selection biases (drafted vs volunteer subjects), Barabasz (1983) presented further data that the correlations are 'not simple covariates of subject self-selection'.

Comparisons between eyes-open and eyes-closed conditions within the same subjects have found significantly positive correlations between alpha amplitude and hypnotic susceptibility in eyes-closed rest conditions, but no such relationships within eyes-open rest conditions (Galbraith et al., 1970; Morgan et al., 1974; MacLeod-Morgan, 1979; DePascalis and Palumbo, 1986) or eyes-closed while performing tasks (DePascalis and Palumbo, 1986). The condition of eyes-closed cannot explain differences across earlier studies since most had subjects close their eyes during EEG recording.

DePascalis et al. (1988) found significant correlations between hypnotic susceptibility and integrated amplitude, but not alpha density scores. When temporal and parietal alpha were evaluated, without consideration of occipital alpha, no correlations with hypnotic susceptibility were found (DePascalis and Imperiali, 1984). Thus, the location of the recording derivations may be of greater importance than previously thought.

Theta frequency differences

Galbraith et al. (1970) reported that theta, not alpha, components (within the range from 3 through 12 Hz) in the occipital location were the most important predictors of hypnotic susceptibility. These authors used a step-wise multiple regression analysis: 5 Hz and 6 Hz components in eyes-closed resting—and 5 Hz through 9 Hz components in eyes-open resting conditions. The best predictors were those in the 5 and 6 Hz range. Using analog frequency analyzer data, Apkinar et al. (1971; Ulett et al. 1972a, b) found significant correlations between hypnotizability and the 3–4.5 and 5–7 Hz range frequency in the right occipital derivation. MacLeod-Morgan (1979) reported no differences between high and low susceptible subjects in an eyes-closed condition in theta frequencies in occipital-parietal derivations of either hemispheres. However, she did find that the highly susceptible subjects generated more theta in an eyes open condition. Tebecis et al. (1975) reported that highly hypnotizable subjects, well practiced in self-hypnosis, generated more theta activity in the parietal location of both hemispheres, during waking and hypnosis, in conditions of eyes open and eyes closed, than did a second group who had never been hypnotized and scored low in susceptibility. Finally, DePascalis and Imperiali (1984) reported no correlations between hypnotic susceptibility and theta generation in the temporal and parietal locations, all bipolarly referenced to vertex.

Differences in electrode placement across these studies make it difficult to compare these findings, but they do indicate the need for simultaneous evaluation of electrocortical activity in posterior, central and anterior locations.

Since hypnosis and meditation have both been considered to produce alternate states of consciousness often resulting in altered awareness, it is interesting to note that increased theta during quiescent meditative states have also been reported, often with a greater increase in experienced than in naive meditators (Kasamatsu and Hirai, 1969; Banquet, 1973; Wallace et al., 1977; Elson et al., 1977; Corby et al., 1978; Hebert and Lehmann, 1979; Taneli and Krahne, 1987; Saletu, 1987). However, the increase in theta activity is more often frontal than occipital or parietotemporal.

Higher frequency differences

While most studies are limited in their spectral analyses by band pass filters that cut off at 35 Hz or lower, some studies have been able to expand the Hz range. Analyzing from 0.5 to 70 Hz, Akpinar et al. (1971; Ulett et al., 1972a, b) reported that regression analysis demonstrated hypnotizability to be related to greater beta EEG activity at the right occipital (O2) derivation in waking. DePascalis and Imperiali (1984) found no relationships between beta and hypnotic susceptibility at temporal and parietal derivations bipolarly referenced to vertex (Cz) in eyes-open and eyes-closed conditions.

EEG CHANGES ACCOMPANYING HYPNOSIS

Another line of research has searched for EEG correlates of the hypnotic state per se, also with rather mixed results. Ulett et al. (1971) reported that both low and high hypnotizable subjects showed similar changes during hypnosis: decreased low frequency, increased alpha, increased low beta, and increased very high frequency beta at the right occipital (O2) derivation. Saletu (1987) reported increased delta and theta, but decreased alpha and beta in left and right occipital locations during hypnosis that correlated positively with hypnotizability. Tebecis et al. (1975) reported no changes during hypnosis in the parietal location of both hemispheres, and Meszaros and Banyai (1975) found no changes in alpha and beta generation in fronto-occipital bipolar derivations across waking and hypnosis or as moderated by hypnotic level. Once again the results are inconsistent, possibly due to methodological differences, differences in derivations used, or differing subject characteristics.

A commonly espoused hypothesis is that hypnosis involves greater right hemisphere involvement as evidenced by enhanced imagery and/or holistic processing that are commonly believed to be right hemisphere functions (e.g. Springer and Deutsch, 1989; but see Farah (1988) who presents evidence that the left hemisphere may be involved in image generation as well). Influenced by findings of lateral differences in electrophysiological correlates of cognitive processing, studies of differences in hemispheric activity during hypnosis were initiated in the 1970s and have continued to the present. Thus, Chen et al. (1981) examined the integrated amplitude within various Hz bands in bipolar recordings from fronto-parietal derivations in a patient undergoing dental surgery with hypnosis as the sole anesthetic. They found the total energy output of the left and right hemispheres to diminish during hypnosis, with a greater diminution in the left than right hemisphere in alpha and theta bands. The greater inhibition of the left hemisphere during hypnosis has also been reported in studies of electrodermal shifts (e.g. Gruzelier et al., 1984; Gruzelier, 1987). Crawford, Mészáros and their colleagues (Crawford, 1989; Mészáros et al., 1989; Crawford et al., 1989c) reported enhancements in alpha and beta power in the right parieto-occipital location during hypnosis in rest baseline and task performance by highly susceptible patients but not by those who were low in susceptibility.

Hemispheric differences during hypnosis have been reported in terms of a laterality quotient. This is computed by taking the difference between the integrated amplitude of the alpha frequency band or total frequency band recorded from the left and right hemispheres and dividing it by their sum: Left − Right / Left + Right. There are, however, inherent difficulties in interpreting ratio scores since one cannot gauge the relative contribution of left and right hemisphere activity to the ratios (e.g. Gevins and Schaffer, 1980; Gevins, 1983; Beaumont et al., 1984). Using occipital-vertex bipolar derivations, LaBriola et al. (1987) reported greater overall total amplitude in the right hemisphere during hypnosis, while two other studies (Morgan et al., 1974; Mészáros and Banyai, 1975) did not. Shifts toward greater right hemisphere relative to left hemisphere involvement during hypnosis have been reported for bipolar derivations of occipital-parietal alpha (MacLeod-Morgan, 1982), occipital-temporal total power (Karlin et al., 1980b; Karlin et al., 1981; LaBriola et al., 1987), and fronto-occipital alpha and beta (Banyai et al., 1985; Mészáros et al., 1986).

