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Journal of Psychoactive Drugs
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujpd20

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Published online: 07 Sep 2011.

To cite this article: Ede Frecska , Keith D. White & Luis E. Luna (2003) Effects of the Amazonian Psychoactive Beverage Ayahuasca on Binocular Rivalry: Interhemispheric Switching or Interhemispheric Fusion?, Journal of Psychoactive Drugs, 35:3, 367-374, DOI: 10.1080/02791072.2003.10400019

To link to this article: http://dx.doi.org/10.1080/02791072.2003.10400019

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Effects of the Amazonian Psychoactive Beverage *Ayahuasca* on Binocular Rivalry: Interhemispheric Switching or Interhemispheric Fusion?†

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Abstract—An early theoretical analysis supposed changes in hemispheric integration as the basis of altered state of consciousness induced by psychoactive drugs. Brain imaging studies revealed right cortical activation after administration of hallucinogens. Recent studies on binocular rivalry suggest that interhemispheric switching is the neural substrate of the perceptual oscillations observed during dichoptic stimulus presentation. The current study tested perceptual alternation in ceremonial participants, who ingested the South American hallucinogenic beverage *ayahuasca*, to examine the claim that there might be changes in interhemispheric function under the influence of hallucinogens. Ingestion of *ayahuasca* resulted in a decrease of rivalry alternation rates, increased length of one percept and there was evidence of phenomenal fusion. The findings are in line with results of brain activation studies and support the concept of interhemispheric fusion in altered states of consciousness.

Keywords—altered state of consciousness, *ayahuasca*, binocular rivalry, hallucinogens, lateralization, visual awareness

Binocular rivalry belongs to a class of visual illusions in which an ambiguous but unchanging sensory input leads to sudden perceptual switches (Blake 2001). Rivalry phenomena occur when dissimilar images stimulate corresponding retinal areas of the two eyes. During rivalry, the image present in one eye disappears from awareness (i.e., is suppressed), while the other eye's image is seen (i.e., is dominant). Phases of suppression and dominance alternate between images: first, one eye's view is suppressed and the other's is dominant; a moment later, the second eye's view is suppressed and the first eye's view dominates. With prolonged viewing, such reversals can continue indefinitely in a quasi-regular manner, usually alternating every few seconds (Wade 1998). This visual competition has a resemblance to spontaneous alternation of reversible figures and ambiguous pictures (e.g. Necker cube, Rubin's vase, or Salvador Dali's *Slave Market and the Disappearing Bust of Voltaire*).

Several theories have been proposed to account for binocular rivalry (Blake & Logothetis 2002; Miller, et al, 2000; Fox 1991; Blake 1989). Such theories generally

†The authors thank Eva Wiesenmayer and Sherman Wissinger for their help in preparation of the manuscript.

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suggest that because increased thresholds occur during periods of rivalry suppression, the suppression originates from some type of cortical inhibition. Specifically, binocular rivalry was proposed to result from reciprocal inhibition of monocular neurons in the primary visual cortex (Blake 1989). Contrary to the early bottom-up concept, Sheinberg and Logothetis (1997) have demonstrated that activity in higher structures of the visual pathways, such as the inferior temporal cortex and the superior temporal sulcus, correlates better with the visual percept than the activity in the primary visual cortex. Referring to their findings, Dayan (1998) argues that perceptual alternation can be generated by competition between top-down cortical interpretations for the disparate inputs. More recently, Miller and colleagues (2000) turned to the highest level of cortical organization for explanation: they provided supportive evidence from transcranial magnetic stimulation that interhemispheric switching mediates perceptual rivalry. These authors propose that it is neither the images nor the eyes that compete with each other for perceptual dominance, but rather separate hemispheric representations of the percepts. According to their interpretation, competition for awareness in both binocular rivalry and reversible figures occurs between, rather than within, hemispheres. They have suggested that each hemisphere adopts one of the rival stimuli, and that the perceptual alternation reflects switching of activity between the hemispheres by a subcortical mechanism. The interhemispheric switching model incorporates elements of both the early bottom-up and the later top-down points of view (Pettigrew 2001) although it is not without challenge (Leopold et al. 2002). The present consensus is that rivalry is a multilevel process that reflects low-level sensory processing as well as high-level cortical activity with significant involvement of the latter (Blake & Logothetis 2002).

