Electroencephalogram characteristics during possession trances in healthy individuals

Norie Kawai[a,b], Manabu Honda[c], Emi Nishina[d], Reiko Yagi[e] and Tsutomu Oohashi[a]

Despite intensive studies on cerebral activity during trances involving tranquil arousal states, there are little data on physiological basis of naturally induced possession trances involving hyperarousal active states because of the difficulty of gathering data from participants within a natural cultural context in the field. We investigated the characteristics of electroencephalograms (EEGs) that were specific for naturally induced possession trances involving hyperarousal states in actual rituals. We measured the EEG signals of 12 healthy participants, seven with trance and five without trance, before, during, and after a dedicatory ritual drama in Bali, Indonesia, using a custom-modified field telemetry system. During trance, θ (4–7.5 Hz), α-1 (8–9.5 Hz), α-2 (10–12.5 Hz), and β (13–30 Hz) signals were significantly increased compared with those during the control phases. Such findings were not observed in participants without trance when they performed similar movements in the rituals. The α-1 and α-2 signals tended to remain elevated for several minutes postritual compared with those recorded during the preritual resting state. These results suggest that spontaneous EEG patterns during possession trances may be related, at least in part, to the activation of the reward-generating neuronal system situated in deep-lying brain structures and deactivation of the cerebral cortex. *NeuroReport* **28:949–955 Copyright © 2017 The Author(s). Published by Wolters Kluwer Health, Inc.**

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[a]Department of Research and Development, Foundation for Advancement of International Science, Tsukuba, [b]Comprehensive Research Organization, Waseda University, [c]Department of Functional Brain Research, National Center of Neurology and Psychiatry, Kodaira, [d]Department of Liberal Arts, The Open University of Japan, Chiba and [e]Department of Early Childhood Education, Tokyo Seitoku College, Tokyo, Japan

Correspondence to Norie Kawai, PhD, Department of Research and Development, Foundation for Advancement of International Science, Tsukuba 305-0821, Japan
Tel: + 81 29 860 3333; fax: + 81 29 860 3336; e-mail: nkawai@fais.or.jp

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Introduction

Bourguignon [1] reported that 90% of human societies have institutionalized one or more altered states of consciousness and that 57% of these states are related to possession trances. It is possible that possession trances have a common neurophysiological mechanism across healthy individuals. Although trances involving tranquil arousal states such as Zen, yoga, and transcendental meditation are well studied with spontaneous electroencephalograms (EEGs) (often in laboratories), there are no neurophysiological studies of possession trances involving hyperarousal active states induced within natural contexts in the field. Access to participants who participate in true possession trances is very limited because these trances typically occur within sacred contexts, many of which disallow outside experimenters [2]. The functional limitations of equipment for field use further complicate the study of these phenomena [3]. Overcoming these problems, we completed the first successful recordings of EEG signals from a participant in a possession trance in the field in Bali, Indonesia [4]. The present study expands upon this initial work. The aim of this study was to examine EEG characteristics during possession trances.

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Participants and methods

Participants

The setting of our investigation was a Balinese dedicatory drama called 'Calonarang', which induces possession trances according to a common protocol throughout many villages in Bali [4]. During this ritual, some members of the village play warriors who are fighting a witch. The players, including musicians, in the drama often enter into a trance-like state during a fight scene without consuming alcohol or psychoactive drugs. It is generally understood that a player in trance is possessed by an evil spirit by the force of the witch.

Participants were selected according to the following criteria: (a) a player within a ceremonial ritual drama; (b) an individual with adequate sleep and nourishment on the day before the ritual; and (c) an individual in good health and mental status on the day of the ritual. Previous

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experience with possession trances was not a selection criterion.

In total, 16 healthy, right-handed Balinese men (mean: 33.5 ± 6.8 years) participated in this study. All the participants had experience with entering trance states in the past. Their previous experience ranged from just once to four times in a year.

