Short Communication

Alpha-wave Characteristics in Psychophysiological Insomnia

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Abstract

Individuals with psychophysiological insomnia (Psych-Insomnia) would show raised cortical arousal through their initiating sleep. Frequent changes in the alpha activity can be indicative of visual cortical activation, even without visual stimulation or retinal input. Therefore, we aimed to investigate alpha-wave characteristics in Psych-Insomnia before and after sleep onset. In a case–control study, 11 individuals with Psych-Insomnia (age: 44.00 ± 13.27) and 11 age-, sex-, and body mass index-matched healthy individuals (age: 41.64 ± 15.89) were recruited for this study. An overnight polysomnography monitoring was performed. Alpha characteristics were calculated from wake before sleep onsets (WBSOs), wake after sleep onset, rapid eye movement, and nonrapid eye movement in the both groups. They include the alpha power and alpha frequency and their variability in the central region. In the WBSO, alpha activity and variability were higher in the Psych-Insomnia individuals compared to healthy individuals. In both groups, alpha frequency variability was observed at approximately 1 Hz. Alpha-wave synchronization in Psych-Insomnia individuals was higher than the group with normal sleep. Individuals with Psych-Insomnia have a lot of imagination in the wake before sleep, which can be caused by stress, everyday concerns, and daily concerns.

Keywords: *Electroencephalography, polysomnography, power-frequency variability, psychophysiological insomnia*

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Introduction

Electroencephalography (EEG) signals have provided new visions to the neocortical dynamic functions at a macroscopic level. EEG is analyzed to different frequency band, including delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (>30 Hz) by signal processing methods. One of the favorite EEG frequency bands is the alpha, which is detected either by EEG or magnetoencephalography in the range of 8–13 Hz[1,2] and predominately comes from the occipital zone during wakeful relaxation with closed eyes. Furthermore, it is detected during different sleep stages with various topographical representations. Alpha waves occur in central areas and migrate to posterior regions in rapid eye movement (REM) sleep. Furthermore, they are centralized in the occipital regions within intra-sleep awakenings.[2] EEG evidence has shown cortical generation mechanism and variation in functional correlations along the sleep-wake rhythm. In addition, the heterologous temporospatial characteristics of the electrical microstates in the ben the alpha band reveal a distinct geometry of active nervous structures under each alpha variant.[3]

EEG-based neural analysis has been used for investigating the neurophysiological bases of insomnia, but methodological concerns remain controversial. Based on the absence of alpha enhancement among patients with insomnia, Pedneault-Drolet and Bastien proposed that spectral analysis is not an optimum method for investigation of hyperarousal in insomnia sufferers during REM stages. Since cortical activity is more during REM stages, more activation in high frequencies can be related to sleep fragmentation.[4] Furthermore, researchers in other study proposed that sensorimotor and sensory zones in insomniac may yet be relatively active, even during the deep sleep.[5] Besides, frequency characteristics of alpha wave were investigated.[6,7]

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One of insomnia subtypes which has encouraged researchers to study alpha characteristics of brain waves is psychophysiological insomnia (Psych-Insomnia).[2,6,8,9] The common idiom "psychophysiology" got into common use in the 1960s and 1970s and represented the effort to prospect the psychological affections on physiological functioning through the utilization of electrophysiological measures such as EEG and EMG. Concept of psychophysiology confirms that the nature of Psych-Insomnia is determined by both physiological and psychological components. Physiological factors consist of conditioned arousal and wakefulness and raised neurohormonal activity. Both cognitive and behavioral elements are psychological factors. Cognitive factors include comprehend stress,[10] anxiety,[11] thoughtfulness, sudden memoirs, and attention bias. Behavioral factors include varied sleep scheduling (expanded sleep chance and snoozing) and the propensity to remain in bed when wakeful.[12] Despite a legitimate amount of data on insomnia and its overall prevalence, there are little data on Psych-Insomnia. According to ICSD-2, it is only estimated that the prevalence and clinical prevalence rates for Psych-Insomnia are 1%–2% and 12%–15%, respectively.[13,14]