Binocular rivalry is a phenomenon of interest in its own right, but its real importance may be that it sheds light on the problem of visual awareness (Kanwisher 2001; Searle 2000; Myerson, Miezin & Allman 1981). The reason is simply that the stimulus is relatively constant yet the perception changes radically over time. Physiological studies on binocular rivalry have revealed how various cortical areas follow the input and/or follow the percept. If the interhemispheric switching model (Pettigrew 2001) is right, then binocular rivalry can be a useful tool in studying variation of interhemispheric effects on conscious experience and it can give more insight into the nature of altered states of consciousness.

Changes in hemispheric integration were discussed by Mandell (1985) as a possible basis for hallucinogenic effects. He suggested that hallucinogens diminish the usual hemispheric dominance in two ways. First, they speed up the rate of naturally occurring intrahemispheric metabolic oscillations by moving fluctuations closer to the background randomness of neural activity, and second, they decrease interhemispheric reciprocal inhibition mediated by collateral pathways crossing the midline. Both mechanisms may lead to an increased amount of hemispheric coupling (i.e. bilateral coherence, interhemispheric fusion). Mandell (1985: 264) says: "The sides can relate, but neither is dominated." Supposedly, this state improves the information exchange between the two hemispheres and creates a thorough integration of left and right hemispheric experiences, resulting in a unique blend of cognition and affect.

Data on hemispheric effects of hallucinogens and related compounds are very limited. The authors are aware of three groups of researchers (from Germany, Switzerland, and the USA) performing studies addressing the differences in cerebral lateralization after administration of hallucinogens. Those studies revealed right cortical activation after mescaline (Hermle, Gouzoulis-Mayfrank & Spitzer 1998; Hermle et al. 1992; Oepen et al. 1989), cannabis (Mathew et al. 1999, 1997, 1992), psilocybin (Gouzoulis-Mayfrank et al. 1999) and 3.4-methylenedioxymethamphetamine (MDMA) (Frei et al. 2001; Spitzer et al. 2001) intake. To the authors' knowledge, no similar investigation has been performed to address interhemispheric fusion or to clarify the characteristics of interhemispheric integration in altered states of consciousness. Mandell's (1985) theory has thus far been unchallenged.

Ayahuasca is a hallucinogenic decoction made of psychoactive plants (*Banisteriopsis caapi* and *Psychotria viridis* or *Diplopterys cabrerana*) indigenous to the Amazon and Orinoco river basin of South America. Known under different names such as *yagé, natem, mihi, dapa, kamarampi* and many others, the brew has been used, probably for millennia, for medico-religious purposes by numerous indigenous groups of the Upper Amazon (Luna 1986, 1984; Schultes 1982; Dobkin de Rios 1972). The ritual use of *ayahuasca* has spread among Amazonian mestizo population of Colombia, Ecuador, Peru and Brazil. In Brazil, its use has taken a new course as members of synchretic Christian religious organizations, with strong Afro- and Amerindian influences, have adopted it as a sacrament under the names of *Santo Daime* and *Hoasca.* Although its use is tolerated in countries sharing the Amazon basin, Brazil is the only country where it currently enjoys legalized status. Its active ingredients are the reversible monoamine-oxidase inhibitor *harmine*, the serotonin-reuptake inhibitor *tetrahydroharmine* which make the serotonin receptor (5-HT2) agonist component *N,N-dimethyltryptamine* (DMT) bioavailable for oral use, relatively potent and long-acting (Callaway et al. 1999). In this combination, DMT is capable of eliciting an intensely emotional, dream-like experience characterized by vivid visual imagery, perceptual and cognitive changes, and profound, meaningful modification in the sense of self and reality (Riba et al. 2001; Strassman 2001). The typical onset of action is within 60 minutes and the peak of visionary effects is between 60 and 120 minutes after drinking the brew (Callaway et al. 1999).