PRESENT STUDY

The purpose of the present study was to validate, clarify and extend previous research in this area of investigation. More stringent criteria were established for subject selection. Most previous studies have used a single testing procedure for hypnotic susceptibility, which did not permit the plateauing of stable hypnotic scores. Further, exclusive use of the Harvard Group Scale of Hypnotic Susceptibility (Shor and Orne, 1962) or the Stanford Hypnotic Susceptibility Scale, Form A (Weitzenhoffer and Hilgard, 1959), emphasizes motor and challenge suggestions rather than more difficult cognitive suggestions (such as hallucinations and cognitive distortions) found in scales such as the Stanford Hypnotic Susceptibility Scale, Form C (Weitzenhoffer and Hilgard, 1962). In the present study, subjects were stringently screened on multiple measures of hypnotic responsiveness, two of which are cognitive, in order to achieve plateaued hypnotic scores. The final selection of subjects was limited to subjects who consistently scored either very high or very low in hypnotic susceptibility across screening sessions.

Within the same experimental session, subjects had their EEG recorded during rest baselines in an ABA design of waking, hypnosis and waking conditions with eyes open and closed, so that we could evaluate possible differences in relationships between spectral power and hypnotic susceptibility across eyes open and closed conditions. Additional EEG recordings were made during the presentation of 3 hypnotic suggestions involving motor and imagery/hallucinatory factors. Thus, we are able to evaluate both state (waking vs hypnosis) and trait (high vs low hypnotic susceptibility) main effects and interactions.

Choice of 6 monopolar EEG derivations, located bilaterally in the major areas of the brain (frontal, central and occipital) with referencing to a non-active site, permitted reasonable evaluation of regional activity. As one physiological indicator of arousal or activation (see Pribram and McGuinness, 1975, for definition of arousal as used here; also see Lacey and Lacey, 1970), concurrent heart rate measures were taken. Fast-Fourier spectral analysis was performed for each EEG derivation and then mean spectral power within 3
bandwidths (theta, alpha and beta) were subjec
to appropriate repeated analyses of variance. Sin
there is evidence for increased coherence duri
meditation (e.g. Banquet, 1973), we felt it i
portant to determine whether coherence betwe
derivations might also increase during hypnosis
moderated by hypnotic level. We evaluated i
trahemispheric and interhemispheric coherence
assess the degree of similarity or covariance in t
EEG from two chosen derivations.

METHOD

Subjects

Subjects were 24 (14 women and 10 men), wh
came from a pool of approximately 600 Stanfo
University undergraduate students which had fir
been given a modified 10-item version of th
Harvard Group Scale of Hypnotic Susceptibili
(HGSHS; Shor and Orne, 1962). Right-hande
subjects scoring either 9 or 10 (high susceptible
and 0 or 1 (low susceptibles) on the HGSHS we
asked to volunteer for further hypnotic testir
with the Stanford Hypnotic Susceptibility Scal
Form C (SHSS:C; Weitzenhoffer and Hilgar
1962). Approximately 100 students were thus ind
vidually tested. Only those scoring 11 or 12, and
or 1 on SHSS:C, and who previously belonged
the same category, were kept for the EEG recor
ing session. These subjects reported strong righ
handedness in writing and other activities. Ad
ditionally, they demonstrated right-eyedness whe
sighting and right-footedness when kicking a bal

Thus, a sample of 26 subjects, 14 highs and 1
lows, were selected; two high susceptibles we
then left out to equalize group numbers. Th
study reports on 12 highs (4 men, 8 women) an
12 lows (6 men, 6 women). Due to the sma
numbers we were unable to assess for possibl
moderating effects due to gender. Six high suscep
tible subjects were further tested with the Revise
Stanford Profile Scales, Forms I and II (Weitzen
hoffer and Hilgard, 1967); the mean score fo
Form I was 23.8/27.0, whereas it was of 24.3/27.
for Form II. Since the objective of obtaining dif
ferential profiles amongst the highs was unattaina

TABLE I

EEG recording session

Experimental condition	*Duration*	*Number of epochs*
1 Eyes-open baseline	5 min	10
2 Eyes-closed baseline	5 min	10
3 Hypnotic induction (eyes-open)	10 min approx.	10
4 Hypnotic induction (eyes-closed)	10 min approx.	10
5 Trance deepening instructions	2 min	4
6 Trace deepening	2 min	4
7 Arm immobilization instructions	2 min	4
8 Arm immobilization challenge	10 s	1
9 Mosquito hallucination instructions	1 min	2
10 Mosquito hallucination	10 s	1
11 Hypnotic dream instructions	2 min	4
12 Hypnotic dream	2 min	4
13 Awakening procedure	3 min	6
14 Eyes-open baseline	5 min	10
15 Eyes-closed baseline	5 min	10
Total	54 min approx.	90

ble (all subjects scored very high in almost every category), this lengthy procedure was soon discontinued. However, the scores on these scales clearly confirmed that the subjects selected were indeed very highly hypnotizable subjects.

Certain factors (like meditation experience, coffee and alcohol drinking, smoking, sleeping habits, drug intake), which may have potential influences on the EEG record were evaluated and found to be either absent or not different in the two groups of subjects. No brain damage was evident.

Experimental procedure

The EEG recording session lasted approximately 90 min, including preliminary instructions and electrode placement. Great care was taken to develop rapport with the subjects and put them at ease. Subjects had previously been administered the SHSS : C and Profile hypnotic scales by the same experimenter in the same room. The EEG recording procedures were described clearly to the subjects and all questions were answered before the session. Each subject benefited from a short adaptation period (approx. 10 min), while the recording equipment was adjusted. Postexperimental reports of 'tension' during the experiment was uniformly low, with no differences between low and high hypnotizables.

After eyes-open and eyes-closed baseline recordings, subjects were submitted to a standardized taped hypnotic induction procedure involving eye-fixation and suggestions of relaxation and eye-closure. Immediately after hypnotic induction, trance deepening instructions were given, and subjects were left to themselves for a period of two min. This was followed by hypnotic testing based on a motor item (arm immobilization), a hallucinatory item (mosquito hallucination), and a fantasy item (hypnotic dreaming); these specific items were selected in order to probe different hypnotic abilities, and because in these cases success or failure did not require different terminating instructions. The awakening procedure was then initiated, and final baselines were recorded. An outline of the procedure is provided in Table I. Immediately after removal of the electrodes, a short postexperimental written questionnaire was given in order to collect the different subjective reactions to the experience. Questions about situation-related anxiety, self-scoring of the hypnotic items, and the content of the suggested hypnotic dream were included. Finally, all questions raised about the experience were answered and all subjects were asked not to discuss these matters with other potential subjects; each subject was given a chart record of his EEG, EOG and EKG as a token of appreciation.