The necessary EEG data for analysis could not be obtained from four participants because of electrode removal or wireless communication equipment malfunction. Thus, data from 12 participants were subjected to analysis. For each participant, a judgment was made as to whether he fell into a possession trance state according to the following criteria: (a) abrupt occurrence of excited behaviors or syncope (necessary condition); (b) fixed or unfocused eyes; (c) muscle rigidity or stiffened limbs; and (d) convulsion-like shaking of limbs. Participants fulfilling criterion (a) and at least one of criteria (b)–(d) were judged to fall into a trance state. As a result, among these 12 participants, seven participants were judged to show a trance state (trance group) and five participants were not (control group).

This study was approved by the Ethics Committee of the Foundation for Advancement of International Science and the Tsukuba Clinical Research and Development Organization, University of Tsukuba. This study also received approval from the State Government of Bali and the National University of Udayana, Indonesia. All participants provided written informed consent forms before participating in any experimental procedure.

Data recording

We developed a custom-modified, portable EEG telemetry system for field use. We specifically designed the device to avoid restricting the participants' vigorous movements [4]. EEGs were recorded in parallel from two participants using two electrocaps and two telemetry systems (Synact and 514X modified; NEC Corporation, Tokyo, Japan) per experiment. We recorded EEG signals from 11 scalp sites (linked Fp1–Fp2, F7, Fz, F8, C3, C4, T5, Pz, T6, O1, and O2 according to the International 10–20 System) using linked earlobe electrodes as reference electrodes. Data were filtered at 60 Hz (−3 dB), time constants of 0.3 s, sampled at 100 or 256 Hz, digitized, and stored on a portable personal computer (Vaio PCG-868, Sony Inc., Tokyo, Japan). We also simultaneously videotaped all participants during the period of the EEG recording.

Approximately 30 min before the ritual started, we placed the electrodes on the participants' scalps and confirmed that the electrodes were comfortable and did not restrict movement. We recorded 3 min of EEG signals during an eyes-closed resting state before the beginning of the ritual and then continued recording throughout the entire ritual. Within 3–8 min after the ritual ended or after the participants recovered from the trance, we repeated the 3 min sampling of eyes-closed resting-state EEG signals. Blood pressure and heart rate were measured just before the eyes-closed resting-state EEG recording both before and after the drama. The participants were interviewed again after the drama and asked about their memories of the ritual and any experienced symptoms.

Data analysis

We extracted frequency ranges that included the four bands of interest (θ: 4–7.5 Hz, α-1: 8–9.5 Hz, α-2: 10–12.5 Hz, β: 13–30 Hz) using a high-performance, digital bandpass filter with equiripple finite impulse response. The passband cut-off frequencies were 4 and 30 Hz, the stopband cut-off frequencies were 3.5 and 30.5 Hz, the stopband attenuation was 20 dB/0.5 Hz, the passband ripple was 0.1 dB, and the filter order was 768. After filtering, the number of high-frequency artifacts caused by myogram and low-frequency artifacts, including baseline wobble caused by body or cable movements, decreased.

We visually inspected the EEG waveforms by checking the unfiltered raw waveforms, the filtered waveforms, and the frequency spectrum of each 2-s block [4]. To confirm that no excessive artifacts remained in the filtered data, we visually examined the raw waveforms and the frequency spectrum and excluded from further analysis any 2-s blocks containing artifacts or periods when the telemetry data were absent. We have reported on the raw and filtered waveforms of a representative participant elsewhere [4].

We divided the EEG data into two states of consciousness, normal and trance, on the basis of behavioral and phenomenal alterations. The normal state was further divided into three phases: the eyes-closed resting period before the ritual started (PRE), the eyes-opened standby period after the ritual started (WAIT), and the eyes-closed resting period after the ritual ended (POST). The trance state consisted of one phase: the eyes-opened period from onset to offset of trance behavior (MOVE).