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The purpose of present study was to use binocular rivalry as a tool for revealing the temporal characteristics of cerebral dominance in altered state of consciousness induced by *ayahuasca*. If Mandell's (1985) theory on interhemispheric fusion is correct, then hemispheric dominance is relatively suspended by the hallucinogen and, according to the interhemispheric switching interpretation of binocular rivalry, longer nonrivalry responses (nondominance periods, or phenomenal fusion) are expected in the altered state of consciousness. Accordingly, the authors hypothesize that *ayahuasca* ingestion will increase the duration or the frequency of nondominance responses. Additionally, in line with the findings of the brain activation studies referred to above, we hypothesize that *ayahuasca* ingestion will cause the dominance responses, when present, to show a bias favoring one of the images more than the other image. Subjects were tested both with and without *ayahuasca* ingestion, to serve as their own control.

METHODS

Subjects

Data were obtained from ten individuals who were participating in rituals held in the Wasiwaska Research Center, Florianópolis, Brazil between April 1 and 29, 2002 and volunteered for the binocular rivalry test. The site in Brazil was chosen for the obvious reason that *ayahuasca* is legal in that country. Enrolled volunteers ingested *ayahuasca* for exploratory and therapeutic purpose and not specifically for participation in the study. The Principal Investigator (LEL) obtained informed consent from participants for the binocular rivalry tests prior to the ingestion of the psychoactive brew, conforming to the guidelines set forth by the Ethical Principles and Guidelines for the Protection of Human Subjects of Research (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research 1979). Originally fifteen candidates were considered for participation. One was not eligible because she had a dose below the range set in the inclusion criteria, two individuals did not participate because they preferred not being disturbed during the sessions, one had mixed handedness, and one male was excluded due to cannabis dependence. The final experimental group included eight males and two females with a mean age of 52 (SD=8.8; range=34 to 65) years.

Inclusion criteria for experimental subjects were: (1) being experienced in *ayahuasca* use (having at least five previous sessions); (2) ingesting *ayahuasca* in a dose not less than 50 ml. at the beginning of the experimental session; (3) right handedness, which was evaluated with a modified Edinburgh questionnaire (Briggs & Nebes 1975); and (4) a likelihood ratio (hits/false alarms) at least threefold better than random guessing in a signal detection task designed to mimic the perceptual switches of binocular rivalry (see below).

Exclusion criteria for experimental subjects were: (1) personal history of psychiatric or neurological disorder and/or use of psychotropic medication for nonpsychiatric condition (e.g., antidepressant for chronic pain, psychostimulant for weight loss); (2) head injury leading to loss of consciousness for greater than five minutes; (3) alcohol, or illicit drug use in the past three weeks; (4) life time history of substance dependence as diagnosed by DSM-IV (American Psychiatric Association 1994); (5) body mass index of less than 20 or more than 25 kg/m2; (6) history of cardiac or endocrine illness; and (7) lack or mild degree of *ayahuasca* experience during the experimental session (see below).

A further sample of 32 healthy volunteers who did not participate in *ayahuasca* ceremonies were enrolled as comparison subjects to estimate test-retest reliabilities of binocular rivalry response measures. Informed consent was also obtained from these participants for the binocular rivalry tests.

Ayahuasca Session

Participants maintained a salt-, sugar- and alcohol-free diet for four weeks during the duration of their participation in the seminar organized by the Wasiwaska Research Center, had three to four sessions per week and were enrolled into the rivalry study during the fourth week. On the test day at 7:30 pm they ingested a self-chosen dose of *ayahuasca* (obtained from one of the Brazilian synchretic churches) ranging from 50 to 100 (mean=74, SD=21.2) ml. For the following four hours they rested supine with lights turned off. Volunteers performed the rivalry test between 90 and 150 min after the ingestion of *ayahuasca* and had the test done on a separate day in the evening hours without the influence of the decoction (baseline condition). Six of them had binocular rivalry with *ayahuasca* as the first procedure and four were scheduled to have the test first without having the brew. Based on participants' previous experiences, the global subjective experience induced by the brew was rated on a five-point Lickert scale ranging from 0-4 (none, mild, moderate, strong, very strong) immediately before starting the binocular rivalry test.