EEG recording

Six monopolar EEG derivations were used, located according to the 10–20 System (Jasper, 1958) at O1, O2, C3, C4 and F3, F4. All recordings were done at an amplification of 50 μV/cm. Ground was attached at a point 3 cm above the nasion; the reference was linked ears (A1–A2), balanced for impedance. A lead I EKG was recorded and a bipolar EOG record was also taken, with electrodes at the outer canthus and sub-orbital to the right eye. EEG and reference electrode placements were tested to insure contact resistance of 10 K or less, and balanced for impedance level as closely as possible.

Eight channels of a Beckman type R Dynograph were used to record these physiological signals. EEG and EOG were recorded using a time constant of 1 with low-pass filters set to HI OUT and High frequency = 2. The empirically derived low-pass frequency response function at these setting had a −3 dB point at 15 Hz, with 50% attenuation at 28 Hz.

A time event marker was encoded by latching two Hunter timers, such that the Beckman event channel was high for 8 s (duration of an epoch) and low for 7 s, in a cycle which produced 4 high periods (or epochs) per min. All 8 channels plus the event signals were recorded on chart paper, and the 6 EEG channels plus the events channel were recorded on a 7 channel Ampex SP-300 FM tape recorder (a Tektronic 120 4-channel scope was used to monitor the Beckman power amplifier backplane outputs and the signals were tape-recorded).

The recording system was calibrated after testing every 6 subjects by feeding a 10 c/s, 100 μV sinewave into each of the EEG couplers, while recording the output to FM tape. An average peak-to-peak amplitude of the calibration signal was calculated, upon playback of the record into the analog-to-digital converter, to generate 6 floating-point scale factors for adjusting raw EEG in order to correct for interchannel differences prior to the Fast-Fourier Transform (FFT).

Primary signal analysis consisted of analog-to-digital conversion of the tape-recorded EEG, editing of the digitized EEG, performing the FFT on selected EEG epochs, power and coherence spectral computation and ensemble averaging of these spectra.

All the analyses were done on a PDP-11/34a minicomputer. Tape-recorded EEG was played back to the AR11 real-time analysis peripheral for analog-to-digital conversion at either the recording speed (1 7/8 ips) for the first couple of subjects or at 4 times this speed (7 1/2 ips) for most subjects, the latter chosen for speed without loss of precision. The conversion rate was 64 c/s per channel real-time, which meant digitizing at 256 c/s/ch. when playback speed was 4 times the recording speed (for about half the subjects in both groups). Each sampling epoch was of an 8-s duration, creating an integer array of 512 points per channel per epoch. One hundred and eighty epochs were digitized for each subject, representing approx. 45 min of the original recording session.

EEG editing was based on several criteria. The first selection occurred during digitizing: although more than 180 EEG epochs had often been recorded, only 180 were kept for conversion. The rejected epochs were those containing obvious muscle or eye-blink artifact. Next, the raw EEG paper record corresponding to each digitized epoch was visually scanned by two observers to identify less obvious eye-movement or muscle artifact contamination of that epoch. The number of each unwanted epoch was entered into a computer file to effect rejection prior to performing the FFT. This editing procedure was necessary to ensure low spectral energy in the 32–64 Hz frequency band, since energy in this band would alias to the 0–32 Hz frequency band of interest (Bendat and Piersol, 1971). A third form of editing was programmed by computer, and thus done automatically. Since the AR11 data buffer is 10 bits in size, the digitized data are represented by values in the range 0–1023, corresponding to an input signal voltage range of −2.5 to 2.5 V. This 5 V voltage window accommodates EEG of 150 μV amplitude, but large transient artifacts cause digitized values to be extreme, either 0 or 1023. For each epoch, a count was kept for each channel, and if the threshold of 10 extremes was exceeded on any channel, that epoch was tagged for rejection prior to performing the FFT. Finally, only 90 of the remaining digitized epochs representing the different experimental conditions were kept for the FFT processing stage.

The selected 90 epochs of digitized EEG data were then subjected to the FFT, thus transforming the time-series into frequency representation. Digitizing at rate X allows the frequencies represented to be from DC to 1/2 X so our data yielded DC to 32 c/s in spectral representation. This procedure is equivalent to subjecting the raw time-series to a cosine bell data window; this is a convolution of the Fourier results with a 3-point Hanning filter (weights $= x_{i-1} = 0.25$, $x_i = 0.50$, $x_{i+1} = 0.25$), which is equivalent to having subjected the original data to convolution with a cosine bell filter (Bendat and Piersol, 1971). The FFT was implemented by using a fixed-point assembly—language program available from Digital Equipment Corporation, and the first and second halves of each epoch were transformed separately; thus, 256 point transforms were accomplished, creating a resolution of 1/4 c/s in the resulting spectra. Ensemble averaging of the two non-overlapping segments per channel per epoch created a peridogram with at least 4 df, and perhaps more due to the Hanning convolution (Bendat and Piersol, 1971).

Autospectral estimates were then ensemble averaged, within each of 15 blocks for each subject, to produce smoothed power spectrum estimates for each condition and for each group.

Data analysis

The EEG of low and high hypnotizables in waking and hypnosis conditions were evaluated by 3 different approaches: (1) Fast-Fourier spectral analysis, (2) EEG coherence between selected derivations, and (3) maximum spectral power within each EEG band. There were no shifts in maximum spectral power during hypnosis even when moderated by hypnotic susceptibility. These analyses are therefore not detailed. Ordinarily, the main effects and interactions of the repeated measures analyses of variances will be reported if subsequent Tukey mean comparisons verified significant differences ($P < 0.05$). Comparisons addressing hypnotic susceptibility level and differences in condition are emphasized. The effects of eyes open or closed during rest conditions were separately assessed but because very few significant differences were obtained between these conditions in terms of the relevant comparisons, only the eyes-closed data are reported unless they are variant with eyes open. Instruction periods prior to the actual suggestions were excluded. After spectral analysis of 0–35 Hz, the mean power estimates for 3 Hz bands, theta (4.00–7.75 Hz), alpha (8.0–12.75 Hz) and beta (13–28 Hz), for each condition were extracted. Although 0–35 Hz was spectral analyzed, the beta bandwidth was attenuated due to the filters employed; thus, beta analyses were limited to the range below 28 Hz.