Frequency spectra of the filtered EEG data, with artifacts excluded as described above, were calculated for each 2-s block with an overlap of 1 s (frequency resolution 0.5 Hz, sampling 256 Hz). The root of the power was computed for each bandwidth for each scalp site as the equivalent EEG potential. These values were averaged over each phase's duration. We calculated the average EEG potential values for the four frequency bands across all channels. We normalized the averages for each phase to remove inter-participant variability. We subjected data from each group to an analysis of variance, with a within-group factor consisting of the four phases. We then used a Fisher's protected least significant difference post-hoc test to detect differences in the normalized EEG potentials among phases. To explore a characteristic change during possession trances, we calculated DELTA by subtracting the WAIT phase data from the MOVE phase data for each of the four frequency bands. We tested for differences in DELTA between the trance group and the control group using an unpaired Student's *t*-test.

Results

Among the 12 participants, seven were judged to fall into a trance state (trance group) and five were judged not to be in a trance state (control group) according to the criteria described above. Manifestation and behavioral characteristics of each participant of the trance and control groups are shown in Table 1. All the trance participants abruptly showed excited behavior; they repeatedly rushed against and attacked the witch, vigorously poked their sword against their chest, abdomen, head, and/or face. All the participants of the trance group had fixed or unfocused eyes and muscle rigidity. Two participants of the trance group also showed convulsion-like limb shaking (Fig. 1) (see Supplementary Video, Supplemental digital content 1, *http://links.lww.com/WNR/A434*, which shows some common behaviors and manifestations of trance participants living in different villages). According to the interview after the ritual, amnesia for events occurring during the trance state was recognized in all the trance participants. The average duration of the trance state was 8.50 min (maximum: 16.80 min, minimum: 3.30 min).

In contrast, none of the five participants of the control group showed signs of a trance state as described above. Three participants of the control group performed actions similar to those of the trance participants, i.e., rushing against and attacking the witch, and poking their sword against their body. Nevertheless, their expression and their eyes appeared normal, they did not display muscle rigidity, and they did not report amnesia for the ritual events. The groups did not differ with respect to changes in blood pressure and heart rate.

A visual inspection of EEG waveforms indicated no evidence of epileptic activity (paroxysmal intermittent spikes or sharp waves) throughout the PRE, WAIT, or POST phases in the trance participants. In the MOVE phase, when the participants in trances made very vigorous movements, it was difficult to distinguish spikes and sharp waves in the raw waveforms because of movement artifacts. Nevertheless, no spikes or sharp waves were observed in signals recorded when the trance participants lay on the ground. Moreover, none of the trance participants showed rhythmic paroxysmal discharge or decremented electrical patterns, suggestive of epileptic seizures, immediately before entering the trance state. No abnormal behaviors or dissociative trance episodes were observed in the daily lives of the trance or control participants.

EEG potentials of four frequencies in each phase are shown in Fig. 2. Analysis of variances indicated a highly significant main effect of the phase in all four frequencies for the trance participants, but only for the α-1 and α-2 frequencies for the control participants. Post-hoc testing showed highly significant differences for all four frequencies between the WAIT and MOVE phases for the trance participants (θ, α-1, β: $P<0.001$; α-2: $P<0.01$; Fig. 2a). In contrast, there were no significant differences between the WAIT and the MOVE phases for the control participants (Fig. 2b). The differences between the MOVE phase and the WAIT phase (i.e. DELTA) were significantly larger in the trance group than in the control group (α-1: $P<0.001$; θ and α-2: $P<0.01$; β: $P<0.05$; Fig. 2c).

