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EEG Gamma Coherence and Other Correlates of Subjective Reports During Ayahuasca Experiences

David E. Stuckey, Psy.D.*; Robert Lawson, M.S.** & Luis Eduardo Luna, Ph.D.***

Abstract—The current study examined QEEG power and coherence of ayahuasca experiences with two experienced participants in a Brazilian jungle setting. An exploratory case series design was adopted for naturalistic field research. EEGs recorded during visual imagery was compared to eyes-closed baselines. The most important findings were increases in global EEG coherence in the 36–44 Hz and 50–64 Hz frequency bands for both subjects. Widely distributed cortical hyper-coherence seems reasonable given the intense synesthesia during ayahuasca experiences. Other findings include increased modal EEG alpha frequency and global power decreases across the cortex in most frequency bands, which concur with the EEG of psychedelics literature. Exploratory analysis revealed the usefulness of analyzing single Hz bins over the standard wide-band analysis. The discovery-oriented naturalistic approach developed for this study resulted in potentially important findings. We believe that finding increases in global gamma coherence during peak psychedelic experiences might contribute to the discussion of binding theory. Also, in light of recent research with gamma coherence during advanced meditative conditions, our findings might further the comparison of shamanic psychedelic practices with meditation.

Keywords—ayahuasca, coherence, EEG, gamma, psychedelic

Ayahuasca is a plant medicine that holds a position of prime importance in the ethnomedical and spiritual practices of indigenous shamanic peoples of the Upper Amazon, probably since antiquity. Still in use by indigenous groups in Brazil, Colombia, Ecuador and Peru, ayahuasca has found its way into use by the Amazonian mestizo population of these countries (Luna 1984a, b; Dobkin de Rios 1972). It is also used as a sacrament in several syncretic religious Brazilian organizations such as the Santo Daime, Barquinha, and União do Vegetal. Its use is not only in South America, but its availability is spreading throughout Europe, the United States, and elsewhere (McKenna, Callaway & Grob 1998). Its various uses include spiritual practice, psychotherapy, addiction treatment, and physical healing.

Despite this growing popularity, ayahuasca has only recently been studied from a Western scientific perspective. There is little research about the physiological impact on individuals who drink ayahuasca or its potential therapeutic applications. There is some evidence that ayahuasca offers pharmacological health benefits in addition to its psychotherapeutic qualities (Grob et al. 1996). Callaway and colleagues (1999) have suggested that it is conceivable that the regular use of ayahuasca might induce upregulation of 5-HT uptake sites on blood platelets and in turn stimulate 5-HT production. The long history of its use and benefits among a variety of cultures lends support to belief in its safety.

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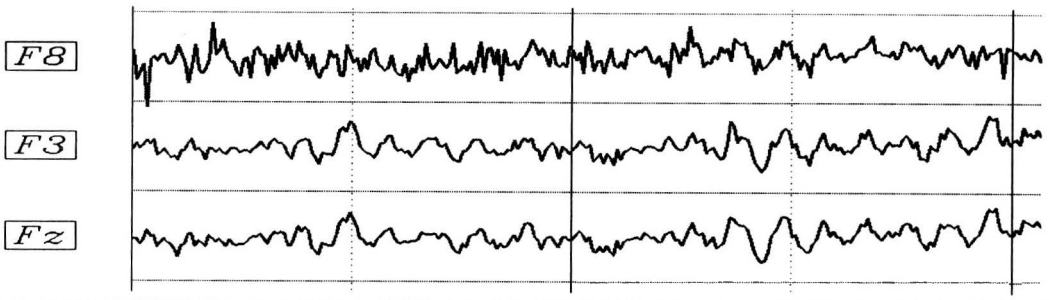
FIGURE 1
Example EEG Tracings



INGREDIENTS, PREPARATION AND PHARMACOLOGY OF AYAHUASCA

Ayahuasca is a strong smelling, bitter tasting, brownish-red drink. It is created from an infusion of the shredded stalk (bark and stems) of the malpighiaceous vine *Banisteriopsis caapi* with other plants, most commonly the leaves of *Psychotria viridis*, commonly known as *chacruna*, or the leaves of *Diplopterys cabrerana*, often known as *chagropanga*, with a number of other possible admixture plants (Luna 1984a). The Quechua term ayahuasca is used not only for the drink created from brewing together one of these two basic combinations, but also refers to the *Banisteriopsis caapi* plant itself. The infusion process varies but commonly includes cooking or soaking the plants together for several hours.

Banisteriopsis caapi contains three characteristic harmala alkaloids including harmine, tetrahydroharmine and lesser amounts of harmaline. The *Psychotria viridis* contains the powerful psychoactive dimethyltryptamine (DMT). The DMT is mainly responsible for the drug's hallucinogenic effects. DMT is not orally active because it is metabolized by the enzyme monoamine oxidase (MAO) in the stomach and liver. However, the harmine and harmaline in ayahuasca act as MAO-inhibitors, which allows the DMT to circulate in the bloodstream and cross the blood/brain barrier. The tetrahydroharmine might contribute to the psychoactive effects by weakly inhibiting serotonin uptake (Riba et al. 2001; Callaway et al. 1999; Metzner 1999; Riba & Barbanoj 1998).

DEFINITION OF EEG TERMS

A brief section defining the technical terms in quantitative electroencephalogram (EEG) research is included for readers unfamiliar with the subject. Figure 1 shows two seconds of EEG for three channels. This graphic shows most of the EEG features discussed in this article. The horizontal axis is time and vertical axis is amplitude. The unit of measure for time is seconds and the solid vertical lines represent one second. The dotted lines represent half second increments. The unit of measure for amplitude is the microvolt and the distance between the horizontal lines represents 75 microvolts (μV).

An EEG has two main attributes, *frequency* and *amplitude*. Frequency is the number of cycles per second. A cycle can be described as the wave form of one channel as it moves from a given position on the vertical axis in one direction, creating either a u-shape or inverted u-shape, then going in the opposite direction and completing its opposite u or inverted u-shape and then returning to the starting position on the vertical axis.

Amplitude is the height of the waveform measured in microvolts and *power* is a synonomous term used in quantitative EEG. Magnitude is the amplitude of the waveform recorded at the scalp electrode averaged over a period of time and is calculated using the square root of the power. The example in Figure 1 shows that the second half of the first second of the lowest tracing (Fz) has around 4.5 cycles, which is equivalent to a frequency of nine cycles per second. The height of these 4.5 cycles is around one quarter the distance of the horizontal lines, so the amplitude is around 18 microvolts.

Over the years, the EEG has been categorized into frequency bands. These categories are an arbitrary frequency range. The classic categories are delta—1–4 cycles per second or Hertz (Hz.), theta (4–8 Hz), alpha (8–12 Hz), and beta (12–20 Hz). Frequencies faster than these are called gamma. Since these categories are arbitrary, all researchers do not use the same frequency bands. Some studies may define alpha as 7–12 Hz and others might define it as 8–13 Hz. These different definitions of the bands can make comparisons between studies difficult.

The 9 Hz activity observed in Figure 1 would be defined as alpha. However, it is important to note alpha is not the only activity in this section of EEG. Note the smaller waves riding on top of the alpha. These are beta waves and are probably around 20 Hz. The first second of the uppermost tracing is a different kind of wave. It is mostly muscle tension, called EMG (electromyogram). Note the fast frequency, perhaps 50 Hz, and the sharp shape. This scalp muscle tension happens outside the skull and is not related to the EEG. Note that the second half of the top tracing has less EMG and the underlying EEG is visible. This EEG is

also in the first second but it is completely masked by the EMG.

The lower two tracings can be seen to have very similar waveforms. That these two wave forms move in unison indicates high coherence between them. Coherence is a measure of the similarity of the EEG at two different sites. The unit of measure is percent of shared variance. Coherence can be thought of as a measure of communication between two regions of the brain.

Though the lower two channels have high coherence with each other, they have much less coherence with the upper channel. This is obvious graphically. The reduced coherence is due to the EMG that is masking the EEG in the upper channel. Note that the EEG that can be seen in the last second of the upper channel is fairly coherent with the EEG in the lower two channels. However, because most of the EEG activity in this channel is corrupted with EMG, coherence calculations between this channel and other channels will show reduced coherence, especially in the faster frequencies where muscle tension has most of its activity.

The last term to be defined is relative power. Power is equal to amplitude squared. Relative power is the portion of all the power at a site that is in a particular band. It is expressed as a percentage. For example, if the total power is 10 microvolts and the alpha power is 4 microvolts, alpha relative power is 40%.