RESULTS

Section I: spectral analysis

Eyes-closed rest conditions

For each of the bandwidths repeated measures ANOVAs were performed separately: 2 (hypnotic susceptibility: low vs high) × 3 (intrahemispheric location: frontal, central and occipital) × 2 (interhemispheric location: left and right) × 5 (condition: initial waking baseline, hypnotic induction after eye closure, hypnosis per se during trance-deepening instructions, awakening procedure before opening eyes, and final waking baseline).

Theta. There was a 3-way interaction between hypnotic susceptibility, condition of hypnosis, and intrahemispheric location, $F_{8,176} = 3.26$, $P < 0.01$ (see Fig. 1). Highly hypnotizable subjects had substantially more mean theta power ($P < 0.01$) than did low hypnotizable subjects in occipital, central and frontal regions in all conditions but one, the central location where there is a non-significant trend during the final waking baseline. While maintaining these significant differences, both lows and highs showed significant increases in mean theta power ($P < 0.01$) from initial wak-

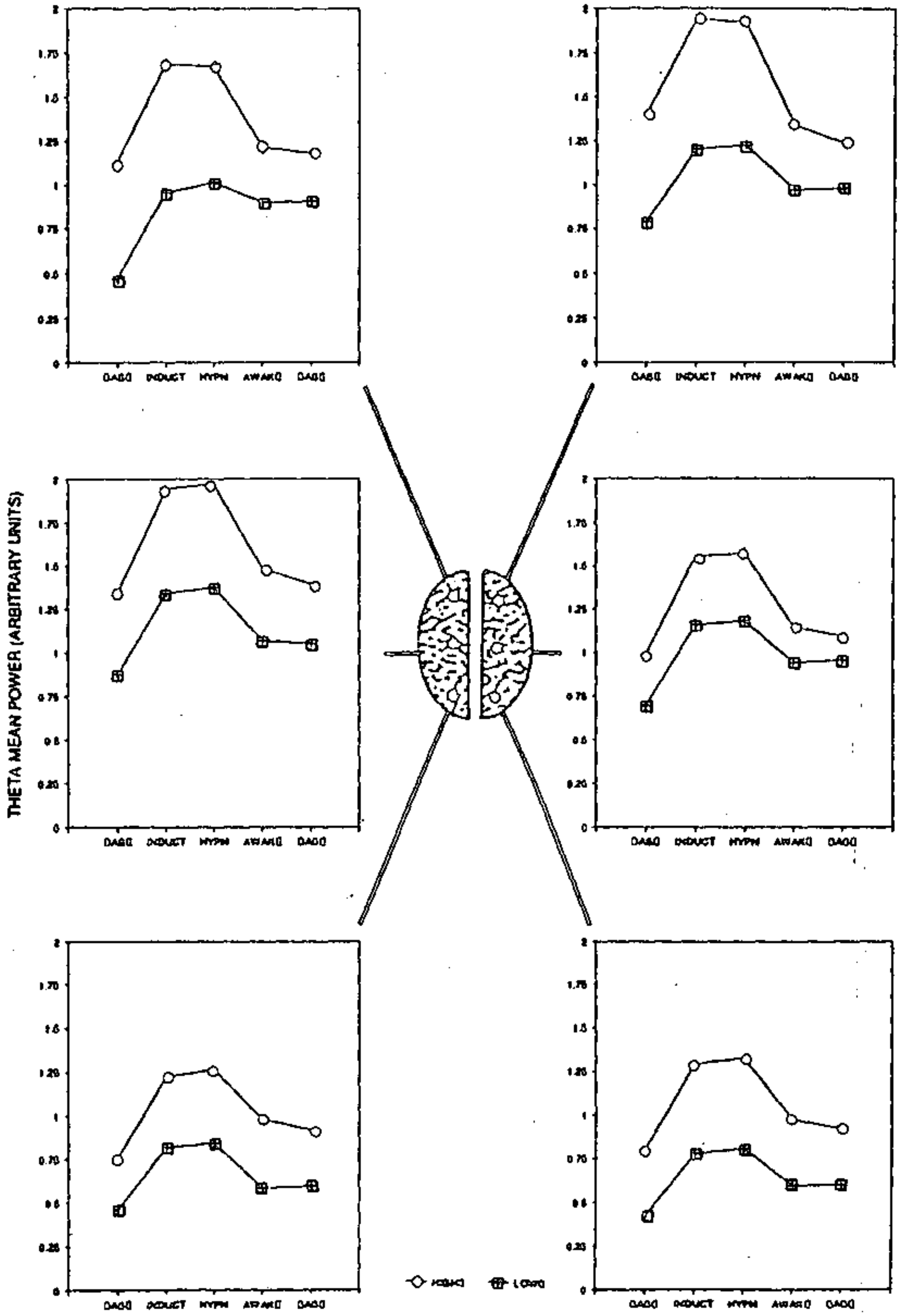

Fig. 1. Theta mean power at frontal (F3, F4), central (C3, C4) and occipital (O1, O2) locations for low and highly hypnotizable subjects across eyes-closed conditions of initial waking baseline, hypnotic induction after eye closure, hypnosis baseline, awakening and final waking baseline.