Rivalry Procedure

The technique for eliciting binocular rivalry was similar to that already published (Pettigrew & Miller 1998), with two small targets presented foveally so that the right eye saw, for example, a moving horizontal grating and the left eye saw a moving vertical grating, in the same apparent location.

Display Apparatus

Custom software (written by KDW) generated the rivalry stimuli in frame or field sequential formats, measured responses, and provided user interfaces. In the frame sequential format, odd numbered frames were presented to one

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eye while even numbered frames were presented to the other eye. The software was triggered by the video vertical synch, which caused the next stimulus to be displayed, then read and stored the status of mouse buttons, and waited for the next vertical synch. Three experimental subjects wore a head-mounted display (Virtual I-O iGlasses) with SVHS resolution, which was synchronized to the frames generated by an IBM Thinkpad computer using 1024 x 768 x 256 at 75 Hz non-interlaced graphics (N mode) by an AverMedia Averkey SVHS scan converter. The iGlasses 3D head-mounted display has separately driven LCD displays (180,000 pixels) for each eye, giving resolutions of 225 x 266. The other seven experimental subjects wore VRex VR Visualizer LCD shutter glasses, which alternately excluded odd or even fields presented on a 1024 x 768 resolution 14-inch video monitor. In the latter case the graphics mode was interlaced at 87 Hz (I mode). Comparison subjects wore Vrex VR Surfer LCD shutter glasses and viewed 17 inch video monitors on which the 1024 X 768 display was interlaced at 96 Hz (U mode).

Stimuli

The stimuli consisted of white binocular fixation guides centered within which was a 1 degree disk filled with horizontal or vertical grating. These fixation guides consisted of (1) a rectangular frame drawn around the borders of the 12 x 9 degree screen, (2) a circle 9 degree in diameter centered on the screen center, and (3) a plus-sign shaped crosshair at the screen center for which the centermost 3 degree horizontal and vertical were removed. All stroke widths for the fixation guides were about 1/16 degree wide. The 1 degree disk at the screen center was filled with 5 cycle per degree square wave gratings. The disk could be presented binocularly (same grating orientation in both eyes) or dichoptically (different grating orientations in the two eyes).

Training in the Reporting Task

Subjects received training in how to use a two-button computer mouse to indicate what kind of gratings they perceive. In this task they were presented with binocular stimuli (both eyes received the same stimulus, there was no rivalry) while holding the computer mouse in both hands (with left thumb above the left button, right thumb above the right button). These binocular stimuli looked exactly like the experimental stimuli (save that the experimental stimuli used dichoptically presented disks). When the grating was horizontal, subjects were instructed to push and hold down the left button. The left button on the mouse had three black horizontal stripes made of plastic tape in order to be tactually distinctive for the left thumb and to provide tactile cue as reminder. The subjects were advised to move their thumb along and across the stripes to feel this cue for the horizontal report button. They were also told to keep this button held down for the entire time they saw horizontal lines in the disk. The right mouse button had three black plastic tape stripes attached vertically to it.

When subjects saw vertical lines filling the disk they were supposed to hold down the right button for as long as they saw vertical lines and were reminded to move their thumb along and across the stripes to feel this shape cue. When the disk was filled with superimposed horizontal and vertical lines (a plaid or crosshatch), the subject was told to report this appearance by holding down both mouse buttons. Lastly, in case the disk was filled with a homogeneous field (blank) the subject was instructed to let up both buttons, and when unsure what to report, to press nothing.