EEG RESEARCH WITH PSYCHEDELIC SUBSTANCES

Most of the Western electroencephalographic research with psychedelic substances was completed during the 1950s and 1960s. At that time the technology for doing computerized analysis of the EEG, called *quantitative EEG* or QEEG, was in its infancy and mostly not implemented.

The most common EEG findings for psychedelic drugs in healthy subjects are small increases in the basic alpha frequency rhythm, desynchronization with an overall decrease in power, and a relative increase in low amplitude beta frequencies. Studies showed a lack of agreement concerning the location of the most salient changes. Researchers noted changes in such varied locations as somatosensory areas, frontal and central areas, parieto-occipital leads, fronto-temporal, parietal regions, and the entire scalp. The most prominent changes have been found in the occipital regions, both left and right. Although these changes have occurred in many subjects, many anomalous cases of very different, even opposite tendencies are common. For example, Itil and Fink (1966a, b) reported some cases, even with high doses, showing no clinical or EEG changes. Shagass (1966) had one anomalous case showing an inverse of his general findings. Itil (1969) had some cases showing no clinical or EEG effects. Serafetinides (1965) showed changes in varying directions. Anderson and Rawnsley (1954) had one case that exhibited alpha frequency slowing, which was an inverse of the trend.

Some speculate that the EEG changes are trait dependent. Two traits have been speculated to account for changes. One is the *alpha response type*, which is indicated by the amount of baseline alpha (Bradley, Elkes & Elkes 1953), while the other is the classification of visualizer or conceptualizer (Brown 1968).

Bercel and colleagues (1956) and Shirahashi (1960) conducted the only two studies that attempted to correlate subjective reports with EEG response to date. They found that alpha suppression correlated with periods of increased visual imagery associated with LSD intoxication. Both used visual inspection of the data. Bercel and colleagues added a method of mean histogram and Shirahashi used an unreferenced analysis technique called Motokawa's method.

Among the EEG studies using ayahuasca, two found increases in relative power in the beta bands and shifts toward higher frequencies. Don and colleagues (1998) found significant power increases in the 36–44 Hz band, particularly at T5 and O1. They also found trending toward reduced power in the alpha (8–14 Hz) and theta (4–8 Hz) frequency bands, and increased power in the 14–30 Hz band. Riba and colleagues (2002) also showed a shift toward higher frequencies, but found an overall decrease in absolute power for all frequency bands. They did find relative power increases in the beta-3 (20–25 Hz) and beta-4 (25–30 Hz) subbands. Unlike Don, who found decreases in alpha power, Riba and his team found a relative power increase in the alpha-1 (7.5–10.5 Hz) subband.

Hoffmann and colleagues (2001) found very different trends than the other two, possibly due to delayed time of assessment. According to their multiple dosing schedule, two of the three doses might have completely run their course by the time EEG data was gathered. Similar to Riba, they did find significant power increases in the 8–13 Hz bands in the occipital region. However, they also found significant power increases in the 4–8 Hz band as well, with no changes in the 13–20 Hz band. It is unclear why the authors made the association that the effects of ayahuasca seem more similar to marijuana than to other psychedelic substances.

DISCUSSION OF THE LITERATURE

Psychedelic substances have the ability to allow their users to enter a state of consciousness that is dramatically different than normal daily waking consciousness. This dramatic change can potentially lie on a wide spectrum that ranges from mimicking psychosis to therapeutic and transpersonal states.

The reviewed literature raises two fundamental issues with psychedelic EEG research. The first is that there are

large differences in findings among the various EEG studies and many examples of anomalous cases. This suggests that the important variables of change are not being adequately isolated.

The second is that the most common findings, such as small increases in the basic alpha frequency rhythm, desynchronization with an overall decrease in power, and a relative increase in low amplitude beta frequencies, do not adequately account for the dramatic subjective changes that psychedelics induce. It seems that there are salient changes that have gone undetected by EEG technology.

The first issue of varied EEG findings and anomalous cases is perplexing. Much of the clinical research with psychedelics emphasizes the lack of drug-specific effect. The clinical research reports large interindividual and intraindividual variability in emotional and other subjective responses to these substances (Grof 1980; Grof n.d.a; Anderson & Rawnsley 1954). Subjective experience is one of the most important factors that correlate with the electrical signals measured by the EEG. This has been shown in both the nonpsychedelic (Fischer 1978) and psychedelic literature (Shirahashi 1960; Bercel et al. 1956). As an illustration, if a group of subjects using a psychedelic substance reports high levels of excited emotions or anxiety, the EEG record will indicate an increase in desynchronized mixed frequencies. If another subject using the same substance finds the psychedelic event more relaxing, perhaps because of extended familiarity and knowledge of the substance, the EEG record of that subject will likely include more synchronized wave forms.

Pharmaco-EEG studies the effects of drugs on the EEG. From this perspective the EEG correlates of a psychedelic experience are considered to be a drug effect. Anomalous EEG findings would be viewed as a result of differing body chemistries that would manifest varying EEG correlates. Thus far, however, there have been no pharmacological traits that have correlated with the variety of EEG response to psychedelics.

Even if pharmacological traits did have predictive characteristics, the inherent problem with this approach is that it misses the point of the primary utility of psychedelic substances. Traditionally, the cultures most experienced at using psychedelics have used them for spiritual and psychotherapeutic benefit. Practitioners are not concerned with the connection between pharmacology and EEG output. The most important factor is whether this desirable state of consciousness has been entered. The phenomenology is the most crucial factor.

Since EEG recordings do correlate with subjective experience, QEEG research must control for the various subjective experiences as well as isolate the effects of pharmacological substances (pharmaco-EEG). The most likely factors that influence the subjective experience of psychedelics are set and setting variables. Many researchers, such as Leary, Metzner and Alpert (1964; also Metzner 1999) believed that psychedelic drugs themselves do not bring about specific subjective changes such as transcendent experiences. Instead the drugs act as chemical keys that open the mind and free the nervous system of its usual patterns and structures. They believed that the nature of the experience depends almost entirely on these set and setting variables. Set includes an individual's personality structure and mood when using the substance. Setting includes the environment in which the substance is being used, the relationships among the participants, and the cultural beliefs about the experience. Set and setting variables are demand characteristics that are not absent with other drugs, but particularly critical when working with psychedelics.

Establishing set and setting is by nature arbitrary and capricious. By doing research with those who are experienced at using these substances for spiritual and therapeutic purposes, achieving the desired state of consciousness is more likely. Then the research can study the physiological correlates of that therapeutically oriented state.

Within that generally agreed upon therapeutic state, there are a variety of discreet experiences that can be focused on, such as the experience of intense visual imagery. This further refinement is important because it is known that experiences of imagery, for example, even without the use of psychedelics, have very different EEG profiles than those with no imagery.

Subjective experiences could act as mediating variables between drug actions and physiological correlates. An important research objective would be to search for EEG correlates of specific phenomenology during psychedelic experiences instead of simply the time course of a drug effect (Grof n.d.a).

Because previous EEG research with psychedelics lacked QEEG analysis techniques and did not incorporate subjective experience, the field is not sufficiently mature for hypothesis testing. It must begin again with a process of systematic exploratory research.

RESEARCH AIMS

The current study conducted exploratory research concerning the EEG correlates of ayahuasca experiences in two individuals who are very experienced with its psychedelic use. There were two aims: (a) developing a methodological approach for correlating physiology with phenomenology and (b) generating hypotheses concerning the physiological correlates of ayahuasca experiences grounded in single subject research findings.

RESEARCH DESIGN

The data includes four ayahuasca sessions, two for each subject, with continuous phenomenological reports of the ayahuasca journey and the concurrent physiological

TABLE 1
Analyzed EEG Comparisons

Subject A, Day 1	Comparison 1. Ayahuasca to eyes-closed baseline
Subject B, Day 1	Comparison 2. Ayahuasca (I) to eyes-closed baseline
	Comparison 3. Ayahuasca (II) to eyes-closed baseline
Subject B, Day 2	Comparison 4. Ayahuasca to eyes-closed baseline

measures of EEG, EOG (electro ocleography), EKG (electrocardiogram), and the EMG. EEG data analysis was completed with data that was linked to targeted subjective reports.

The psychedelic research illustrates a wide range of subjective states that occur within and among different individuals having psychedelic experiences (Grof 1980; Grof n.d.a.; Brown 1968; Anderson & Rawnsley 1954; DeShon, Rinkel & Solomon 1952). However, the current study focused only on experiences of *medium to intense imagery* as the one category of subjective reports that would be subjected to QEEG analysis. This category is also referred to as the ayahuasca condition. This category was selected after the phenomenological data was gathered and organized to determine salient features. The imagery experiences were predominantly visual, but also incorporated some kinesthetic, tactile, and other synesthetic combinations.