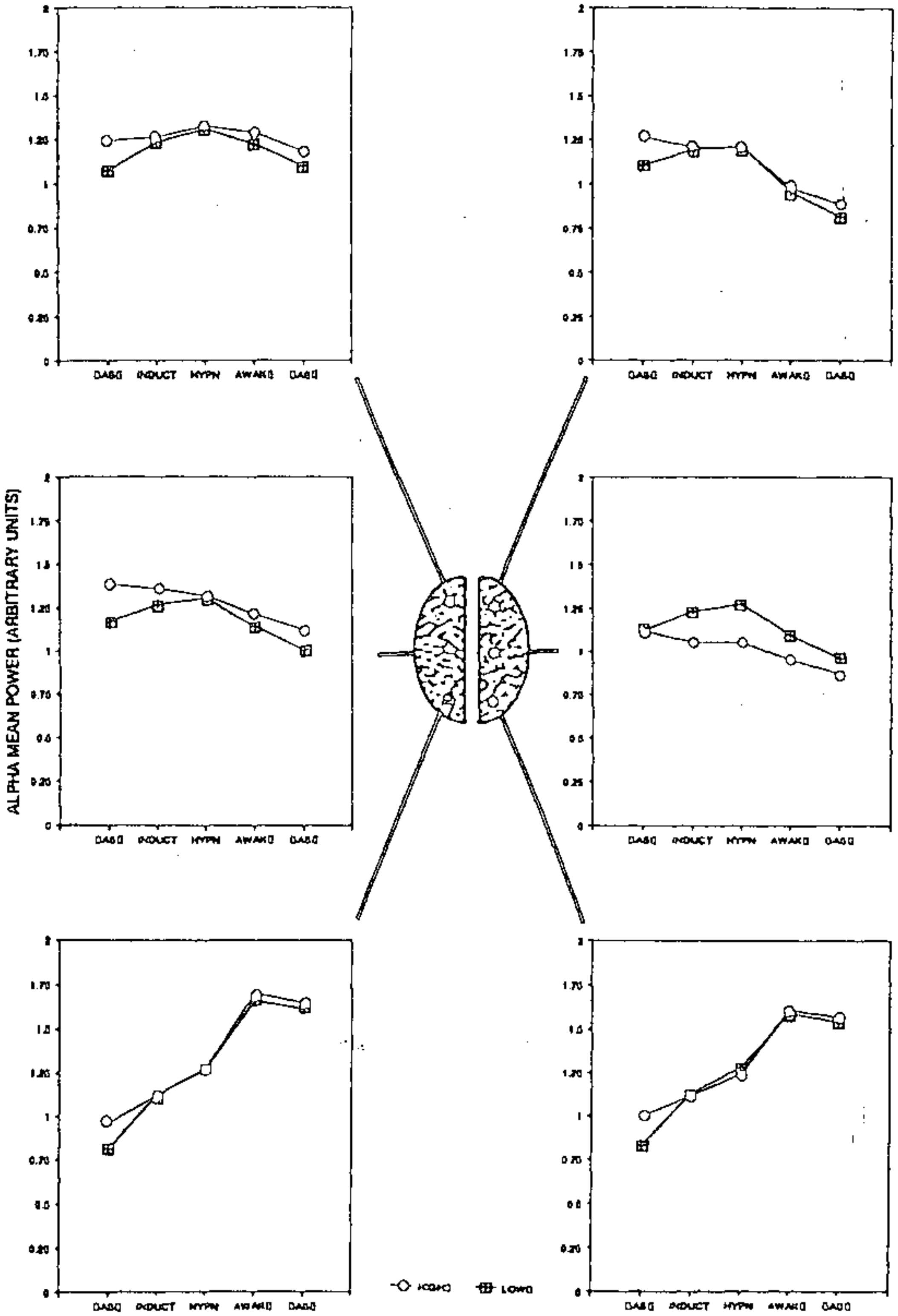

Fig. 2. Alpha mean power at frontal (F3, F4), central (C3, C4) and occipital (O1, O2) locations for low and highly hypnotizable subjects across eyes-closed conditions of initial waking baseline, hypnotic induction after eye closure, hypnosis baseline, awakening and final waking baseline.

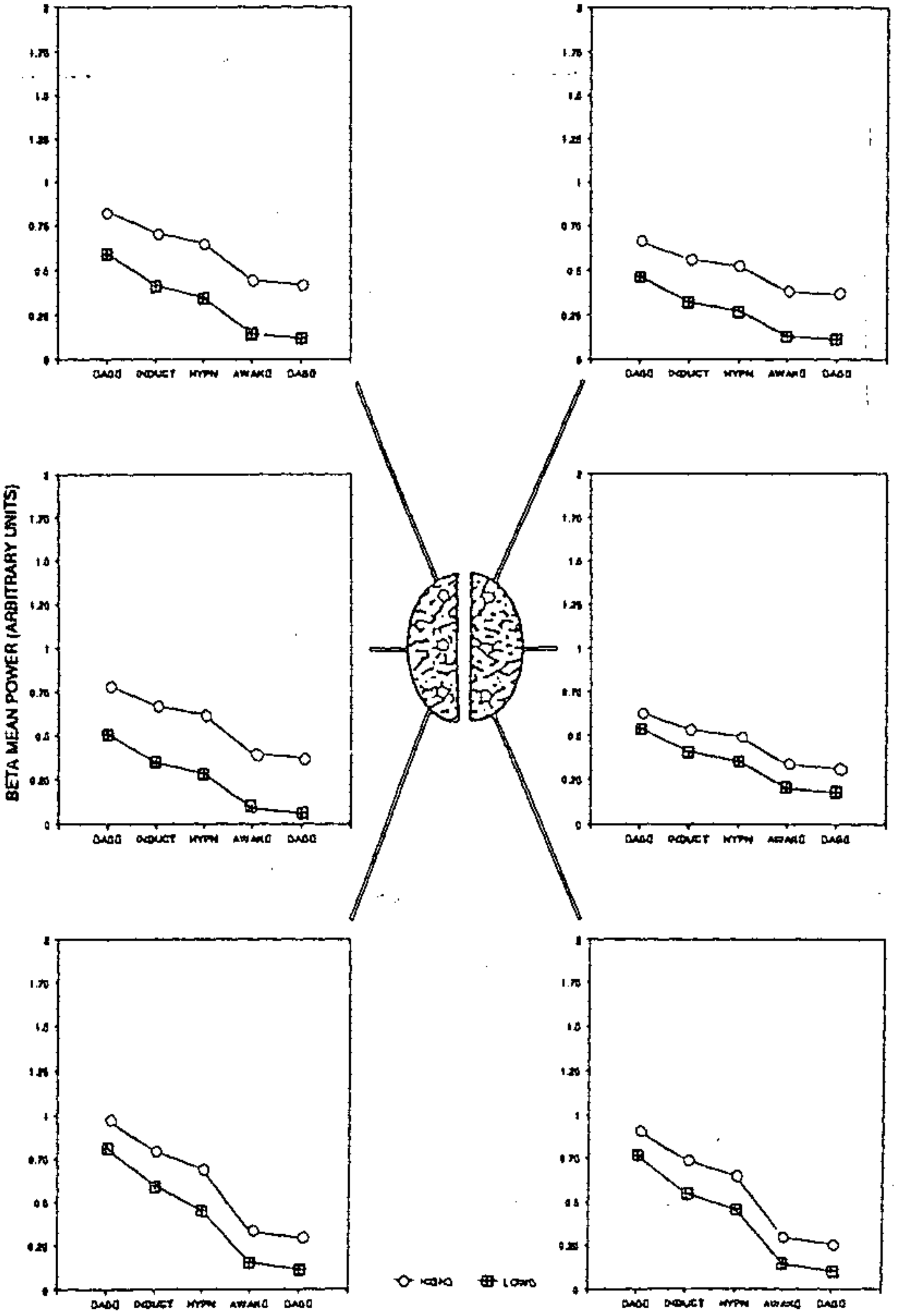

Fig. 3. Beta mean power at frontal (F3, F4), central (C3, C4) and occipital (O1, O2) locations for low and highly hypnotizable subjects across eyes-closed conditions of initial waking baseline, hypnotic induction after eye closure, hypnosis baseline, awakening and final waking baseline.

ing to hypnosis in all 3 locations. Both low and high hypnotizable subjects showed a substantial decrease in mean theta power in all 3 locations when coming out of hypnosis. There were no significant interactions involving interhemispheric location with hypnotic susceptibility or conditions of hypnosis.