Considering the functions involved in Psych-Insomnia,[15,16] the importance of alpha qualities in various studies,[17-19] and that there is not enough data on Psych-Insomnia specifically for the variables of interest,[13,14] it is imperative that characterization of alpha activity should be further investigated. This study focused on characterization of alpha variability in terms of both amplitude and frequency in Psych-Insomnia that has been largely ignored in past studies except a study only in the frequency variability in insomnia generally.[6] Considering that the brain cognitive, behavioral, and physiological function change EEG amplitude and frequency, three hypotheses were adjusted H1: both the alpha amplitude and frequency oscillate around a state-dependent set point; H2: the set-point amplitude and frequency evoke the neurophysiological state;[20,21] and H3: the amplitude and the frequency variability may be different between Psych-Insomnia and normal sleepers.

The study is organized into five sections. Section 1 describes the assumption of the study briefly along with the literature review for the problem investigation. The materials and methods with subsections including participants and procedure, insomnia diagnosis, artifact reduction, alpha-wave frequency, and variability analyses; statistical analysis is presented in section 2. The results and discussion are expressed in sections 3 and 4 in which demographic, polysomnography (PSG), Pittsburgh Sleep Questionnaire Index (PSQI), and alpha analyses findings are presented in the results. Conclusion based on all the outcomes is provided in section 5.

Materials and Methods

Participants and procedure

Inviting participants to sleep laboratory were done 1 day before the experiment. They were informed not to have coffee, cigarette, and heavy diet as well as snooze and sleep during the day of the experiment. They arrived to the laboratory at 9 p.m. The participants completed the questionnaires. The Pittsburgh Sleep Questionnaire was used to assess subjective components. Components include sleep quality, total sleep time (TST), sleep efficiency (SE), sleep latency, disturbances, sleeping medication, daytime dysfunction, and PSQI sleep quality index total. Then, the PSG procedure was explained to the subject. PSG room was standardized for any noise and visual stimulus based on international standards.[22] PSG signal recording was implemented based on the American Academy of Sleep Medicine guideline on all participants on the second night according to the method presented[23] into determine the presence, type, and severity of insomnia. For recording signal, we used PSG SOMNOscreen equipment, model SOMNOscreen™ plus PSG constructed by SOMNOmedics GmbH, Germany. PSG instrument includes electroencephalogram scalp sites (F3, F4, C3, C4, A1, A2, O1, O2, F3A2, F4A1, C4A1, C3A2, O1A2, O2A1); 256 Hz sampling rate in frontal, central, and occipital zones and six electrooculogram channels; 256 Hz sampling rate that all referenced to the mastoid of the left and right ears for rederivating a connected ears reference offline [Figure 1]. Rochester Electro-Medical silver-silver chloride electrodes were applied based on the International 10–20 System. In addition, three electromyogram channels (EMG, EMG1, and EMG2), electrocardiographic lead II; 256 Hz sampling rate, oxyhemoglobin saturation by pulse oximetry; 4 Hz sampling rate, and thoracic and abdominal respiratory effort (induction plethysmography) by inductance plethysmography (Pleth) using piezoelectric strain gauge; 128 Hz sampling rate, flow pressure, and flow temperature by oronasal thermistor and nasal air pressure transducer; and 256 Hz sampling rate was used.

The type of disorder was diagnosed by a sleep specialist. Objective data were derived from PSG results and also monitoring by expert technician. Subjective data were obtained based on subjects' reports and clinical interviews on the diagnosis of sleep disorders. Next, the final diagnosis was done by sleep specialists by comparing and matching objective and subjective data. Criteria for healthy group included: (a) TST of more than 7 h; (b) SE of more than 85%; and (c) sleep latency of fewer than 15 min. Furthermore, diagnostic criteria for Psych-Insomnia were considered according to ICSD-2 such as higher sleep onset latency, higher wakefulness after sleep onset, lower SE, increment of N1, and a decrement of delta waves.