Because the literature indicates the importance of the effects of music on psychedelic journey experiences, and because one emphasis of the current research was on creating a set and setting that was as naturalistic as possible, live music and prerecorded music that was selected by the subjects were part of the experimental sessions. Data gathered during periods of silence were used for the final analysis.

The EEG of each ayahuasca condition was compared to eyes-closed (EC) baselines. This choice relied upon the naturalistic observation that most traditions use ayahuasca in the dark with eyes closed. The study participants confirmed that this was also their practice. During the data acquisition procedures, it was agreed that the participants would generally experience the ayahuasca journey with their eyes closed. Preliminary analyses of both power and coherence also revealed that the ayahuasca conditions were more similar to the EC than to the eyes-open (EO) condition. Therefore, a conservative approach to describing the effect size is better served with the EC as the baseline comparison.

Both subjects each completed two session days. However, there is only one comparison for Subject A which was recorded on the first session day. There are two comparisons for Subject B day 1 and one comparison for Subject B day 2. This imbalance is due to lack of artifact free data. Field conditions made it such that much of the data was contaminated by a variety of artifacts including muscle and movement artifacts as well as the expected artifacts from speaking during the reporting of subjective experiences.Table 1 outlines the comparisons in which EEG analysis was completed.

RESEARCH PROCEDURES

The study was conducted in Brazil in July and August of 2000. Data were collected by D. Stuckey and F. Echenhofer over a period of nine days in four separate data recording sessions. Each recording session lasted approximately 10 hours. Some of these 10 hours were postsession sleep recordings that were not analyzed for this study. EEG hookups took place in one room and data acquisition was completed in the adjacent room. In the hookup room, a large plastic tube was connected to a large fan with one end positioned over the top of the subjects head. This ventilated the fumes of the colodian adhesive used to attach all scalp electrodes. Facial, chin, and chest electrodes were attached with cloth adhesive tape. The hookup procedure took between 1–1 1/2 hours to complete.

After hookup, the subject was then brought into the adjoining room where s/he was comfortably seated on a mattress with pillows and blankets. The electrode sets were plugged into the system and tested. The subject and researchers were equipped with microphones and earphones. All prerecorded music and researcher/subject communications could be heard through the earphones. Camera and audio adjustments were made and a presession interview was conducted. At that time, subjective reporting strategies were clarified between researchers and subject. An important consideration was the ways in which the participants would be able or willing to communicate during the journeying process. Each subject was asked to report recurring experiential components of the session that would be correlated with the physiological data. Knowing that speaking creates artifacts in the EEG data, subjects agreed to remain silent during various journey experiences followed immediately by a detailed verbal account of that experience.

TABLE 2
Frequency Bands

Standard Four Bands		Eleven Frequency Bands	
Frequency Band	**Range in cps or Hz**	**Frequency Band**	**Range in cps or Hz**
1. Delta	0.5–3.5	1. Delta	1–3.5
2. Theta	3.5–7	2. Theta	3.5–7.5
3. Alpha	7–13	3. Alpha 1	7.5–10.5
4. Beta	13–22	4. Alpha 2	10.5–13
		5. Beta 1	13–16
		6. Beta 2	16–20
		7. Beta 3	20–25
		8. Beta 4	25–30
		9. Gamma	36–44
		10. Total	1–44
		11. EMG	50–64

DATA ACQUISITION PROCEDURES

Recordings of the two subjects with EEG, EOG, EMG and EKG were completed for each session. Two-minute eyes-open and a two-minute eyes-closed baseline recordings were made before and after each session and were recorded at 256 samples per second. Data were recorded using a Neurosearch-24, manufactured by Lexicor Medical Technology, Inc. This system records 19 channels of EEG and four additional auxiliary channels that were used for horizontal EOG, vertical EOG, chin EMG and EKG. The 19 EEG electrodes were attached to the scalp with colodian following known anatomical landmarks using the 10-20 system (Jasper 1958) and referenced to physically linked earlobes. The amplifier gain was 32 k and data were digitized at 256 samples per second. High-pass and low-pass filters were set at 0.5 Hz and 128 Hz, respectively. Impedances at the contact points of the electrodes with the scalp were below 5 K ohm at every location. Scalp locations included Fp1, Fp2, F7, F8, T3, T4, T5, T6, O1, O2, F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4.

Following a standard sleep recording procedure (Rechtschaffen & Kales 1968), auxiliary channel 1 recorded EMG by means of two bipolar electrodes placed beneath the chin. Auxiliary channel 3 recorded horizontal eye movements using bipolar electrodes placements near the outer canthus of both eyes. Auxiliary channel 4 recorded vertical eye movements, also by means of two bipolar electrodes, one placed over the supra-orbit of the right eye and one placed beneath the lower lid of the right eye. The EMG and EOG auxiliary channels were grounded with an electrode attached over the right cheekbone. All EMG and EOG electrode impedances were below 10 K ohm. In addition, auxiliary channel 2 recorded EKG by means of two bipolar electrodes placed equidistant from the center of the chest approximately seven inches apart and grounded with another electrode placed on the chest. All EKG electrode impedances were below 3 K ohm.

The audio and video were temporally linked with the physiological recordings during all sessions. These were mixed and recorded onto VHS cassette tapes. The VHS recordings show the physiological data file name and *epoch* counter for accurate matching. An epoch is a data recording unit, which in our methodology equates to one second and includes 256 data samples per second (additional baselines were recorded at 128). Recording at 256 samples per second was chosen because it allowed for the observation of the faster frequencies that we were interested in, such as the 36–44 Hz frequency band. This band allowed for a comparison with Don and colleagues' (1998) findings with ayahuasca at around 40 Hz, which was not done by the two other EEG ayahuasca studies (Hoffmann et al. 2001; Riba et al. 2002). The data files were stored on 100 MB removable disk drives and subsequently burned onto CDs.

EEG POWER ANALYSIS

The process of identifying usable physiological recordings with video and audio recordings of subjective reports becomes a time consuming and complex endeavor. It includes tracking artifact-free periods of no talking or music with associated phenomenological reports.

The raw EEG, EOG, EMG, and EKG signals were acquired and visually scored initially using Lexicor's Neurosearch 70e (Lexicor Medical Technology 1992) software. Epochs that contained eye movements, muscle tension, or other sources of artifact were manually deleted. When artifacts occurred in one or more channels of any epoch, data from all channels during that epoch were deleted. Magnitude (the square root of power) in microvolt units was calculated using Fast Fourier Transforms (FFT) in the Lexicor software.

Two additional EEG software packages were used for further editing and analysis. Nova Tech EEG's NTE Pack 2004 (Nova Tech) was used offline for bandpass filtering

from 1–64 Hz and manual edited (Congedo 2002). It was also used for analysis of selected frequency bands that replicated the work of Riba and colleagues (2002) and Don and colleagues (1998). Grey Matter Inc.'s Neurorep (Hudspeth 1999) was used to perform 1–30 Hz spectral analysis, single Hz frequency band analysis from 1–30 Hz, and power analysis using the more standard four bands. The spectral analysis shows gradient levels of magnitude across the domain of 1–30 Hz. Standard four band analysis shows the summation of power across the cortex for each of these four finite frequency bands.

Data were analyzed for the eyes-closed baselines, eyes-open baselines, and the no music ayahuasca conditions. Power/magnitude analyses were completed for all 19 EEG electrode sites. Comparisons included standard four frequency bands ranging from .5–22 Hz, single Hz power analysis for 1–30 Hz, and power analysis of 11 uniquely designed frequency bands ranging from 1–64 Hz. Table 2 shows range values for the standard four frequency bands and the 11 unique frequency bands.

EEG COHERENCE ANALYSIS

In addition, preliminary visual analysis of this data has indicated that synchronous wave forms may be an important component of the changes that occur during psychedelic experiences. These changes could be detected using coherence analysis. With the exception of Abraham and Duffy's (1996) work with HPPD, which will be defined and described shortly, coherence measures have not previously been used in psychedelic drug research. Therefore, a rationale for their use is important and will now be discussed before summarizing the analysis strategies.

Coherence is a measure of synchronous EEG activity occurring at different scalp locations. It seeks to measure communication between brain regions by observing the power in specific frequency bands that rise and fall together at different locations (Hallett 2000). The unit of measure is percent of variance shared between two sites.