Alpha. There were no significant main effects or interactions involving hypnotic susceptibility. There was a significant location by condition of hypnosis interaction, $F_{8,176} = 61.95$, $P < 0.001$ (see Fig. 2). During initial waking baseline, central and frontal locations showed significantly more mean alpha power than the occipital location ($P < 0.05$), while when coming out of hypnosis and in the final waking baseline, the occipital location showed substantially more power than the other two locations ($P < 0.05$); during hypnosis, the locations were equal. Thus, there was a significant increase in mean alpha power as the experimental progressed at the occipital locations but not at the central and frontal locations. Significantly more mean alpha power was found overall in the left hemisphere, $F_{1,22} = 16.39$, $P < 0.01$.

Beta. There was a significant location by condition interactions, $F_{8,176} = 47.57$, $P < 0.001$. As is seen in Fig. 3, mean beta power decreased significantly as the experiment progressed at the occipital locations, but not significantly at the central and frontal locations.

During eyes-open rest in waking and hypnosis, there was a significant interaction between interhemispheric location and hypnotic susceptibility, $F_{1,22} = 4.38$, $P < 0.05$. As is seen in Fig. 4, highly susceptible subjects had substantially more beta power in the left hemisphere than did low hypnotizable subjects, while subjects did not differ significantly from one another in recordings made from the right hemisphere. In addition, the highly susceptible subjects showed significantly more overall beta power recorded from the left than from the right hemisphere, while the low suscepti-

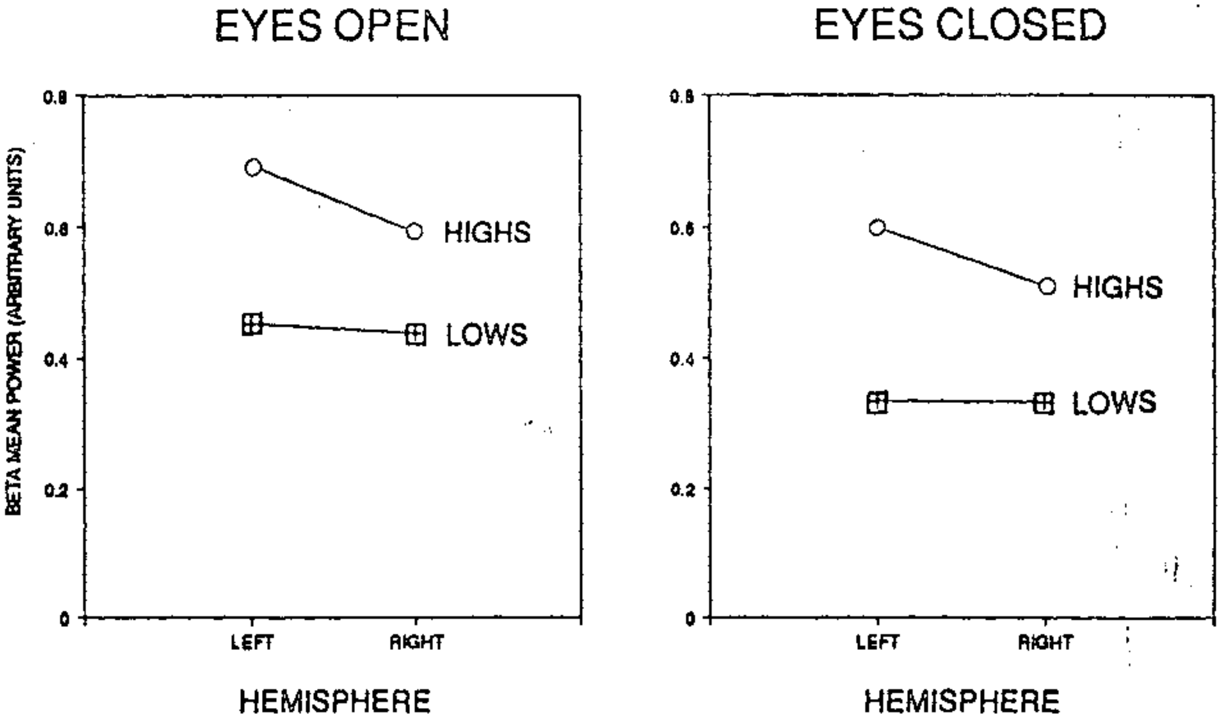

Fig. 4. Beta mean power of left and right hemispheric locations for low and highly hypnotizable subjects across eyes-open and eyes-closed baseline measurements.

ble subjects did not. There was a non-significant trend, $F_{1,22} = 4.17$, $P < 0.10$, for a similar interaction between hypnotic susceptibility and interhemispheric location for the eyes closed resting conditions. Overall, there was more mean beta power in the left hemisphere, $F_{1,22} = 4.39$, $P < 0.05$.

Hypnotic suggestions

For each of the bandwidths, repeated measures ANOVAs were performed separately: 2 (hypnotic susceptibility: low vs high) × 3 (intrahemispheric location: frontal, central and occipital) × 2 (interhemispheric location: left and right) × 4 (hypnotic suggestions: trance deepening, arm immobilization, mosquito hallucination, and hypnotic dream).

Theta. Consistent with the previous analyses, highly susceptible subjects (M = 1.38) had significantly more theta power than did low susceptibles (M = 0.94), $F_{1,22} = 4.31$, $P < 0.05$, across all 3 locations.

Alpha. There was no significant main effect or interaction for hypnotic susceptibility. An intrahemispheric location by condition interaction, $F_{6,132} = 47.14$, $P < 0.001$, found the 3 intrahemispheric locations equal in mean alpha power for the deepening suggestion, but during each of the subsequent hypnotic suggestions there was significantly more mean alpha in the occipital location than in the frontal and central locations, which did not differ from one another. In addition, in the occipital location the deepening suggestion had substantially less alpha mean power than the subsequent 3 hypnotic suggestions ($P < 0.01$), while in the central and frontal locations there were no significant differences in mean alpha power between the 4 conditions.