Finally, 22 individuals (8 males and 14 females), 18–63 years (M = 42.81 years, standard deviation

[SD] = 14.34 years), were selected for the study, including 11 healthy and 11 Psych-Insomnia referred to sleep disorders researches center. All participants completed personal information and consent forms to participate in the study. Furthermore, they were checked in terms of confounding factors such as medication, drugs, alcohol, and psychiatric disorders. The study was conducted in two introductory sleep disorder classes including Psych-Insomnia (n = 11; age: 44 ± 13.27 years; body mass index (BMI): 26.6 ± 3.71 kg/m) and healthy (n = 11; age: 41.64 ± 15.89 years; BMI: 26.81 ± 4.28 kg/m) participants. Ethical approval for this work was done by the Ethics Committee of Kermanshah University of Medical Sciences (KUMS), and informed consent was completed all individuals.

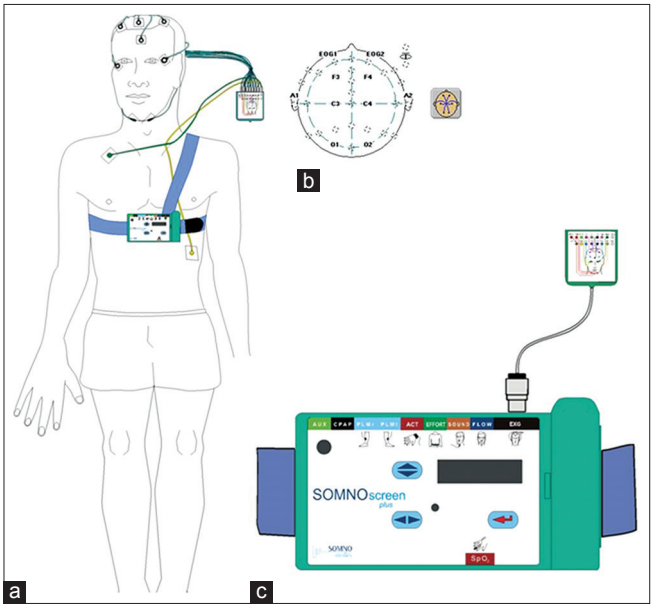

Figure 1: The international 10–20 system for Electrode montage: (a) Polysomnography electrode placement. (b) Placement of the electroencephalography electrodes on the scalp according to the recording 10–20 system. (c) View of the SOMNOscreen™ plus polysomnography constructed by SOMNOmedics GmbH, Germany

Artifact reduction

First, filtering was applied to the EEG signal to remove some artifacts. To do this, a high-pass filter, cutoff frequency of 0.5 Hz[24,25] was used to remove background signals, and low-pass filter, cutoff frequency of 35 Hz[25] was used to remove undesired signals and noise. One of the artifacts that should be eliminated in EEG processing is EMG. Some of the properties of EMG have a negative effect on the EEG. Since EMG contains a wide spectral distribution, it perturbed all of the bands of EEG. Removing this artifact and others such as cardiac activity and less common physiological artifacts is not possible with filtering. To eliminate them, independent component analysis by AMUSE algorithm was used as a blind source separation method. AMUSE algorithm is a subgroup of the second-order statistics spatiotemporal decorrelation algorithms.[26-28] AMUSE algorithm handles a simple principle that the estimated components tend to be less complex; they have better linear predictability than any blend of those sources.