The current study is interested in imagery and perception. The occurrence of synesthesia in psychedelic experiences raises the issue of perceptual binding in different brain regions. Mima and colleagues (1999) showed that EEG coherence may correlate with perceptual binding.

Two recent studies have suggested a relationship of coherence to the hallucinatory phenomenon. The first concerns the theory that LSD use in certain individuals may result in chronic visual hallucinations. The DSM-IV categorizes this syndrome as hallucinogen persisting perception disorder (HPPD). Abraham and Duffy (1996) studied 44 LSD-induced HPPD subjects (ages 16.6 to 47.4 yrs) and 88 matched controls. The HPPD subjects showed alpha acceleration and shortened flash visual evoked response latency, suggesting LSD-induced cortical disinhibition that mostly involved temporal and left parietal scalp regions, confirmed by a split-half analysis. The click auditory evoked response also showed latency change but in the opposite direction with slightly prolonged latencies. They speculated that LSD acts via partial chronic disinhibition of the visual nervous system. These same researchers completed a second study (2001) in which they compared 38 HPPD subjects (mean of 9.7 years of persistent visual hallucinations) to 33 control subjects. They found increased occipital coherence and hypersynchrony over many frequencies, particularly in the eyes-closed condition. Their findings suggest that occipital disinhibition in HPPD subjects, coupled with a relative isolation of the visual cortex, facilitates hallucinations and illusions.

TABLE 3
Analysis Procedures

A. Power analysis of four standard frequency bands from 1–22 Hz
B. Power analysis of single Hz band analysis for 1–30 Hz
C. Power analysis of 11 uniquely configured bands
D. Coherence analysis of 11 uniquely configured bands

The Abraham and Duffy research sheds light on the possible connection of coherence with hallucinatory/imagery phenomena as well as giving strategic guidance in coherence analysis and discriminative analysis procedures. Therefore, the degree of coherence becomes an important question in a study of ayahuasca experience, with its associated intense imagery. It is a question that was unanswerable in earlier studies and simply not explored in the more recent work with ayahuasca. It became one of the current studies' most important analysis procedures. Coherence analysis was completed for all 171 electrode combinations in the 11 uniquely selected frequency bands.

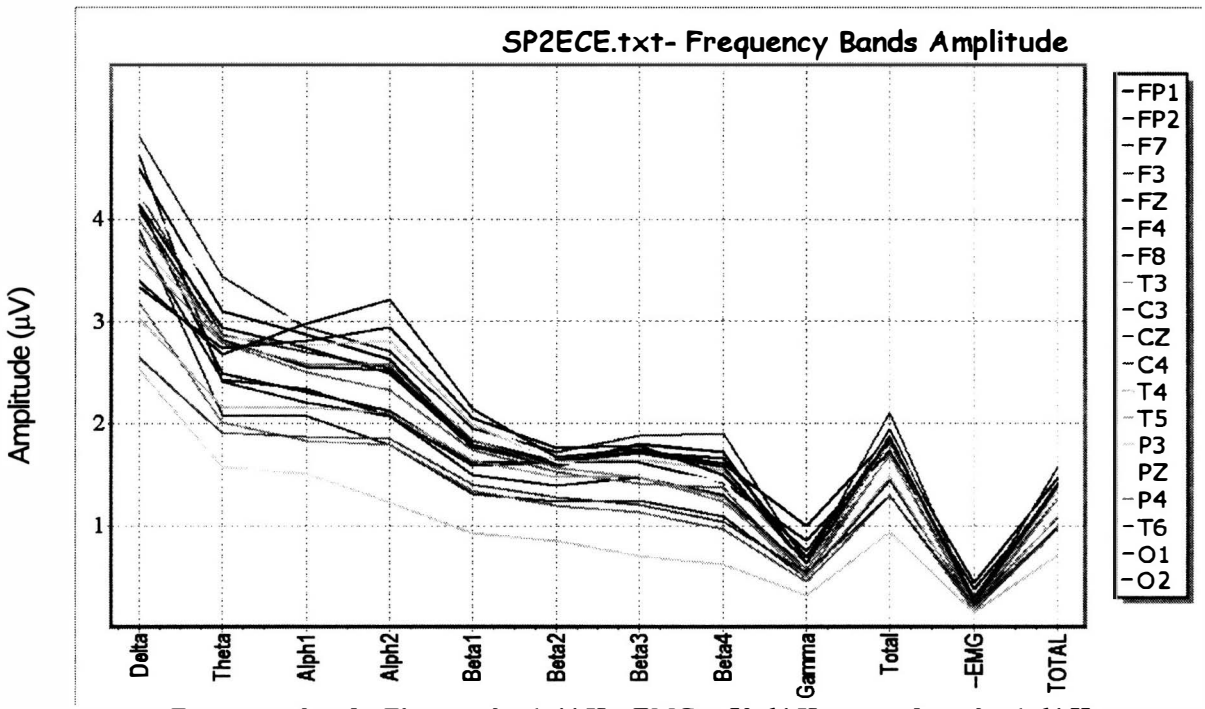
In the Research Aims section, Table 1 showed the basic 4 EEG comparisons that were analyzed. Table 3 outlines the four EEG analysis procedures that all four comparisons underwent.

RESULTS

The EEG power results for the EC to ayahuasca comparisons indicate that theta power decreased overall by approximately 28% for all four comparisons. Alpha 2 showed a 33% overall decrease in power for only one of the four comparisons at P3, P4, O1, and O2, beta 1 showed a 22% average decrease in all four comparisons, and beta 2 showed a 22% average decrease for all four comparisons. The alpha 1, beta 3, beta 4, gamma, and EMG bands showed

FIGURE 2

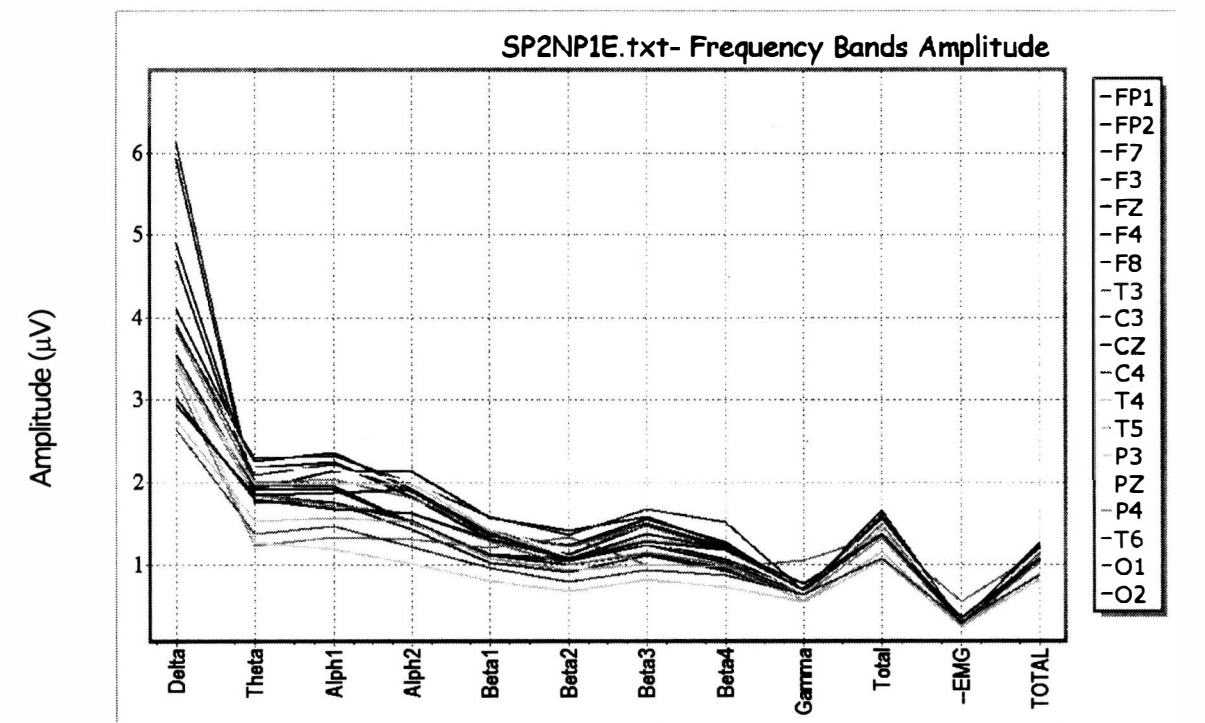
Comparison 4 (Subject B, Day 2)—Eyes-Closed—Eleven-Band Amplitude Ribbon Chart



