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Original Article:

Daytime qEEG Hyperarousal Model in Psychophysiological Insomnia

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Abstract

Introduction: To address a hyperarousal model with daytime qEEG frequency band fluctuations in frontal, central, and parietal regions in Psychophysiological insomnia(PPI) compared to good sleepers(GS).

Materials and Methods: qEEGs in resting states of Patients with Psychophysiological insomnia (n = 16) were contrasted with those with good sleep (n = 20). To serve this purpose, a daytime hyperarousal model is developed with a linear model.

Results: psychophysiological insomnia(PPI) recorded significantly high beta band activity in all brain regions as their eyes closed condition compare to the control. In addition, low frequency in the frontal region and high frequency in the parietal and central regions were detected in eyes open conditions.

Conclusion: The hyperarousal model results suggest that patients with psychophysiological insomnia were undergoing daytime neurophysiological hyperarousal because of upregulation in arousal and low-frequency band fluctuation in the frontal region in eyes closed condition is the most effective index.

Keywords: Psychophysiological Insomnia, qEEG, hyperarousal model

1. Introduction

Sleep disorders are frequently encountered in pediatric treatments since over 3.7 percent of the global population suffers from this condition [1]. This value is significantly lower than the numbers in epidemiological studies. This might indicate that primary care providers haven't diagnosed a sufficient number of patients with sleep disorders.

ID (abbrev. Insomnia disorder) refers to challenges in falling asleep, remaining asleep, or waking up too soon. During the day, ID might cause fatigue, moodiness, and cognitive challenges [2,3]. As mentioned in the International Classification of Sleep Disorders (ICSD-3) [4,5], ID refers to the consistency of insomnia symptoms for a minimum of three times a week which continues for more than 3 months and it is referred to as a distinct disease rather than as a disease that is solely dependent on other conditions [6]. The increasing prevalence of ID (3.9–22.1%) is likely caused by genetic and psychosocial factors such as the aging population, significant stress levels, and the rising rate of depression and anxiety in modern communities. Although ID is characterized by significant medical and mental outcomes, its pathophysiology is not known properly [4,7-11].

Insomnia is presumed to result from dysfunctional

perceptions, maladaptive behavior (e.g., short sleep during the day and staying awake late into the night), worries about the outcomes of being deprived of sleep, and physiological and cognitive stimulation.

Meanwhile, insomnia could be the outcome of the typical sleep non-activation prevention (de-arousal) process. The major distinctions between good sleep and sleep deprivation (e.g., insomnia) are highlighted in the following. There are numerous cognitive differences between proper sleepers and people who undergo psychological insomnia. Undisturbed low arousal (i.e., waking up or de-arousal) is a typical sleep process that enables homeostasis and satisfies circadian rhythm requirements to boost sleep. However, insomnia is the outcome of significant arousal as a result of trying to fall asleep. A typical sleep, a partly spontaneous psychophysiological event, can be influenced by focused attention and direct attempts to constrain its symptoms.

Insomnia disorder might be diagnosed when sleeping challenges and relevant dysfunctions during the day are found while enough time and chance to sleep are available.

Psychophysiological insomnia (PPI), as a subtype of insomnia, should be considered as an individual undergoing stress-ridden condition. As a case of independent insomnia, PPI possesses its pathophysiology. It is presumed to be a learned condition as it originates from conditioning in which sleep-related conditions and hyperarousal are found. In PPI cases, poor sleep boosts sleep-associated anxiety, and this adds to hyperarousal even more. Due to the consistent experience of sleepless nights, PPI patients will worry more about proper sleep [12]. Although insomnia is a common disorder with negative impacts on functioning during the day, some patients experience “pure” psychophysiological insomnia; the disorder is typical with mental disorders [13].

Furthermore, EEG-based studies of patients with insomnia disclosed significant intensification of highly frequent NREM sleep (i.e., nonrapid eye movement) and REM sleep (i.e., rapid eye movement) during the sleep initiation period [14-21].

Patients with PPI also record shorter total sleep time (TST) for the nighttime but longer sleep latency during the daytime [22-25]. They also experience more high-frequency power as they are awake [26,27].

Previous research on insomnia highlighted that hyperarousal continues throughout the daytime and is not constrained to nighttime sleep. Thus, this hyperarousal state remains for 24 hours. Consequently, insomnia is correlated not only with low-quality sleep at night, but also with psychological terminology and conditions.

However, Previous studies on EEG have predominantly focused on investigating the hyperarousal state of the cerebral cortex during bedtime, before sleep, or shortly after sleep onset in individuals with insomnia. In addition, few other studies were done during the phases of increasing melatonin mainly in the late evening. Hence, there are several complications when it comes to the study of resting EEG when daily routine activity is intense.