Beta. There was a non-significant trend for an interaction between hypnotic level and hemisphere, $F_{1,22} = 3.85$, $P < 0.10$, in the same direction as that found for the eyes open and closed rest conditions in waking and hypnosis. There was a significant interaction between condition and intrahemispheric location, $F_{6,132} = 30.41$, $P < 0.001$. At the occipital location, there was a greater reduction in beta power over the 4 items than in the central and frontal locations.

Section II: coherence between derivations

The calculated coherence index ranges from 0 to 1.0, with higher values indicating more similarity in spectral phase at a given frequency between EEG derivations. There were no main effects or interactions which involved hypnotic susceptibility. The only hypnosis per se effect was during the rest baseline conditions: in theta there was more coherence during hypnosis (0.08) than during the initial and end waking baseline conditions (both 0.06) for frontal-occipital derivations within each hemisphere, but it continues to be quite low.

In eyes closed baseline rest conditions in waking and hypnosis, there was greater intrahemispheric coherence between frontal-central derivations than occipital-central derivations, in theta (respectively, left: 0.36, 0.17; right: 0.39, 0.09) and alpha (respectively, left: 0.34, 0.14; right: 0.42, 0.09). Beta coherence was substantially lower and only showed non-significant trends in the same direction (respectively, left: 0.07, 0.05; right: 0.11, 0.03). Similar intrahemispheric coherences were found for the hypnosis suggestions.

Section III: heart rate

While the overall heart rate mean for low hypnotizable subjects ($\overline{X} = 61.8$/min) was lower than for the highly hypnotizable subjects ($\overline{X} = 66.9$/min), this difference was not significant. There was a significant hypnotic level by condition interaction, $F_{12,264} = 31.67$, $P < 0.001$. Subsequent mean comparisons indicated that while highly susceptible subjects had somewhat higher heart rates than low susceptible subjects across all conditions, during the following conditions this difference was significant: mosquito hallucination, 71.1 vs 60.3; hypnotic dream, 70.4 vs 63.7 (but not during the preceding dream instruction).

Section IV: ability to image

To assess the commonly observed relationship between hypnotic susceptibility and the ability to image (e.g. Sheehan, 1979), 19 (12 highs, 7 lows) subjects were recontacted 6 months later and administered the Individual Differences Questionnaire (Paivio, 1971), which assesses the main factors of (1) use of verbal abilities and (2) use of imagery. While the low and high hypnotizables did not differ on verbal-related factors, the highs reported significantly higher involvement on the main imagery factor, as well as the additional scales of mental pictures, daydreams and the use of mental pictures (all $P < 0.02$).

DISCUSSION

Mean theta power

The major robust finding of this study is that mean theta power seems to be strongly and positively related to the trait of hypnotic susceptibility. This confirms what other studies based on similar techniques had previously reported (Galbraith et al. 1970; Ulett et al., 1972a; Tebecis et al., 1975). In both eyes-open and eyes-closed conditions in waking and hypnosis highly hypnotically susceptible subjects generated substantially more mean theta power than did low hypnotizables. Moreover, the interactions indicate that this difference held up at all occipital, central and frontal locations in all conditions but one, with a larger difference in frontal locations. While maintaining a significant difference between groups, both low and highly susceptible subjects showed a substantial increase in mean theta power at all 3 locations after the hypnotic induction, that continued at a similar level through the various hypnotic suggestions. Both low and highly hypnotizable subjects showed a substantial decrease in mean theta power in all 3 locations upon leaving hypnosis. The literature concerning theta and psychological phenomena (for review, see Schacter, 1977) shows that increments in theta activity occur in a variety of problem-solving, perceptual processing and cognitive tasks. While this increment can be observed in a variety of locations, it is most prominent in the fronto-central areas.

As for state differences, hypnotic susceptibility level did not play a moderating role. Enhancements in mean theta power during hypnosis occurred for both low and high hypnotizables. While differences between low and high hypnotizable subjects were maintained in hypnosis, the percent increase from the initial waking baseline to the hypnosis baseline was somewhat larger for the lows than the highs: respectively, 86% vs 71% at the occipital locations, 76% vs 53% at the central locations, and 76% vs 43% at the frontal locations.

It is possible that the theta observed in our highly susceptible subjects reflects common underlying cognitive mechanisms that differentiate them from low susceptible subjects. One such mechanism could be related to attentional components. Highly hypnotizable subjects often report greater absorptive attentional skills on questionnaires as well as demonstrating greater attentional skills in experimental tasks (e.g. Tellegen and Atkinson, 1974; Crawford et al., 1989a). The hypnotic induction is thought to intensify selective attention or inattention. In the same vein, we can also refer, as Galbraith et al. (1970) have done, to the Class II concept of Vogel et al. (1968), which postulates that slow waves represent 'a selective inactivation of particular responses so that a continuing excitatory state becomes directed or patterned (p. 172)'. It should be noted that slow EEG waves represent two kinds of behavioral inhibition. The enhanced theta of the high hypnotizables in the present study is thought not to be associated with 'Class I inhibition', which is correlated with general inactivity or drowsiness, but rather to be associated with 'Class II inhibition', which is correlated with more efficient and attentive performance (Vogel et al., 1968).

Further support for the relationship between theta and problem solving (Vogel et al., 1968; Schacter, 1977) comes from recent work by Crawford (1990) which examined the EEG correlates of cold pressor pain in hypnosis, with and without suggested analgesia. In low theta (3.5–5.5 Hz) there were no differences in power between low and high hypnotizables, but in high theta (5.5–7.5 Hz) highs generated substantially more power than low hypnotizables at frontal, temporal, parietal and occipital locations. Crawford et al. (1986; see also Crawford, 1989) found substantial increases (as much as 28% in comparison to waking conditions) in regional cerebral blood flow, an indicator of cortical metabolism accompanying cognitive arousal/performance, in anterior, parietal, temporal and temporal-posterior regions, during hypnotic rest and ischemic pain (with and without suggested analgesia) conditions in high, but not low, hypnotizables.

A complementary hypothesis can be based on reports involving the hypnagogic state, a state also characterized by the presence of low voltage theta activity (for review, see Schacter, 1977). In such research, many experiments, like those of Foulkes and Vogel (1965) and Stoyva (1973), have shown that psychological phenomena related to imagery production accompany the low voltage theta EEG. It follows that those individuals who produce more theta may be higher in imagery abilities. Supporting such a hypothesis in the present study were the positive relationships found between hypnotic susceptibility and greater reports of imagery mediated mentations in a subset of the sample.