Frequency bands. First total = 1-44 Hz, EMG = 50-64 Hz, second total = 1-64 Hz

FIGURE 3

Comparison 4 (Subject B, Day 2)—Ayahuasca—Eleven-Band Amplitude Ribbon Chart



Frequency bands. First total = 1-44 Hz, EMG = 50-64 Hz, second total = 1-64 Hz

FIGURE 4

Comparison 2 (Subject B, Day 1, Example I)—Eyes-Closed—Single Hz (1–30) Magnitude Topographic Maps

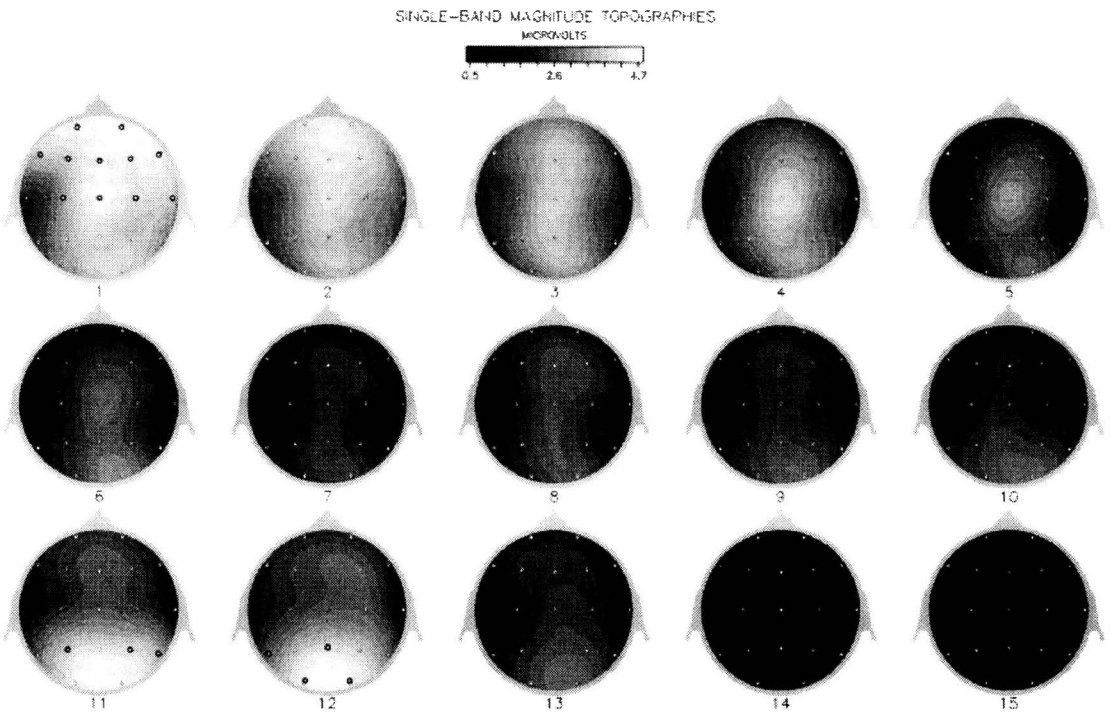


FIGURE 5

Comparison 2 (Subject B, Day 1, Example I)—Ayahuasca—Single Hz (1–30) Magnitude Topographic Maps

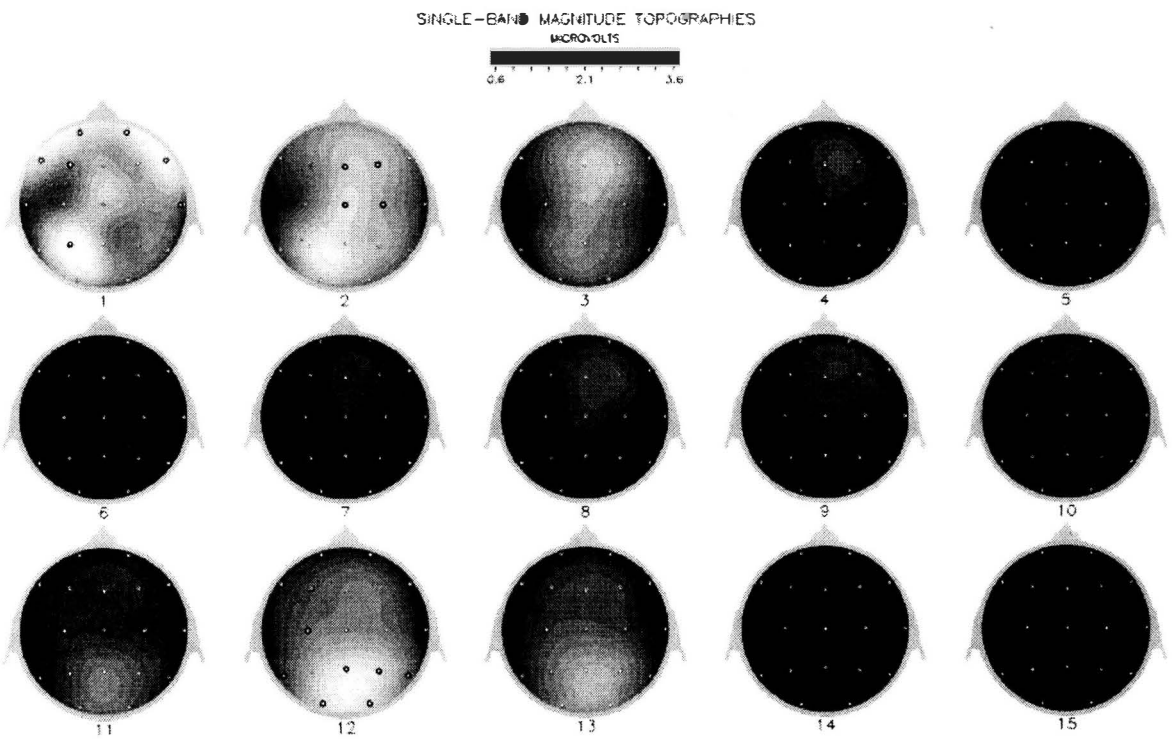
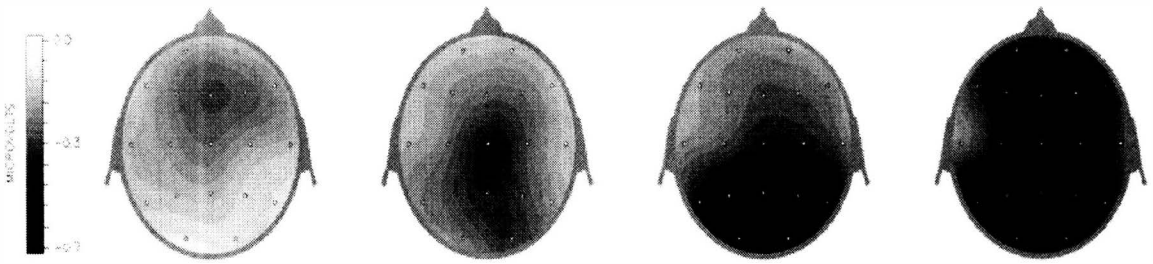


FIGURE 6

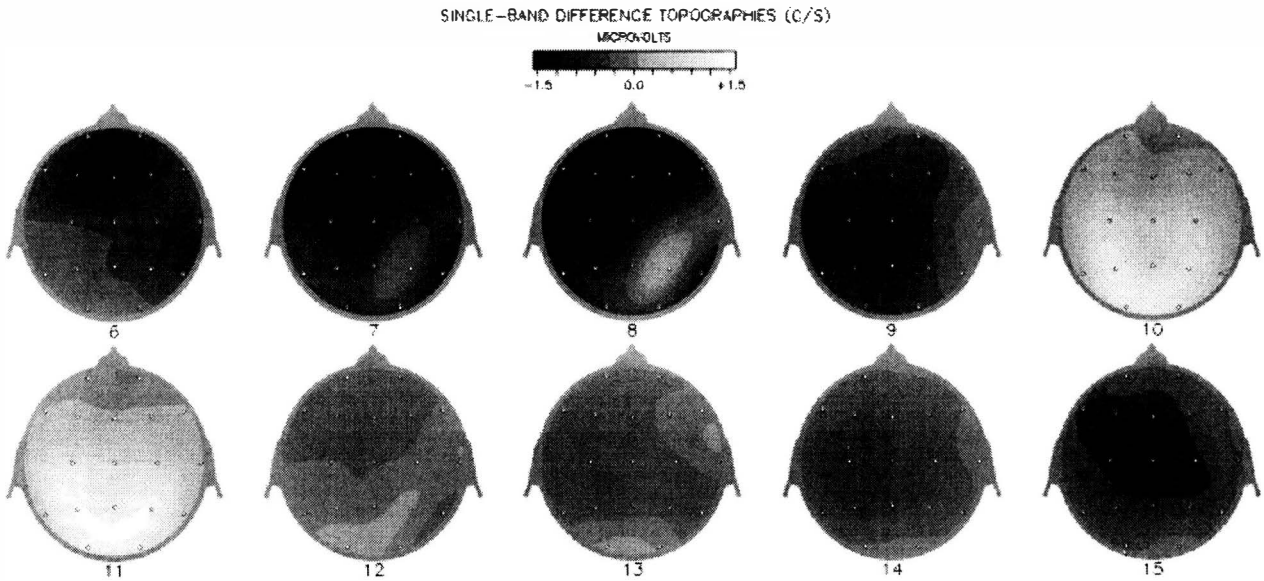
Comparison 3 (Subject B, Day 1, Example II)—Eyes-Closed to Ayahuasca—Standard Four-Band Amplitude Topographic Maps