Alpha-wave amplitude and frequency and their variability

Hypnogram of all participants was scanned in four conditions which include wake before sleep onsets (WBSOs), wake after sleep onsets (WASOs), REM, and non-REM (NREM). As demonstrated in Figure 2, power of the alpha, alpha frequency, and their variability were computed. For this purpose, we calculate power spectral density of separated signals on 30 s epochs in all of four conditions including WBSOs, WASOs, REM, and NREM stages. To calculate PSD, short-time Fourier transform was used. The data to be transformed could be segmented in epochs. Each epoch is Fourier transformed, and the result is added to a matrix which records the magnitude and phase for each segment in time and frequency. It can be expressed as:

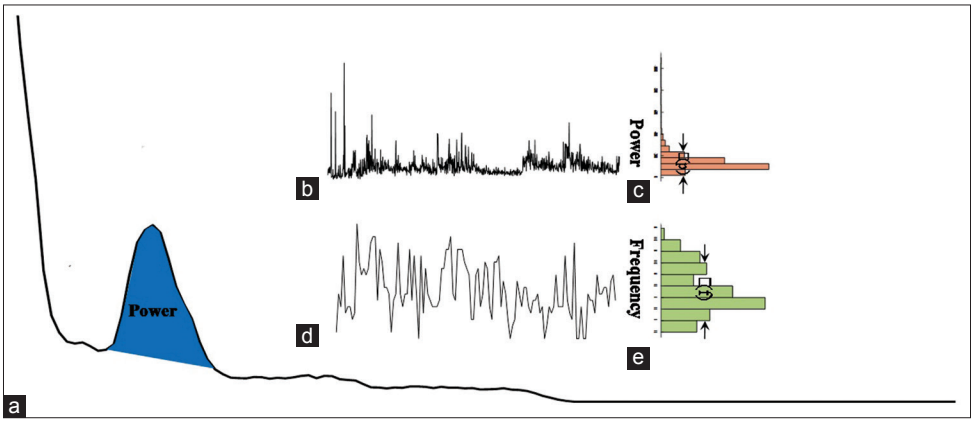

Figure 2: Extraction of alpha peak characters including power and frequency and their variability. (a) A power spectral density of an artifact-free segment electroencephalography activity shows alpha peak (blue surface). (b and c) A fluctuating sequence of power and its histogram; this sequence characterized by its average, indicating alpha power, and its standard deviation, δ(p), indicating variability of alpha power. (d and e) A fluctuating sequence of frequency and its histogram; this sequence characterized by its average, indicating alpha frequency, and its standard deviation, δ(f), indicating variability of alpha frequency

$$STFT\left(x[n]\right)(m,\omega)\equiv X(m,\omega)=\sum_{n=-\infty}^{\infty}x(n)w(n-m)e^{-j\omega n} \quad (1)$$

Where x(n) is the EEG signal and w(n) is window function as discrete and quantized variables.[29] Considering that PSG scoring is done in the period of 30 s, epoch time is 30 s, and the resolution of frequency in spectrum analysis is 0.1 Hz. The frequency resolution is specified as Fs/N in FFT. Therefore, after calculating power spectral, the alpha power was measured for each epoch. Next, in an epoch, total power and the frequency in the maximum power as alpha frequency were computed and saved in the time series. Finally, average power in all epochs was considered as alpha power. Average of alpha frequency as the final alpha frequency was measured using the calculation of histogram, and also, SD subtracted alpha frequency range was considered as the alpha variability. This process was applied to EEG channels C3-A1, C4-A1, C3-A2, and C4-A2. References A1 and A2 are right and left-ear electrodes, respectively. In this study, all signals, time to go to bed until awake in the morning, were processed.

Statistical analysis

Based on PSG results, the participants were divided into Psych-Insomnia and healthy groups. The Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL, USA, version 16.0) software was used for data analysis. The normal distribution of variables was investigated by Kolmogorov–Smirnov test. Sex was compared using Chi-square test, and BMI and age were compared by independent-sample *t*-test between the healthy and the Psych-Insomnia. Alpha characteristics were compared by independent sample *t*-test.

Results

Demographic findings

Twenty-two individuals that include 14 females aged among 18–63 years (43.2 ± 14.2) were recruited. Furthermore, 11 individuals were suffering from Psych-Insomnia (18.18% male; age: 44 ± 13.2 years; BMI: 26.6 ± 3.7 kg/m) and 11 individuals as healthy group (54.5% of males; age: 42.4 ± 15.4 years; BMI: 27.53 ± 4.24 kg/m). Demographic characteristics of the Psych-Insomnia and healthy individuals are demonstrated in Table 1. As indicated in table, the two groups were age, gender, and BMI matched.