Discussion

Electroencephalogram characteristics of the possession trance state

There were several significant changes in the spontaneous EEG signal recordings of participants during possession trances induced under natural conditions compared with EEG

Table 1 Manifestation and behaviors of participants in the trance and control groups

Groups	No.	Abrupt excitement	Repeated rush against witch	Self-poking with sword	Fixed or unfocused eyes	Muscle rigidity	Convulsion-like limb shaking	Amnesia
Trance	1	o	o	o	o	o	x	o
	2	o	o	o	o	o	o	o
	3	o	o	o	o	o	o	o
	4	o	o	o	o	o	x	o
	5	o	o	o	o	o	x	o
	6	o	o	o	o	o	x	o
	7	o	o	o	o	o	x	o
Control	8	x	o	o	x	x	x	x
	9	x	o	o	x	x	x	x
	10	x	o	o	x	x	x	x
	11	x	x	x	x	x	x	x
	12	x	x	x	x	x	x	x

The role of all the participants except for no. 3 and no. 11 in the ritual drama was that of a warrior, whereas the role of no. 3 and no. 11 was that of a music player. Participant no. 3 abruptly stopped playing the instrument and rushed to the witch. In contrast, participant no. 11 kept playing the instrument until the end of the ritual. Although participant nos 8, 9, and 10 repeatedly rushed against the witch and poked themselves with their swords, such behaviors did not start abruptly, and their eyes were not fixed or unfocused. No. 12 did not show such fighting actions, but he only walked and looked around the ritual space.
o, observed; x, not observed.

Fig. 1

States of the trance participants. (a) A trance participant poking himself with his sword. After attacking the witch with his sword, he poked his sword strongly against his chest as a result of the magic of the witch, without showing pain. (b) The trance participant falling down. At the climax of the trance state, he fell down with stiffened limbs. (c) The trance participant wearing an electrocap. An electrocap was fixed on his head to measure the electroencephalogram. His face was expressionless with unfocused eyes. (d) The trance participant holding a live chick in his mouth. He devoured the live chick as a sacrifice, with muscle rigidity.

signals recorded before and after the trance state and compared with control participants under similar circumstances who did not enter a trance state. Within the trance group, but not in the control group, there were highly significant differences in all the frequency potentials between the WAIT (normal phase) and the MOVE phases (trance phase). In particular, increases in α-2 potentials during the MOVE phase carried over into the POST phase in trance participants.