Delta (0.5–3.5) Theta (3.5–7 Hz) Alpha (7–13 Hz) Beta (13–22 Hz)

FIGURE 7

Comparison 1 (Subject A, Day 1)—Eyes-Closed to Ayahuasca—Single Hz (1-30) Magnitude Topographic Maps



no changes in power. There was an global decrease of about 15% in total absolute power for 1–44 Hz in the ayahuasca condition for both subjects. There are no figures showing averaged summations of all four comparisons. Figure 2 is an example ribbon chart of Subject B day 2 eyes-closed baseline showing each of the 19 electrodes using a different gray-scaled line. The original figure was designed with a different colored line identifying each of 19 electrode sites. The current limitation of gray scale can only illustrate the general trend of electrical power for all the electrode sites. The y-axis includes the 11 bands that were selected for this study and an additional 1-64 Hz total, which was automatically generated by the Nova Tech software. The x-axis shows the amplitude values for each band. Figure 3 shows the ayahuasca condition for Subject B day 2.

A comparison of the EC and ayahuasca conditions using single Hz analyses showed that in both subjects, modal alpha frequency increased by about 1 Hz in the ayahuasca condition. Figure 4 shows an example of the EC condition for Subject B day 1, example I. The figure shows 15 topographic maps, with the corresponding frequency listed below each map. The perspective is looking down at the top of the head with the nose at the top of the maps and the ears to the left and right. In Figure 4, modal alpha frequency is predominantly at 11 and 12 Hz in the posterior region of the scalp, which can be seen as circular patterns at the bottom of the 11 and 12 Hz maps. Figure 5 shows the corresponding ayahuasca condition, in which the modal alpha frequency has shifted from 11 and 12 Hz to some power at 11 Hz, but mostly at 12 and 13 Hz.

Power analysis showed that the most prominent changes in the ayahuasca condition occurred over the occipital lobe. Using the standard four EEG bands for analysis, both subjects showed a major reduction in alpha (7–13 Hz) power, focused squarely over the occipital region. Figure 6 shows a sample of this change using a

TABLE 4

Comparison 2 (Subject B Day 1, Example 1)—Compare Eyes-Closed to Ayahuasca—Gamma Band Absolute Coherence Differences

	F1	F2	F7	F3	FZ	F4	F8	T3	C3	CZ	C4	T4	T5	P3	PZ	P4	T6	O1
F1																		
F2	0.4517																	
F7	0.3078	0.3747																
F3	0.4050	0.4283	0.2428															
FZ	0.4149	0.3886	0.2388	0.1689														
F4	0.5425	0.4812	0.4066	0.4107	0.2831													
F8	0.2640	0.1517	0.2680	0.2792	0.2093	0.4053												
T3	0.4548	0.4187	0.2326	0.3393	0.3309	0.4291	0.3072											
C3	0.4532	0.4286	0.2363	0.2691	0.2579	0.4042	0.3080	0.0798										
CZ	0.5202	0.4632	0.4267	0.4121	0.3018	0.4584	0.3456	0.3942	0.3032									
C4	0.4932	0.4368	0.4328	0.4212	0.3317	0.4082	0.3088	0.4214	0.3827	0.2359								
T4	0.5542	0.4985	0.4998	0.5254	0.5074	0.5675	0.3246	0.5163	0.4899	0.5027	0.4777							
T5	0.4556	0.3983	0.4641	0.4847	0.4497	0.4349	0.3223	0.3741	0.3777	0.4428	0.4164	0.4892						
P3	0.4746	0.4163	0.4551	0.4942	0.4589	0.4723	0.3362	0.3554	0.3302	0.3764	0.3815	0.4908	0.1888					
PZ	0.4806	0.4278	0.4565	0.4777	0.4375	0.4843	0.3485	0.4190	0.3633	0.2823	0.2931	0.4939	0.3572	0.1448				
P4	0.4862	0.4401	0.4654	0.4874	0.4619	0.5016	0.3753	0.4660	0.4246	0.3746	0.2594	0.5041	0.3956	0.3006	0.1669			
T6	0.4547	0.4294	0.4269	0.4467	0.4499	0.4814	0.3888	0.4407	0.4074	0.4373	0.4037	0.5641	0.3745	0.3597	0.3349	0.1351		
O1	0.3812	0.3328	0.3762	0.4060	0.3795	0.3707	0.2659	0.3884	0.3481	0.3808	0.3247	0.4234	0.1976	0.1525	0.2364	0.2392	0.2300	
O2	0.4147	0.3736	0.4024	0.4271	0.4152	0.4230	0.3223	0.4267	0.3913	0.4249	0.3690	0.4740	0.3557	0.3075	0.2898	0.1276	0.0511	0.1852

Max = 0.5675 Average = 0.3807 Trimmed Max = 0.2750

Min = 0.0511 Median = 0.4050 Trimmed Min = -0.2750

TABLE 5

Comparison 4 (Subject B Day 2)—Compare Eyes-Closed to Ayahuasca—50–64 Hz Band Absolute Coherence Differences

	F1	F2	F7	F3	FZ	F4	F8	T3	C3	CZ	C4	T4	T5	P3	PZ	P4	T6	O1
F1																		
F2	0.5864																	
F7	0.4608	0.2769																
F3	0.6347	0.4838	0.2203															
FZ	0.6411	0.4759	0.2144	0.2256														
F4	0.6971	0.5622	0.3854	0.4881	0.4216													
F8	0.5585	0.3786	0.2608	0.4363	0.4122	0.6308												
T3	-0.0095	-0.0491	-0.4063	-0.2100	-0.2031	-0.0499	-0.0746											
C3	0.5397	0.3989	0.2250	0.2723	0.2678	0.4711	0.3945	-0.2831										
CZ	0.5838	0.4607	0.3119	0.3686	0.2753	0.4664	0.4823	-0.1794	0.2752									
C4	0.5959	0.4807	0.3221	0.4314	0.3278	0.4303	0.5157	-0.1203	0.3601	0.2230								
T4	0.5880	0.4625	0.3356	0.4711	0.4387	0.5580	0.3799	-0.0766	0.3912	0.4133	0.3437							
T5	0.3916	0.2823	0.1960	0.3239	0.3339	0.3821	0.2969	-0.3926	0.2781	0.3098	0.3392	0.2866						
P3	0.5159	0.3841	0.3069	0.4456	0.4450	0.5118	0.4396	-0.2695	0.3343	0.3479	0.3860	0.4131	0.1267					
PZ	0.5247	0.4070	0.3440	0.5225	0.5594	0.5726	0.5081	-0.1004	0.4824	0.4801	0.4460	0.4806	0.3031	0.2808				
P4	0.5229	0.4098	0.3676	0.4973	0.4766	0.5188	0.5036	-0.0570	0.4285	0.3600	0.2834	0.4148	0.2827	0.2591	0.3383			
T6	0.4211	0.3377	0.3043	0.4095	0.4045	0.4422	0.4261	-0.0496	0.3679	0.3768	0.3383	0.3544	0.1933	0.2886	0.4029	0.1739		
O1	0.4854	0.3622	0.3291	0.4860	0.5143	0.5446	0.4578	-0.1474	0.4454	0.4799	0.5059	0.5131	0.0751	0.1910	0.3106	0.3882	0.3629	
O2	0.3355	0.2494	0.2597	0.3449	0.3460	0.3749	0.3223	-0.0482	0.3303	0.3389	0.3201	0.3502	0.1605	0.2231	0.3382	0.1388	0.1226	0.2208

Max=0.6971 Average = 0.3317 Trimmed Max = 0.2750

Min=-0.4063 Median = 0.3676 Trimmed Min = -0.2750

difference map from Subject B day 1, sample II. The most prominent change can be seen by the darker circular pattern at the bottom portion of the alpha map, which represents a reduction in power in the ayahuasca condition. However, closer inspection using single Hz analysis revealed that in Subject A's case, there was actually a major increase in power at 10 and 11 Hz, which could not be seen when using the 7–13 Hz alpha band for analysis. Figure 7 illustrates this increase. The increase can be seen in the lighter shaded areas at the bottom portion of the 10 and 11 Hz maps, which appear "U" shaped.