Signal Detection Analysis of Reporting Accuracy

This task was run with a computer generated "movie" that simulated rivalry alternation using binocular stimuli. Stimulus durations were sampled at equal probability intervals from a cumulative gamma distribution (Levelt 1965), and the disk content (horizontal, vertical, plaid, blank) randomly assigned that duration, with the proviso that two durations with the same content could not occur in immediate succession. A 90 second sequence of such quasi-randomly selected stimuli changed unpredictably in pattern content and duration, but in such a way that 25% of the time each pattern appeared. A software program scored the observer's button presses during the movie. Responses were scored as correct or incorrect by the software depending upon which stimulus pattern preceded pressing of the button(s). These calculations were carried out for time lags between stimulus and response from 0.3 to 3.0 seconds in 0.1 second steps, comparing button press to stimulus each 1/60 second. Random guessing produces 25% correct (hits) and 75% wrong (false alarm) choices. An observer was not allowed to begin the experiment unless three of the four response types reached a criterion of least 50% hits. The movie could be repeated if further training was found to be necessary. Repetition did not have to be done more than once with participants of this study. The training and evaluation procedures were generally be completed in about five minutes. Typical performances were 85% to 95% hits with 5% to 15% false alarms by observers without the drug, and 70% to 90% hits with 10% to 30% false alarms by the same observers under drug influence. Estimated response latency (time lag for maximum percent correct) was 0.65 seconds without *ayahuasca* and 0.93 seconds on *ayahuasca*. No observer had to be excluded from further participation due to failure to achieve criterion performance (three times greater likelihood of correct to wrong responses than random chance).

Sequence for Experimental Subjects

At first, traditional binocular rivalry was presented for 2.8 to 3.2 minutes as practice, with responses excluded from data analysis. Subsequently, it was presented in four 1.3- to 1.5-minute epochs to obtain the endogenous perceptual

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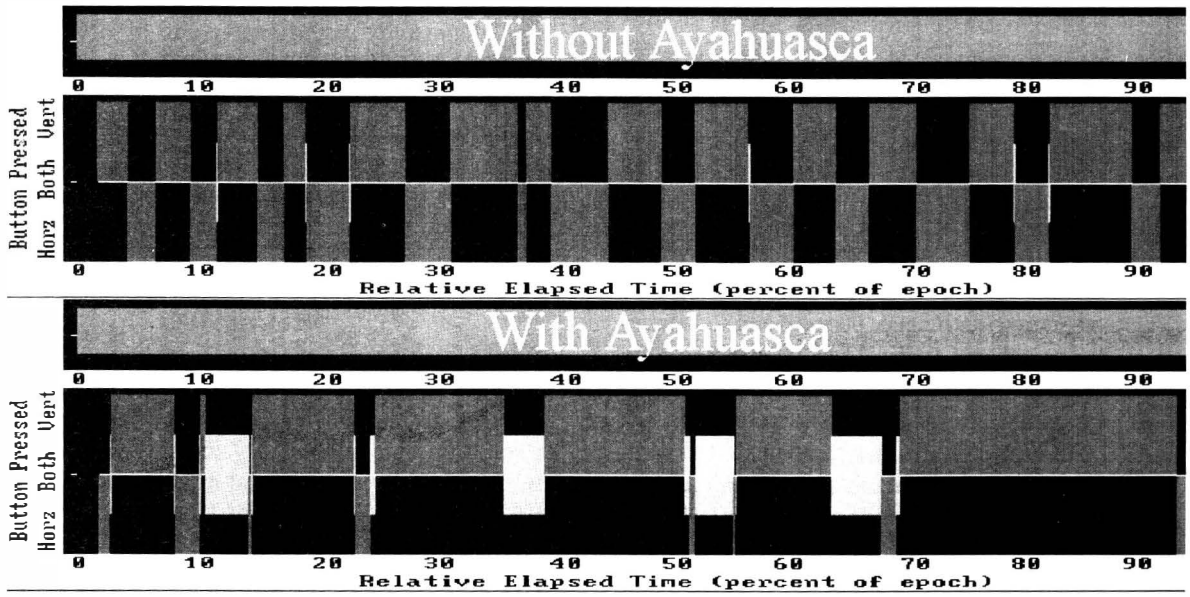
FIGURE 1
Typical Pattern of Perceptual Alternation in Binocular Rivalry for One Experimental Participant Without *Ayahuasca* and With *Ayahuasca*