This study intends to support the indicators of hyperarousal specifications of psychophysiological insomnia during the daytime through determining the resting EEG signals.

2. Materials and Methods

Participants

Sixteen patients with psychophysiological insomnia and 20 good sleepers visited the Sleep Research Center, Shiraz University of Medical Sciences, and Dana Brain Health Institute and agreed to participate in the study.

The participants were screened through polysomnography (PSG) evaluation a month before the start of the study. To do so, SOMNOscreen ™ plus model (Somnomedics, Germany) was used and this took 8 hours minimum. Meanwhile, a somnologist interviewed all of the patients to ascertain that they meet the diagnostic requirements. This included psychiatric interviews covering each ICSD psychophysiological insomnia, overnight PSG, Pittsburgh sleep quality index (PSQI), and insomnia severity index (ISI)

Neuropsychiatric drug use, and other medical-neurological or psychiatric disorders were among the factors which excluded several patients. The patients with insomnia exposed to a high risk of sleep apnea and restless legs syndrome were removed from this study.

Finally, the PPI subjects with pure psychophysiological insomnia diagnosis(selected by expert somnologist, PSG results are as listed in Table 1) who recorded higher than 5 scores on the Pittsburgh Sleep Quality Index (PSQI) [28] and higher than 8 scores on Insomnia Severity Index (ISI) [29] with no other insomnia signs were included in the study. In contrast, the good sleepers had no current or past neurological or psychiatric disorders and their total PSQI and ISI scores were less than 5. In the end, 16

Table 1. Clinical characteristics and PSG variables of participants (M, SD).

Sleep variables	PPI	GS	*P*-Value
Time In Bed (TIB) (min)	445.3(23)	483.6(26.6)	<001
Total Sleep Time (TST) (min)	370.5 (61)	443.1(23.5)	<0001
Sleep Efficiency (%)	83.2(13.2)	95.3(3.9)	<0001
Sleep Latency (min)	59.2(23.6)	21.5(9.7)	<0001
Cyclic Alternating Pattern (CAP Rate) %	33.6 (6.3)	48.5(7.2)	<0.001
# Wake (Index)	22 (10)	4.1(2)	<001
Stage N1 (%) TST	7.9	4.9	<001
Stage N2 (%) TST	55.8	53.3	**
Stage N3+N4 (%) TST	15.9	19.11	<001
Stage REM (%) TST	20.4	23.5	<001
NREM Sleep (%) TST	79.8	76.2	<001
* Spontaneous MA%(out of Total Arousals)	76.5	22.7	<0001
HR(average heart rate)	73	55.4	<001

*Total arousals contain Respiratory MA, Flow Limitation MA, Desaturation MA, PLM MA, LM MA, Snore MA, Heart rate MA, and Spontaneous MA. **p > .05(Not Significant)

PPI patients and 20 control subjects were analyzed (Figure 1). Every participant received all information regarding the study and they then were approved to announce their agreement to participate.