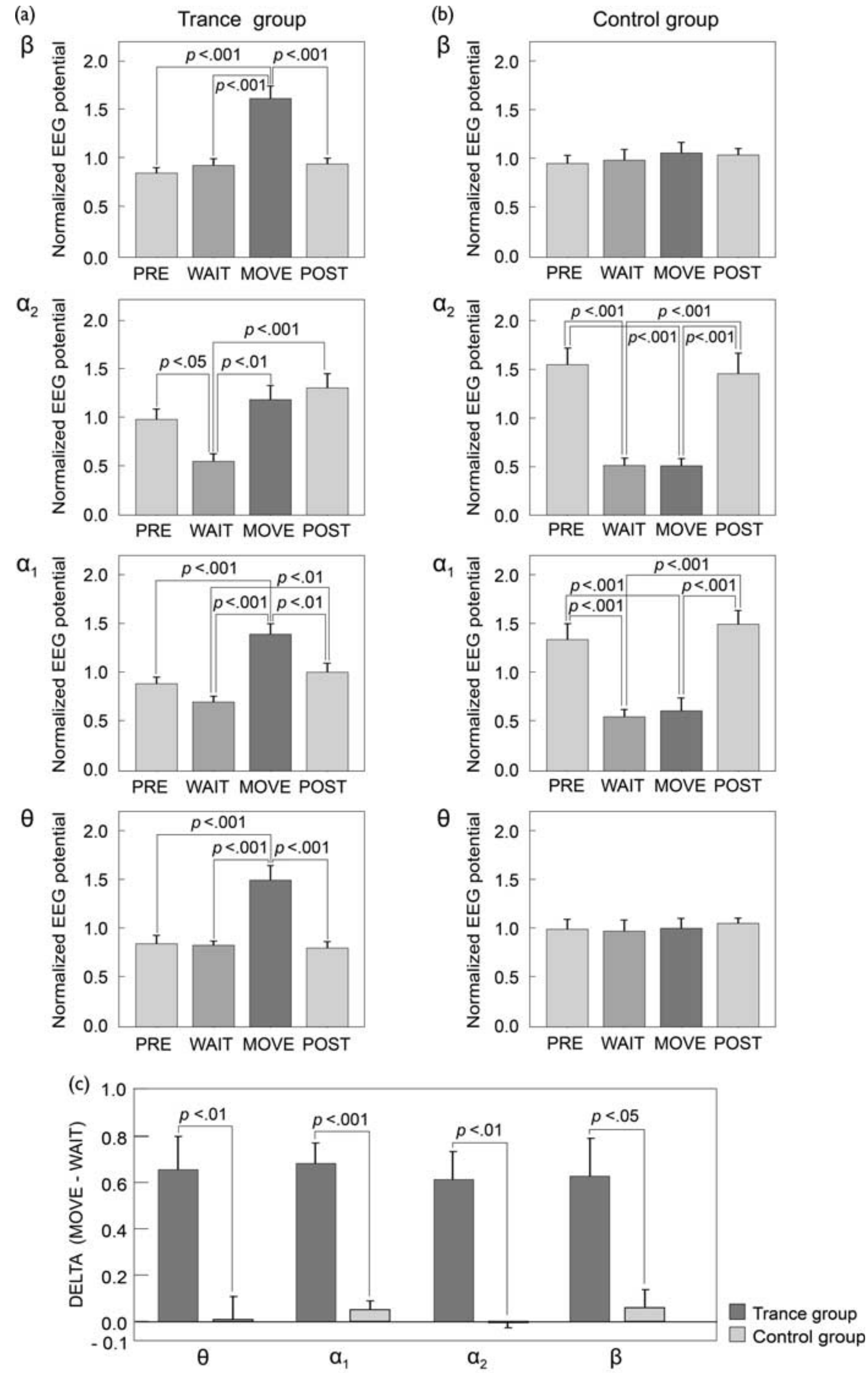
The participants of this study lived in different villages, and they performed the dramas in the rituals at different times. In addition, their age and experience of trance were different as described in the Methods section. Nevertheless, the EEG characteristics of the trance group, as described above, were very consistent and statistically different from those of the control group. This suggests that these characteristics represent the general electrophysiological hallmarks of a possession trance state.

Electroencephalogram characteristics of healthy individuals in various kinds of trances

Previous studies examined the altered states of consciousness, induced without alcohol or drugs, in healthy individuals. These states were roughly classified into two different types: trances in a tranquil arousal state accompanied by immobility (e.g. Zen, yoga, Transcendental Meditation) and trances in a hyperarousal state accompanied by unusual body movements (e.g. possession trances, shamanic trances).

Numerous reports have examined EEG signals recorded during trances in tranquil arousal states. In Zen meditation, there is an initial appearance of α waves (despite the eyes being open); an increase in the amplitude of persistent α waves; a decrease in α frequency; and among experienced practitioners, the appearance of a rhythmical θ train [5]. Yoga meditation is characterized by an increase in the amplitude of α waves and persistent

Fig. 2



Normalized electroencephalogram (EEG) potentials. Each value is expressed as the mean ± SE. (a) Differences between each phase among participants of the trance group. The differences between the WAIT and MOVE phases were significant for all four frequency bands. There were also significant differences between the PRE and MOVE phases and between the MOVE and POST phases. (b) Differences between each phase for control group participants. θ and β waves did not change significantly. α-1 and α-2 did not change between the WAIT and MOVE phases, but decreased significantly from the PRE to the WAIT phase and increased significantly again from the MOVE to the POST phase. (c) Differences between the WAIT and the MOVE phases (DELTA). Comparisons between the trance and control groups using unpaired Student's *t*-tests showed that all four frequency bands were significantly higher in the trance group than in the control group.

unblocked α activity, despite strong experimental stimuli such as bright lights or loud sounds [6]. Transcendental meditation is also characterized by increases in α rhythm amplitude, decreases in α frequency, and high-amplitude θ bursts [7] or longer rhythmic θ trains [8]. Rhythmic amplitude-modulated β waves over the entire scalp are observed in advanced practitioners [9]. Enhancement of α and θ wave activity such as in those studies on trance in a tranquil arousal state was also commonly observed during the possession trance in the present study. This suggests that these two different kinds of trances may share some common neurophysiological mechanisms, although their phenomenal and behavioral appearances are different.