Table 1: Demographic characteristics of the studied groups

	Healthy (*n*=11)	Psych-Insomnia (*n*=11)	*P*
Age†	41.64 (15.89)	44.00 (13.27)	0.709[a]
Sex (%)			
Female	5 (45.45)	9 (81.82)	0.183[b]
Male	6 (54.55)	2 (18.18)	
BMI	26.81 (4.28)	26.60 (3.71)	0.904[a]

Mean (SD). Age and BMI compared with [a]*t*-test and sex compared with, [b]Fisher's exact test. Means with the same superscript letters within a row were not significantly different (P>0.05). SD – Standard deviation; BMI – Body mass index

Polysomnography and Pittsburgh Sleep Questionnaire Index findings

We considered subjective score for sleep quality, TST, SE, sleep latency, disturbances, sleeping medication, daytime dysfunction, and PSQI sleep quality index total for subjective sleep characteristics. Furthermore, objective TST, SE, percent of sleep stages, wake index, and Apnea–Hypopnea index obtained from PSG were considered for analysis. According to *t*-test results, all subjective sleep characteristics other than disturbances and also objective TST, SE, and percent of REM sleep were significantly different between the Psych-Insomnia and healthy individuals ($P < 0.01$) [Table 2].

Alpha-wave analyses findings

Alpha-wave characteristics including the amplitude of power spectral density signal and frequency and their variability for all epochs of WBSOs, WASOs, REM, and NREM are presented in Tables 3 and 4. The investigated channels included C3A1, C3A2, C4A1, and C4A2.

Discussion

We analyzed the alpha waves in Psych-Insomnia and healthy individuals. The power and frequency of alpha and their variability were calculated. Alpha metrics were compared for all epochs of WBSOs, WASOs, REM, and NREM in the two groups.

Alpha power and variability

In WBSO, both the alpha activity and its variability were higher in the Psych-Insomnia individuals than in healthy individuals. This variability in Psych-Insomnia individuals can be indicative of a decrease and increase in the intensity of the alpha activity. Carole H *et al.* found such symptoms in a study conducted on psychophysiological insomniacs. They predicted that Psych-Insomnia individuals would show raised cortical arousal through their initiating sleep.[30] Another study found that frequent changes in alpha activity can be indicative of visual cortical activation, even without visual stimulation or retinal input.[31] High variability of alpha in Psych-Insomnia before starting sleep (WBSO), and in sleep stages (REM and NREM) in C4A2 and C3A2 [Table 3], as confirming the results in,[31] indicates that visual cortex is active even in the closed eyes. This may be because the Psych-Insomnia individuals have a lot of imagination in the wake before sleep, and imagination can also be caused by stress, everyday concerns, and daily concerns.

Two interesting results in our study were important. First, by comparing alpha activity in awakening states before and after initiating sleep, a difference was significantly observed Psych-Insomnia and healthy individuals. Before

Table 2: Demographic and sleep architecture between Psych-Insomnia patients and healthy participants - *t*-test

	Healthy	Psych-Insomnia	*P*
Subjective			
Score of subjective sleep quality	1.45±0.93	2.81±0.40	0.00025
SOL (score)	1.18±1.17	3.00±0.00	4.72E-05
TST (score: >7 h=0, 6-7 h=1, 5-6 h=2, <5 h=3)	1.27±1.10	2.63±0.92	0.005138
SE (score: >85%=0, 75%-84%=1, 65%-74%=2, <65%=3)	1.09±1.30	2.72±0.90	0.002674
Disturbances (score)	1.27±0.46	1.45±0.68	0.476564
Sleeping medication (score)	0.27±0.90	2.36±1.02	5.89E-05
Daytime dysfunction (score)	0.54±0.68	1.45±1.12	0.033563
Sleep quality index total	7.09±3.59	16.45±2.38	5.61E-07
Objective			
TST (hours)	6.69±1.28	4.99±1.86	0.02
SE (%)	85.60±15.54	64.92±23.65	0.02
Wake index	4.52±5.97	15.636±16.91	0.05
REM (TIB)	6.78±6.55	17.05±14.24	0.04
N1 (TIB)	42.26±17.61	44.27±12.94	0.76
N2 (TIB)	22.83±13.75	20.76±10.15	0.69
N3 (TIB)	28.12±14.59	17.89±18.92	0.17
AHI	2.59±1.93	2.80±1.46	0.76