alternation rate. Order of presentation of vertical or horizontal lines to either eye was random. At the end of each epoch a graph of the responses was displayed. The experimenter described in words the general features shown in the graph in order to verify that these recorded responses were representative of the observer's perceptions. The whole experimental procedure (training included) was completed in 20 minutes.

Sequence for Comparison Subjects

In each of two sessions, traditional binocular rivalry was presented for 2.0 minutes as practice, with responses excluded from data analysis. Subsequently, it was presented in ten 2.0 minute epochs to obtain the endogenous perceptual alternation rate. Order of presentation of vertical or horizontal lines to either eye was alternated. At the end of each epoch a graph of the responses was displayed for the subject to verify that these recorded responses were representative. A session (training included) was completed in about 35 minutes. The retest session followed the initial test session by an average of 14 days (range one day to 28 days).

Data Management

For the purpose of identification, all subjects received an alias upon entering the study to aid in maintaining confidentiality. For binocular rivalry, the raw data consisted of the time (in one video frame increments) each button press lasted. These data were imported into spreadsheets and analyzed with macros that extracted the lengths of time when horizontal, vertical, plaid responses, or nothing was reported. The following quantitative measures were used to characterize performance for binocular rivalry (i.e., dichoptic stimulus alternation): (1) mean dominance period (MDP) = total duration of horizontal and vertical responses divided by the number of horizontal and vertical responses; (2) cycle per minute (CPM) = the total number of horizontal and vertical responses/2*(length of measurement in minutes)*(summed percentage of horizontal and vertical responses)/100—this measure, which was derived for comparability to the literature, expresses performance closely related to MDP; (3) horizontal-vertical bias (HVB) = (percentage of horizontal responses)–(percentage of vertical responses)/ (percentage of horizontal responses)+(percentage of vertical responses); and (4) percentage of no-rivalry responses = percentage of total time reporting plaid or unsure responses. Since 0.5 seconds is close to the mean reaction time for those not using *ayahuasca* during the movie session, button presses lasting less than 0.5 seconds were excluded in the analyses as being too short to be perceptually meaningful (this value was not critical, however, as the basic findings held when no responses were excluded and also when responses shorter than one second were excluded). As the values for MDP, CPM and HVB were

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not normally distributed, these measures were compared with nonparametric tests (Wilcoxon matched pairs test of significance). The percentage of no-rivalry responses was analyzed by Student t test for paired samples and by repeated measures ANOVA (using Statistica for Windows v6.0).

RESULTS

Five participants rated the strength of their global subjective experience as "very strong," four rated it "strong" and one rated it "moderate." The five individuals with "very strong" ratings took *ayahuasca* doses above the median (more than 75 ml).

All subjects, regardless of drug condition (with or without *ayahuasca*), showed binocular rivalry. They reported successive percepts of a moving horizontal grating or a moving vertical grating (dominance periods) and sometimes a blend of horizontal and vertical gratings mixed with uncertain responses (nondominance periods). The typical pattern of perceptual alternation is illustrated for one experimental participant on *ayahuasca* compared to without it in Figure 1. Periods of horizontal dominance appear as blocks below the time line, periods of vertical dominance as blocks above the line, and periods of the blended (plaid) or uncertain percepts as blocks straddling the line.