The coherence analysis was illustrated using a series of triangular matrices showing difference values for the 171 relationships among 19 EEG channel combinations. Coherence is measured as the percentage of activity that is shared between two sites. Table 4 shows an example of a coherence matrix for comparison 2 (Subject B day 1, example 1) for the 36-44 Hz band. The values in each cell represent the ayahuasca condition minus the EC baseline. To better illustrate coherence differences, values of +0.275 or greater are printed in bold. These values indicate that for a given pair of electrodes, the amount of shared activity between them increased at least 27.5% for the ayahuasca condition compared to EC baseline. The selection of ±0.275 was an arbitrary value chosen as the best way to visually characterize the data. Table 5 is an example of comparison 4 (Subject B day 2) for the 50-64 Hz band. Even though this example shows extremely high increases in coherence in the ayahuasca condition, there is an equally dramatic reduction in coherence in several electrode pairings with T3, which is where there was known EMG activity in the ayahuasca condition. Negative values indicate decreased coherence in the ayahuasca condition. Values showing -0.275 or less are printed in bold and underlined.

The coherence analyses for the EC to ayahuasca comparisons show that coherence increased in the fast frequency bands, particularly the 36–44 and 50–64 Hz bands for both subjects. For comparison 1 (Subject A day 1), increases were most prominent in the 25–30 Hz, 36-44 Hz, and the 50–64 Hz bands. For comparisons 2 and 3 (Subject B day 1, samples I and II respectively), the prominent increases were in the 36-44 Hz, and 50–64 Hz bands. For comparison 4 (Subject B day 2), the prominent increases were again in the 36-44 Hz, and 50–64 Hz bands. As shown in Table 5, channels in which there were suspicions of muscle tension artifact showed less coherence.

Table 6 summarizes the four comparisons of ayahuasca to EC conditions for power and coherence analyses in 10 of the 11 selected frequency bands (excluding delta).

DISCUSSION OF POWER ANALYSIS

The visual cortex in the occipital lobe is primarily involved with visual perception and mental imagery. Several studies have reported that visual imagery attenuates alpha activity in this cortical region (Kaufman et al. 1990; Williamson & Kaufman 1989; Gale et al. 1972; Slatter 1960; Costello & McGregor 1957; Short 1953). Marks and Isaac (1995) showed that vivid imagers show alpha attenuation in the occipital cortex during visual imagery, but show alpha enhancement during kinesthetic imagery. Concerning these findings and previous reports that psychedelic experiences produce the most prominent changes over the occipital lobe, the current data concurs, but with a caveat. Only single Hz analysis could show that in Subject A's case, there was actually a major increase in power at 10 and 11 Hz, which could not be seen when using the 7–13 Hz alpha band for analysis. This finding confirms the belief that classical wide band analysis often clouds important EEG changes. In addition, the current study found that modal alpha frequency increased by about 1 Hz during the ayahuasca condition in both subjects. This agrees with the previous reports in the psychedelic literature that showed small increases in modal alpha frequencies.

The current study also found a global decrease in absolute power, with specific reductions in average power in the theta, beta 1, and beta 2 bands for the ayahuasca condition, which validates findings of Riba and colleagues (2002). The current findings included absolute power changes, but did not conduct relative power analysis. Therefore, these results cannot confirm or disconfirm earlier findings of relative increases or decreases in spectral power.

The current research cannot confirm Don and colleagues' (1998) finding of increased power in the gamma band. In fact, all four comparisons, one with Subject A and the other three with Subject B, all show a decrease in gamma power.

It is important to explore the results of the current study in light of the literature regarding EEG power spectra's relationship to behavioral efficiency, information processing, arousal, and subjective experience. Increased arousal is associated with EEG desynchronization (Fischer 1978). Strong, excited emotions produce desynchronized mixed frequencies with low to moderate amplitude or decrease in power. This EEG desynchronization occurs when beta frequencies are the predominant frequencies in the EEG. The literature suggests that the brain regions showing these frequencies are actively involved in information processing. There is not a clear consensus regarding the differences in the functional significance of the lower, middle, or highest beta and the gamma frequencies.

The current results showed that in the ayahuasca condition, theta power decreased by an average of 28%, and beta 1 and beta 2 power both decreased by an average of 22% for all four comparisons. Overall power also decreased in the ayahuasca condition. This might suggest a widespread increase in cortical activation, arousal, and an increase in widespread information processing. Very high levels of information processing might be expected by the

TABLE 6
Summary of Four Comparisons of Eyes-Closed to Ayahuasca

Frequency Band	Power Decrease EC to Ayahuasca Comparisons 1-4	Power Increase EC to Ayahuasca Comparisons 1-4	Coherence Decrease EC to Ayahuasca Comparisons 1-4	Coherence Increase EC to Ayahuasca Comparisons 1-4
Theta 3.5–7.5 Hz	1: 20% at FZ 2: 33% overall 3: 33% overall 4: 26% overall 28% overall decrease t	No increase for EC to ayahuasca for either subject 4: 0	1: 0 2: 0 3: 0t 4: 0	1: 0 2: 0 3: 0
Alpha 1 7.5–10.5 Hz	Not discussed	Not discussed	1: 0 2: 0 3: 0 4: 0	1: C4-T6 2: 0 3: C3-P3 4: 0
Alpha 2 10.5–13 Hz	Not discussed	Not discussed	1: 0 2: 0 3: 0 4: 0	1: 0 2: 0 3: 0 4: F4-P4,CZ-P4,C4-P4
Beta 1 13–16 Hz	1: 8–10% overall 2: 25% overall except PZ 3: 25% overall 4: 29% at CZ 22% overall decrease	No increase for EC to ayahuasca for either subject	1: 0 2: 0 3: 0 4: 0	1: C4-T6 2: 0 3: 0 4: CZ & C4-P4
Beta 2 16–20 Hz	1: 10–12% overall 2: 20% overall 3: 33% overall 4: 25% overall 22% overall decrease	No increase for EC to ayahuasca for either subject	1: 0 2: 0 3: F2-F4 4: 0	1: 0 2: 0 3: 0 4: 0
Beta 3 20–25 Hz	Not discussed	Not discussed	1: 0 2: 0 3: F2-F4 4: 0	1: 0 2: 0 3: 0 4: F1-all frontal &C4, F2-F4, CZ-P4
Beta 4 25–30 Hz	Not discussed	Not discussed	1: 0 2: 0 3: 0 4: 0	1: F3-F8, FZ-F8, F8-CZ, F8-C4, T6-O2 2: T3-F1, T3-F2, T3-FZ, T3-F4, T3-F8, T3-C4, T3-T4, 3:0 4: F1-F2 & F7, CZ & C4-P4
Gamma 36–44 Hz	No change for the comparisons from EC to ayahuasca for either subject	No increase for EC to ayahuasca for either subject	1: 0 2: 0 3: 0 4: 0	1: F7-F8, F7-C4, F3-F8, F3-C4, FZ-F8, F8-C4, C3-C4, C4-T6 *2: Most channels* 3: FP1-FZ, F7-T5, F3-T5, F3-P3, CZ-T5 *4: Most channels except all T3 & T5*
Total 1–44 Hz	1: 7–8% overall 2: 15% overall 3: 15% overall 4: 23% overall 15% overall decrease	1: 0 2: 0 3: 0 4: 0	1: 0 2: 0 3: 0 4: 0	1: 0 2: 0 3: 0 4: 0
EMG 50–64 Hz	1: artifact in EC at T4 2: 3: 4: artifact in EC at FP1, FP2, O1, O2. No overall change in power.	1: Artifact in ayahuasca at T3 2: General increase 3: Right hemisphere 4: Artifact in ayahuasca at T3, O1, O2	1: 0 2: 17 remaining 3: 0 4: 0	1: F7-F8, F7-C4, F3-C4, FZ-F8, F8-C4, C3-C4, C4-T6 *2: Most channels* 3: F1-with 8 sites, T5 & P3 with many sites, C4-O1, T6-O1 *4: Most channels except all T3 & T5 connects*

intensity of subjective experiences during the ayahuasca journey.