Mean alpha power

Mean alpha power was never a predictor of hypnotic susceptibility in this study. Since our subjects were all familiar with the experimenter and the research situation, due to prior hypnotic tests and precautions taken to make the subjects feel at ease, we believe situational variables had less of a differential effect upon low and high hypnotizables than in some prior studies (for review, see Evans, 1979). Contrary to many findings that report no hemispheric asymmetry for alpha or greater right hemisphere alpha production (e.g. for review, see Butler and Glass, 1973; Gevins and Schaffer, 1980), in our very quiescent conditions, mean alpha power was significantly greater in the left hemisphere across locations and conditions for total subjects.

Unexpectant distributions of mean alpha power amplitude across locations in the waking, hypnosis, waking series were found. During preliminary waking measurements greater power was found in frontal and central, than occipital, locations. This is contrary to the common finding in the literature that alpha is greater in the occipital than in the more anterior locations. As the experiment proceeded, significant shifts occurred: during hypnosis the locations were equal in mean alpha power, while in the post-waking measurement the occipital location had significantly more mean alpha power. These unexcepted distributions cannot presently be fully explained; however, recent findings regarding a parietal location for an alpha generator at the lower end of the band may provide a clue.

In the present study we examined the broad alpha range of 8.0–12.75 Hz. Recent findings (e.g. Herrmann, 1982; Coppolo, 1986; Coppolo and Shassy, 1986) indicate that low and high alpha are differentially distributed across individuals, and that there are different alpha generators in the occipital (high alpha) and parietal (low alpha) locations. Crawford et al. (1989b) found differential changes in integrated amplitude power in low and high alpha bands at frontal and parietal locations across induced happy and sad emotional states in waking and hypnosis, as moderated by hypnotic level. Thus, future research should evaluate separately low and high alpha bands (as well as low and high theta bands).

As the experiment progressed, mean alpha power increased while mean beta power decreased significantly in the occipital locations (Figs. 2 and 3). Yet, there were no significant increases or decreases of alpha and beta, respectively, at the central and frontal locations. Given the substantial increases in the theta band in hypnosis, these results suggest the need to examine the patterns of location changes across Hz bands as they relate, perhaps differentially, to both cognitive and physical arousal levels.

Mean beta power

An interesting interaction between hypnotic susceptibility and interhemispheric location occurred only in the beta band. Highs had substantially more mean beta power in the left hemisphere across the 3 locations than did low hypnotizables, while they did not differ significantly from one another in the right hemisphere. While the mean beta power was essentially the same in both hemispheres for the low hypnotizable subjects, the high hypnotizable subjects showed significantly more overall beta power in the left than in the right hemisphere. This was significant in the eyes-open rest conditions, and showed non-significant trends in the same direction for eyes-closed conditions. Thus, regardless of condition, high hypnotizable subjects seem to show greater asymmetry between the two hemispheres in the beta band than do low hypnotizable subjects.

The results suggest that there are differences in characteristic patterns of hemispheric arousal associated with hypnotic susceptibility. The highly hypnotizable subjects in the present study demonstrated characteristically higher left hemisphere arousal in beta, the cause of which is unknown.

Highly stable individual differences in asymmetries of electrocortical activity over time have been reported (Morgan et al., 1971; Ehrlichman and Weiner, 1979). These differences were found to be correlated with differential behavioral performance (e.g. Furst, 1976; Glass and Butler, 1977; Rebert, 1977; Davidson et al., 1979; Levy et al., 1983). Crawford, Mészáros and their associates (Crawford et al., 1988; Crawford, 1989; Mészáros et al., 1989) reported differential bipolar frontocentral and parieto-occipital asymmetries in the low and high alpha bands during waking and hypnosis in low and highly hypnotizable subjects. Using either the alpha band or overall total power, several studies (Karlin et al., 1980a; MacLeod-Morgan and Lack, 1982; Mészáros and Banyai, 1985) have demonstrated that high hypnotizable subjects have greater hemispheric specificity during the performance of tasks during waking; that is, highs show greater left hemisphere activation when performing analytical tasks and greater right hemisphere activation when performing visuospatial, holistic tasks. While DePascalis et al. (1988) found no evidence supportive of occipital-parietal hemispheric specificity differences, a follow-up study (DePascalis and Palumbo, 1986) found hemispheric asymmetry differences for low but not high difficulty tasks. While the above hypnosis studies used bipolar recordings of different derivations and are difficult to compare with the present study's monopolar recordings, recent research using monopolar recordings have found highs to show greater hemispheric asymmetries in certain EEG bands than lows, in induced emotional states during waking and hypnosis (Crawford et al., 1989b) and in cold pressor pain with and without suggested analgesia (Crawford, 1990).

Worthy of further investigation is the suggested hypothesis in all of these studies that differences in hypnotic susceptibility may accompany differential patterns of asymmetric hemispheric arousal. Like DePascalis and Palumbo (1986), we found these differences to occur more in the left hemisphere. Interestingly, when hemispheric electrocortical activity differences have been reported across cognitive tasks, often it is the left hemisphere which appears to shift in power more than the right hemisphere (e.g. Gevins, 1983).

Heart rate changes

While highly susceptible subjects tended to have somewhat higher heart rates across all conditions, only highly susceptible subjects had significantly higher heart rates during the mosquito and hypnotic dream suggestions during hypnosis.

Tasks which require acceptance of the input of external stimuli are accompanied by heart rate deceleration while tasks which require the rejection of external stimuli and the focusing upon internal mental processes are accompanied by heart rate acceleration (Lacey et al., 1963; van der Molen et al., 1984; Cole and Ray, 1985). It is of interest, therefore, that the two hypnotic suggestions that required the strongest focusing upon internal mental processes, with a giving up of reality testing, are the ones which discriminated between low and high hypnotizable subjects. The significant increase in heart rate among highly susceptible subjects may indicate deeper involvement by the subjects in the internal mental processes. Future research could test the hypothesis of greater attentional involvement in highly susceptible subjects by evaluating heart rate differences while performing input acceptance and rejection tasks, such as those used by Ray and Cole (1985).

CONCLUSION

In summary, the results of the current study demonstrate that highly hypnotizable subjects had more mean theta activity in frontal, central and occipital locations than did low hypnotizable subjects in both waking and hypnosis conditions. Interactions with hypnotic susceptibility show that highly susceptible subjects had more beta activity in the left than right hemispheres, while low susceptible subjects showed only weak asymmetry. Both low and high hypnotizable subjects showed enhancements of theta during hypnosis, suggesting an intensification of attentional processes and an enhancement of imagery.

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