Analysis of Dominance Periods

The results for this sample of 32 comparison subjects indicates that mean dominance period and alternation rate (cycles per minute) are stable characteristics within an individual over periods of days or weeks (MDP test-retest r = 0.69, CPM test-retest r = 0.86). *Ayahuasca* decelerated binocular rivalry, as revealed by Wilcoxon's paired test: median alternation rates in CPM (no-brew versus on-brew) = 44.1 versus 22.3, Z=2.19, $p<0.03$; and had a tendency to increase the mean dominance period: median MDP (no-brew versus on-brew) = 2.90 versus 4.36, Z=1.89, $p<0.06$. The subjects did not respond significantly longer to the movie simulating rivalry (see the discussion of signal detection analysis of reporting accuracy under Methods) on brew than with no brew (paired t = 1.62, n.s.). Therefore, the lower CPM and the tendency for longer MDPs during the *ayahuasca*-induced conditions cannot be explained by response perseveration.

When the measures of horizontal-vertical bias were analyzed, no drug effect was found: median HVB (no-brew versus on-brew) = 0.03 versus -0.07, Z=0.26, n.s. However, by taking the absolute values of the horizontal-vertical bias, a profound difference was revealed: median absHVB (no-brew versus on-brew) = 0.09 versus 0.19, Z=2.50, $p<0.02$. In the group of comparison subjects this measure has test-retest r = 0.72.

Analysis of Nondominance Periods

The total length of nondominance periods was not significantly longer on brew: mean±SD of the percentage of no-rivalry responses (no-brew versus on-brew) = 13.1±10.2 versus 20.3±14.8, t=-1.32, n.s. When repeated-measures ANOVA was applied to the percentage of no-rivalry responses measures using rated strength of global subjective experience as the grouping variable (one group consisted of five subjects who rated it "very strong" and the other group included the five participants with lesser ratings), the analysis demonstrated significant group by drug interaction (F=5.44; df=1,8; $p<0.05$) although there was no drug main effect (F=2.60; df=1,8; n.s.). Post hoc comparison using contrasts indicated that significant increase of the "on brew with very strong effect" cell mean (28.7± 5.62) versus the other cells was responsible for the interaction. In comparison subjects the total length of nondominance periods had a test-retest r = 0.83.

DISCUSSION

Binocular rivalry alternation rates decelerated after drinking *ayahuasca*. This is very similar to the effect of alcohol on binocular rivalry (Donnelly & Miller 1995; Barany & Hallden 1947) and does not appear to be specific for hallucinogenic action. Decreased alternation rates might be the result of several factors: (a) response perseveration, which has been ruled out; (b) changes in oculomotor function, but no available data support that *ayahuasca* has oculomotor effects; (c) decreased stimulus strength, although the stimuli were unchanged physically—if the subjective feeling of visual stimulation strength was intensified, as it can be expected with the use of a hallucinogen, that might influence the rate but in the opposite way to these observations; or (d) reduced contrast sensitivity and depth perception, since alcohol and cannabis are known to affect these visual functions (Leweke et al. 1999; Andre et al. 1994)–however, to our knowledge, no data show how hallucinogens affect them.

Subjects with intense psychedelic experiences on *ayahuasca* had longer non-rivalry periods than when they had not ingested *ayahuasca*. The proportion of time spent seeing both alternatives simultaneously (phenomenal fusion) shows marked individual differences but it is fairly constant in an individual over time (Pettigrew 2001). More extended phenomenal fusion was also reported by Barany and Hallden (1947) in subjects with alcohol intoxication. Donnelly and Miller (1995) were not able to replicate that finding but argued that their subjects might have been less intoxicated. Phenomenal fusion apparently occurs when the psychoactive effect is very strong. The authors believe that our experimental setup worked against the intensity of the *ayahuasca* psychedelic experience. Subjects had to get up from a supine position, walk to the experimental room, look at a computer screen, listen to instructions and be occupied with a task. The nonpharmacological "talk down" treatment of drug-induced hallucinosis (with the exemption of delirious conditions) is very similar: get the

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patients gently out of the bed, make them slowly walk around, turn some dim lights on, talk to them softly and keep them engaged. More prominent effects might be expected within a more "psychedelic friendly" experimental setting than the one we could provide.