In terms of shamanic trances with a hyperarousal state accompanied by unusual body movements, Hughes and Melville [10] measured EEG signals in a laboratory setting of 10 channeling trance experts and found that the incidence of α, θ, and high-amplitude β waves was much greater during a trance than either before or after a trance. Furthermore, for each of the three frequency bands, the degree of increase from the pretrance phase to the trance phase was greater than the degree of decrease from the trance phase to the post-trance phase. This suggests there is a temporary residual aspect of the trance state. The behavioral manifestations of channeling trances are similar to those observed during possession trances, at least in part, raising the possibility that the similarity of EEG patterns between channeling trances and possession trances indicates a shared neurophysiological base.

Interpretation of electroencephalogram activity during possession trances

During possession trances, α activity increased, with distinct peaks in the power spectra. Although the mechanisms that underlie α wave generation are not fully understood, the thalamus, specifically neurons of the thalamic reticular nucleus, likely plays an important role in generating the rhythm [11,12]. This rhythm travels to the cortical neurons through thalamic–cortical projection neurons. When the transmission of α activity from the thalamus to the cortex is uninhibited through cortical hypoactivity, cortical neuron activity synchronizes with the α rhythm and α waves are measurable through the scalp. It is suggested that the decrease or the elimination of ordinary perception and memory of trance participants may be related to the lowering of cerebral cortical activity.

We reported previously [13–15] that regional cerebral blood flow in deep brain structures, including the midbrain and thalamus, correlated positively with the α-2 potentials on EEGs recorded from healthy participants. Furthermore, we reported that the plasma levels of noradrenaline, dopamine, and β-endorphin increased significantly during possession trances in the same kind of rituals in Bali [16]. Taken together with these findings, this suggests that increased activity of α potential during trance may at least partly reflect the activation of deep-lying brain structures including the reward-generating neuronal network, such as monoaminergic or opioid peptidergic neurons. The persistence of α activity during the POST phase in trance participants in the present study compares well with long neurotransmitter residence times at synaptic junctions and the participation of an intracellular messenger in the postsynaptic neurons of the monoaminergic neurons or the opioid peptidergic neurons in the deep-lying brain structures [17–19].

It is known that slow waves such as θ waves are generated in the thalamus [20], and thalamic neurons are controlled by the brainstem reticular formation [21]. The brainstem is rich in neurons producing psychoactive substances that increase during possession trances [16]. Therefore, it is possible that increased θ signal amplitudes, observed in the present study, may also be related to increases in specific brainstem activities, with roles in the alteration of perception, consciousness, and possession trance behaviors.

The trance that participants showed increased β waves significantly during trance. This result may indicate that there were physiological changes related to the hyperarousal state during the possession trance; however, it is very likely that this was because of artifacts in the same frequency range as β waves, produced by body movements and myoelectricity. The interpretation of β waves therefore requires careful consideration.

In 1968, Prince noted that the neurophysiological aspects of possession states could be studied in two ways: using either electrophysiological or biochemical indices [3]. Nevertheless, no research had been carried out applying these two approaches to the same material of possession trances in the field until our study. We report electrophysiological indices of possession trances in this paper and have previously reported biochemical indices [16]. In a future study, simultaneous measurement of the two indices and analysis of their relationship may further characterize the neurophysiological mechanism underlying possession trances involving hyperarousal and hyperactive states.

Conclusion

The present study represents a preliminary effort toward the characterization of the neurophysiological mechanisms underlying naturally induced possession trances involving hyperarousal and significant increases in α and θ activity, suggestive of decreased cortical activity and increased activity of deep-lying brain structures including the brainstem.

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Conflicts of interest

There are no conflicts of interest.

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