Statistical analysis for the equality of the mean values between two groups was evaluated using *t*-test ($P<0.05$). Psych-Insomnia – Psychophysiological insomnia; TST – Total sleep time; SE – Sleep efficiency; SOL – Sleep onset latency; REM – Rapid eye movement; N1 – Stage 1 of sleep; N2 – Stage 2 of sleep; N3 – Stage 3 of sleep; AHI – Apnea-Hypopnea index

Table 3: Power of the alpha and its variability for all epochs of wake before sleep onsets, wake after sleep onset, rapid eye movement stage, and nonrapid eye movement stage

	Amplitude		*P*	Variability		*P*
	Healthy	Psych-Insomnia		Healthy	Psych-Insomnia	
WBSO						
C3A1	343.24	380.63	0.81	246.89	886.34	0.27
C3A2	339.65	374.69	0.78	205.07	618.95	0.14
C4A1	355.74	402.39	0.77	272.53	896.43	0.28
C4A2	301.03	353.68	0.66	198.62	637.37	0.15
WASO						
C3A1	410.90	187.78	0.05	619.86	177.97	0.20
C3A2	477.12	214.09	0.06	1367.09	284.43	0.28
C4A1	437.65	207.24	0.05	1006.19	190.65	0.15
C4A2	456.21	196.74	0.07	1647.79	284.75	0.21
REM						
C3A1	252.42	98.58	0.04	187.73	102.48	0.11
C3A2	258.21	124.29	0.13	164.51	343.82	0.50
C4A1	250.57	104.37	0.04	167.58	110.71	0.20
C4A2	224.01	108.57	0.14	133.07	345.90	0.43
NREM						
C3A1	252.90	76.20	0.02	244.28	96.99	0.02
C3A2	271.90	145.32	0.25	280.31	1193.98	0.42
C4A1	244.74	82.22	0.02	226.64	98.17	0.02
C4A2	228.66	130.49	0.32	241.63	1184.85	0.40

Statistical analysis for the equality of the mean values between two groups was evaluated using *t*-test ($P<0.05$). Psych-Insomnia – Psychophysiological insomnia; WBSO – Wake before sleep onset; WASO – Wake after sleep onset; REM – Rapid eye movement stage; NREM – Nonrapid eye movement stage

initiating sleep, alpha activity was higher in Psych-Insomnia individuals with much more variability. However, after initiating sleep, the results are completely reversed, so that alpha activity was higher in healthy individuals with much more variability. Second, by measuring alpha activity, although it is more in healthy individuals, variability is different in the use of the A1 reference versus A2 reference. Using A1 reference, both in REM and NREM, there is

Table 4: Frequency of alpha and its variability for all epochs of wake before sleep onsets, wake after sleep onset, rapid eye movement stage, and nonrapid eye movement stage