Bias was observed in the increased dominance of one of the two percepts on *ayahuasca* (the absolute value of the horizontal-vertical bias showed a significant difference) possibly indicating that one hemisphere had been dominant for a longer period of time than the other hemisphere (Miller et al. 2000). Based on the results of brain activation studies (Frei et al. 2001; Spitzer et al. 2001; Gouzoulis-Mayfrank et al. 1999; Mathew et al. 1999; Hermle, Gouzoulis-Mayfrank & Spitzer 1998; Oepen et al. 1989), the authors speculate that under the influence of *ayahuasca*, it was the right (subdominant) hemisphere which might have been responsible for the shift toward the dominance of one percept. Neurotransmitter systems involved in hallucinogenic action are not symmetrically distributed (Arato et al. 1991a, b; Lee & Mandell 1985; Glick, Jerussi & Zimmerberg 1977); therefore psychoactive drugs can alter hemispheric dominance through differential changes in biogenic amine inhibition.

According to the interhemispheric switching model (Pettigrew 2001), one hemisphere adopts one of the percepts (in our case horizontal or vertical). In general, the majority of individuals show horizontal preference by the dominant hemisphere in dichoptic presentation of horizontal and vertical stimuli. However, in order to tell in each individual case what percept is preferred by the left or right hemisphere, one needs to turn to the use of an invasive technique (contralateral hemispheric activation by caloric vestibular stimulation or unihemispheric disruption by transcranial magnetic stimulation). To make the issue more complicated, there is eye preference as well, such that presenting vertical to the left eye and horizontal to the right eye is what Pettigrew (2001) suggests to get the strongest preferential hemispheric activation (horizontal for the left hemisphere and vertical for the right), because of the slight advantage of the crossed versus uncrossed visual pathways in addition to hemispheric pattern preference. In summary, on *ayahuasca* the subjects are more biased but not consistently toward horizontal or vertical, since in the present experiment the orientation presented to each eye varied randomly from epoch to epoch.

For the site of the interhemispheric switching mechanism, Miller and colleagues (2000) mention the corpus callosum connecting the cortical hemispheres as an obvious candidate, but consider a bistable oscillator in the brainstem more likely. The problem in localizing the interhemispheric switch lies in the multiplicity of interhemispheric oscillations. Putative interhemispheric switch rate varies considerably, from thousands of seconds in the hypothalamus to a few tens of milliseconds in caudal midbrain. There is a gradient of switch rate from the rostral pole of the brain to the caudal suggesting that the more anterior regions of the cortex switch more slowly than posterior regions (Pettigrew 2001). The prefrontal cortex has a very slow switch rate linked to the nasal cycle of the hypothalamic period of two to three hours (Galioto et al. 1991) and oscillators become more rapid as one moves posteriorly to the visual cortex, where the 30 msec cycle is the fastest known. It is difficult to explain this wide range of oscillations with one central agency governing them all, and it may not be necessary to postulate a designated central switch for hemispheric alternation. It is more parsimonic to suppose that frequency change and phase shift between contralateral intrahemispheric oscillators could manifest itself as interhemispheric switching at a beat frequency. Those hallucinogens, which act on brain monoamine systems, may slow down the intrahemispheric oscillation of neurotransmitter mechanisms via autoreceptors, and delay the phase of the corresponding contralateral oscillator system through collateral regulatory afferents (Mandell 1985). When the rostral to caudal variations in base rates and hallucinogen-induced phase shifts are also considered, an interhemispheric beat frequency could become close to zero in amplitude due to these variations. Hallucinogens could in this way promote binding the two hemispheres through coherent gamma activity instead of their switching. It is possible that this effect is not unique to hallucinogens, but common to many means of inducing altered states of consciousness and represents the neurophysiological basis of the condition that Winkelman denoted by the term "psychointegration" (Winkelman 2000, 1996).

The present study raises more questions than it answers, exactly what may be expected from a pioneering work. The authors hope that these findings are provocative and will initiate follow up studies on how binocular rivalry may serve as a useful tool for studying altered states of consciousness.

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