Even after both the EC and ayahuasca EEG conditions were artifacted for EMG, the chin EMG power in the ayahuasca condition showed slight increases compared to EC for some of the comparisons. It is possible that some of the power in the EEG frequency bands was being influenced by this *noise*. This is not surprising given the subjective intensity of the ayahuasca experience and the tendency for subjects to react using their muscles during these experiences.

DISCUSSION OF COHERENCE ANALYSIS

Prior to a discussion of the EEG coherence results, it may be helpful to very briefly summarize one possible view of the functional significance of changes in coherence across the frequency spectrum from 1–64 Hz. In this view, the general assumptions about the functional significance of coherence are that (a) increasing coherence can be viewed as an index of stronger electrical linkages among the distributed cortical regions that are involved in increased cortical information processing, while (b) decreased coherence can be viewed as a decrease in such electrical linkages of distributed regions that are involved in the cortical information processing. These circuits of coherent energy across the cortex are proposed to support both the maintenance of specific mental states or information processing modalities and the specific information processing that takes place during the operation of such mental states (Siegel 2001). This view might account for the high coherence values observed in the ayahuasca condition. These values may suggest that compared to EC, the ayahuasca condition is comprised of different kinds of information processing specific to either the ayahuasca experience or psychedelic experiences in general.

Tables 4 and 5 show the changes in EEG coherence values for the EC to ayahuasca condition for all the combinations of 19 EEG recording locations for Subject B on day 2 in the 36–44 Hz (gamma) and the 50–64 Hz bands respectively. The unusually high EEG coherence values, which reflect extremely high levels of widespread cortical information processing is extraordinary. Such high levels of information processing and such widely distributed cortical coherence might be expected given the extremely vivid and intense ayahuasca experiences such as intense synesthesia across many sensory modalities.

Most of the increased coherence between various EEG electrode sites in the ayahuasca condition occurred in both the 36–44 Hz and 50–64 Hz bands. Originally, the 50–64 Hz band was designed to be an additional method of detecting EMG activity when doing power analysis. When analyzing power, what is problematic about any investigation of the beta and gamma frequencies is that EMG activity from scalp, neck, jaw, or facial muscle sources can easily be recorded at any scalp electrode site, at least in small amounts. This EMG is then recorded along with EEG activity. Since these EMG and EEG frequencies can be identical in frequency, it has long been difficult to determine if beta or gamma frequencies have been contaminated by EMG sources of energy. Sometimes studying the raw waveforms alone can be the only way to separate the signals of these different sources. This confounding of EEG data with EMG may be one reason that there is relatively less research in the higher EEG beta and gamma frequencies. In addition to studying the raw wave forms to isolate EMG artifact, it was felt that if the power in the 50–64 Hz frequency band mirrored the power findings in the other beta frequency bands, that this information might aid in the detection of muscle artifact, since power in the 50–64 Hz band might more likely be muscle. As it turned out, it was also in this frequency band that dramatic coherence increases were found. In order to help with the interpretation of these findings, an expert in EEG and EEG artifacting was consulted (J. Gunkelman, personal communication, April 29, 2004). Based upon the information provided during this consultation, it is most probable that the high level of coherence in these fast frequency bands do not primarily reflect EMG activity but rather higher frequency EEG activity. The reason for this view is that EMG activity is a waveform of very low coherence.

The 50–64 Hz power analysis still seems to provide an index of EMG artifact in that it reflects the distribution of power that was seen in the previous results reported for power, often at the T3 and T4 locations. These locations are characteristically susceptible to EMG artifacts because they are just over the temporalis muscles.

It is ironic that the 50-64 Hz frequency band, which was designed to detect EMG artifact, has instead detected one of the more interesting findings: very fast frequency global coherence. Further evidence that the finding is not EMG activity is that the only major pairings within the 171 coherence relationships that do not show a high level of coherence are the pairings with T3, a location where there was known muscle tension artifact.

These 36–44 Hz and 50–64 Hz findings of increased coherence in ayahuasca compared to EC baselines are of a surprisingly high magnitude. These results have not previously been reported, either in the EEG ayahuasca research or in the EEG psychedelic research. Furthermore, there is no prior psychedelic EEG research to aid in the interpretation of these results. However, Lutz and colleagues (2004) recently found that advanced meditators have more coherent gamma activity than controls during resting baseline. These advanced meditators also exhibit greater increases in gamma coherence during meditation than do control subjects during meditation. It appears that for both shamanic psychedelic experiences and meditation, gamma coherence is a variable that warrants further study.

LIMITATIONS OF THE STUDY

The original plan for this research was to categorize by subjective report the EEG data during the ayahuasca condition. Hence, examples of various subjective states of consciousness, such as intense visual and kinesthetic imagery could be related to EEG. Also, music and no music conditions were recorded. Comparisons of this data were intended to determine differences in a variety of subjective states and experiences during the ayahuasca experience. However, because of the environmental conditions, there was not enough artifact-free data for this type of extensive comparison.

Because of the lack of clean data, the analyzed EEG data is not as precisely linked to specific subjective reports as was intended. It was required that data accompanying several diverse reports be analyzed together in a category that roughly represented a medium-intense psychedelic experience during the ayahuasca condition.

Another limitation was that the quantities of ayahuasca and times of drinking were not strictly scheduled. The intention was to emphasize the ayahuasca experience and not quantities of psychoactive substances. However, a lack of dose scheduling made it difficult to predict peak drug effect and to compare findings with those of Riba and colleagues (2002) and others.

Because the present study used the single subject design approach, in which the ayahuasca EEG data for each of the two research participants was examined for changes compared to their own eyes-closed condition, no attempt will be made to suggest that the results of this study can be generalized to other individuals.

RECOMMENDATIONS FOR FUTURE RESEARCH

The EEG psychedelic literature reviewed reveals a range of sometimes divergent findings. Some studies showed that among subjects using the same psychedelic substance, those whose subjective experiences deviate the most from the norm also have the most distinct alterations in their EEGs. One hypothesis concerning those findings is that the EEG changes during psychedelic experiences are more related to the phenomenology of a psychedelic experience than to their pharmacological effects. This hypothesis is extremely difficult to test empirically since biological and psychological effects are so entwined. Nevertheless, this view can be used to speculate about the meaning of individual EEG differences observed between and within subjects. The current study found several of the same EEG correlates to the ayahuasca journey condition that were common for both subjects and within the same subject on separate session days. This does not lend support to the above hypothesis. After reflecting on the data, a suggested variant of the above hypothesis would be that EEG correlates might have both a biological underpinning and one that is more tied to personality structure or mood. This hypothesis could be tested by returning to a method first attempted by Bercel and colleagues (1956) in which the recording periods selected for analysis were those in which the subject was lying motionless in a darkened room and not reporting any hallucinations or delusions in particular. As noted earlier, they believed that this condition was most representative of background EEG activity present during maximal drug effect. Current technology can better examine whether some EEG correlates vary with mood and experiential effects, while others remain consistent throughout periods of changing phenomenology. For example, it might be that EEG power correlates more with phenomenology and coherence is more representative of background EEG caused by the ayahuasca brew.

The discovery of such a strong hyper-coherent EEG gamma activity relationship to the ayahuasca experience should be extended to examine the relationships between specific kinds of ayahuasca experiences and the distribution of cortical coherence patterns. This might lead to more understanding of the relationships between specific exceptional experiences and the degree of information processing in different cortical regions. This approach for relating specific experiences to gamma coherence distribution patterns could also be used to explore experience and brain relationships in other psychedelic and nonpsychedelic exceptional states.

A final suggestion for future research is to continue to modify and refine exploratory methods for recording in naturalistic environments. For example, it would be of benefit to incorporate Riba and colleagues' (2002) method of gathering data every 15 minutes throughout the journey experience. During a two or three minute recording period, if music is being used during the session, one could agree to discontinue the music and agree to maintain a relaxed, consistent posture with eyes closed. For participants, these modifications might be experienced as only a minimal distraction from the psychedelic journey experience, and their incorporation might even turn out to be unexpected enhancements. A good example of this emerged during the current study when participants were asked to continually report their subjective experiences, even though it was not their customary practice. Both subjects were pleasantly surprised to find that verbalizing these nonordinary states of consciousness while journeying seemed to solidify their own memories of their experience, allowing better integration into ordinary states of consciousness.

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