	Frequency		*P*	Variability		*P*
	Healthy	Psych-Insomnia		Healthy	Psych-Insomnia	
WBSO						
C3A1	8.99	9.99	0.29	0.93	0.73	0.24
C3A2	9.09	9.84	0.44	0.86	0.69	0.32
C4A1	9.10	10.04	0.33	0.94	0.73	0.23
C4A2	9.10	9.89	0.41	0.85	0.67	0.34
WASO						
C3A1	9.48	8.70	0.40	0.99	0.78	0.18
C3A2	9.57	8.63	0.31	1.03	0.70	0.05
C4A1	9.51	8.72	0.40	0.943	0.77	0.30
C4A2	9.64	8.64	0.29	0.94	0.71	0.17
REM						
C3A1	9.32	8.55	0.40	1.13	0.79	0.02
C3A2	9.38	8.52	0.35	1.21	0.76	0.002
C4A1	9.42	8.56	0.35	1.09	0.81	0.05
C4A2	9.58	8.54	0.27	1.17	0.76	0.006
NREM						
C3A1	9.48	8.26	0.20	1.30	1.02	0.15
C3A2	9.51	8.18	0.15	1.44	0.94	0.02
C4A1	9.46	8.23	0.19	1.29	0.99	0.11
C4A2	9.66	8.17	0.11	1.35	0.94	0.05

Statistical analysis for the equality of the mean values between two groups was evaluated using *t*-test ($P<0.05$). Psych-Insomnia – Psychophysiological insomnia; WBSO – Wake before sleep onset; WASO – Wake after sleep onset; REM – Rapid eye movement stage; NREM – Nonrapid eye movement stage

more alpha variability in healthy individuals, while using reference A2, it is more in Psych-Insomnia individuals.

There are two possibilities for this issue. One is that the brain's activity is different on the right and left regions. Maybe, it implies to change activity in the two hemispheres within the initiating sleep process or the wake-sleep transition.[32] Cerebral zones are known to fall asleep at different times. The initiating sleep process follows an anterior–posterior patch. Therefore, when frontal zones have only fallen sleeping, central zones are only sleepy and occipital zones are awake.[33,34] Yet, what occurs in both hemispheres is questionable. Based on EEG data, the average amplitude of both hemispheres differenced in the beta-to-delta ratio.[35] By analyzing electroencephalogram within the transition to sleep from sleeplessness, other investigations have resulted a reduction in interhemispheric coherence on sleep onset.[33,36,37] Probably, within the initiating sleep, all bands but not beta reverse to predominate at the right hemisphere.[36-38] Based on these data, there is a switch in hemispheric incommensurability for initiating sleep.

The difference in the amount of noise in A1 and A2 references can also be another possibility. In a study, the asymmetry of alpha activity has been observed when choosing different references. In this study, by selecting different references including common reference (Cz), converted to computer-averaged ears (A1 + A2), and average reference (AR), the results showed that the reference scheme validation is related to the signal-to-noise ratio of the electrical activity at target and reference places.[39]

Alpha frequency and variability

In both groups, alpha frequency variability was observed at approximately 1 Hz. In a research, the same variability was achieved.[6] This amount of variability implies that the alpha sub-band activity should also be separately investigated. Because the variation of alpha frequency indicates that there are several alpha activities.[40]

Based on the finding, alpha frequency variability in Psych-Insomnia individuals is less than healthy individuals, which indicates the synchronization of alpha waves in them. Hence in terms of frequency, setting up a set-point in Psych-Insomnia patients is more plausible and it can be said that H2 assumption is a valid assumption. This means that the probability of a neurophysiological state is higher in Psych-Insomnia individuals.[20,21]

In a study performed on posttraumatic stress disorder patients, alpha peak frequency was evaluated. The results revealed which frequency of alpha peak was higher.[41] In this study, in WBSO, the results indicate that the frequency of alpha peak is also higher in Psych-Insomnia individuals. Therefore, the probability of having stress symptoms before going to bed is expected for them.

Conclusions

The significant difference in the results of before and after sleep onset proves the importance of investigating WBSOs and WASOs. Due to more alpha variability in WBSOs in Psych-Insomnia individuals which can be a sign of visual cortical activation, even without visual stimulation or retinal input, we conclude that the psychophysiological insomniacs have a lot of imagination in the wake before sleep and it can also be caused by stress, everyday concerns, and daily concerns. Furthermore, REM-alpha variability results by considering two different references showed that the asymmetry of alpha activity should be considered.

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Conflicts of interest

There are no conflicts of interest.

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