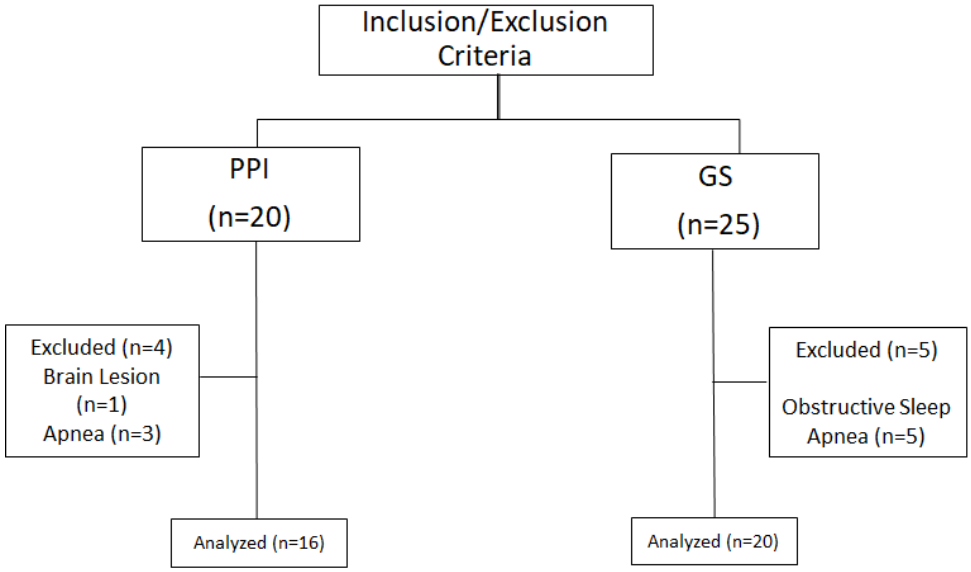

Figure 1: Flow of participants in PSG and QEEG test

The complexity of subtypes of insomnia-related disorders could have made the process for computational modeling subject to several confounders leading to imprecision upon analyses. Given the fact that primary insomnia includes psychophysiological insomnia, idiopathic insomnia, and paradoxical insomnia or sleep state misperception, we had to funnel down and isolate specific subtype which was the clinical diagnosis made by the sleep expert and based on the 1th edition of the International Classification of Sleep Disorders (ICSD-10). We perused with our computational model based solely on

our study population of patients with psychophysiological insomnia (PPI) to deliver precision. Also, psychophysiological insomnia is one of the most common forms of insomnia which can emerge due to chronic affective disorder, somatized tension anxiety, and negative thought conditioning which ultimately hamper sleep integrity.

In addition, the duration of suffering from insomnia symptoms was balanced across all included patients and was reported as 36±6 months.

The study design was addressed and approved by University of Tehran, Institute of cognitive science (No: IR.UT.IRICSS.REC.1401.021).

EEG Recording and Analyses

Every participant was asked to stop consuming caffeinated or alcoholic drinks and not to smoke for 24 h prior to EEG measurements. Physiological signals were recorded in a sound/light-proof room from 10:00 am to 4:00 pm so as not to be bothered with external noise and other factors. The EEG data for open and closed eyes are presumed to represent different conditions. As a result, EEG records were captured by shifting between two conditions; the eyes open condition (EO) and eyes closed condition(EC) scenarios, and each condition was analyzed twice as each lasted 2 minutes [30].

EEG records were developed by Neuron-Spectrum-AM-Neurosoft device (AMBULATORY WIRELESS EEG/PSG RECORDER) with the international 10-20 electrode system. Both cap electrodes (the device is equipped with a special connector) and EEG electrodes can be used for the EEG acquisition. Linked-ears reference montage, 256 Hz/S sampling rate, and lastly a 60Hz notch filter was used for signal processing and artifact reduction.

Version 3.0.5 of Neuro Guide was used to analyze EEG data. Then, other artifacts such as eye muscle shifts were removed visually and automatically inspected. At least, a 60-second period of EEG signal (split-half reliability >95%, test-retest reliability >90% and with no artifact) was approved and then a fast Fourier transform algorithm (FFT) was applied to confirmed EEG data. Delta band (1–4 Hz), theta band (4–8 Hz), alpha band (8–12 Hz), beta band (12–25 Hz), and high beta (25–30 Hz) were defined as certain EEG power spectra.

Statistical evaluation

The statistical analysis was performed in IBM SPSS software. To highlight the distinction between the two groups, a linear model (LM) was used for clinical characteristics. The scores of the Beck Depression Inventory (BDI) questionnaire as depression level indicator and the Beck Anxiety Inventory (BAI) questionnaire as anxiety level indicator were used as covariates in analyzing the model because these two characteristics are founded crucially higher in patients with psychophysiological insomnia. More than that, 19 channels (out of 21) were averaged into 3 basic regions (Figure 2).

3. Results

Clinical characteristics of PPI and GS

No significant difference in age was found between patients with PPI and GS (Table 2). In comparison with GS, PPI recorded higher scores on PSQI and ISI. Based on Epworth Sleepiness Scale (ESS) [31], there are no significant differences in daytime sleepiness between the two groups. This suggests that PPI grudged more about daytime sleepiness but it was not statistically significant in comparison with patients with chronic insomnia [30]. In addition, the BDI and BAI scores for PPI were much higher compared to GS.

EEG analyses

Eyes Open condition

The delta band ($x^2 = 151.85$, $p < 0.001$) and high beta band ($x^2 = 4.19$, $p < 0.050$) had higher impact than other frequency bands on groups. The interaction between group and region shows significant differences in every brain frequency band, too; the results of the post-hoc test specified that the frontal region recorded much higher absolute power compared with other regions in the delta band ($x^2 = 621.75$, $p < 0.001$) and theta band ($x^2 = 11.54$, $p < 0.050$) as well as central and parietal regions recorded higher absolute power in the beta band ($x^2 = 15.1$, $p < 0.050$) in patients with PPI.

Eyes closed condition

There were significant differences in the high beta band in group and group-region interaction (Table 3b). Meanwhile, the post-hoc test results revealed that the high beta band of the PPI had higher absolute power compared with GS in all regions ($x2 = 11.28$, $p < 0.001$).

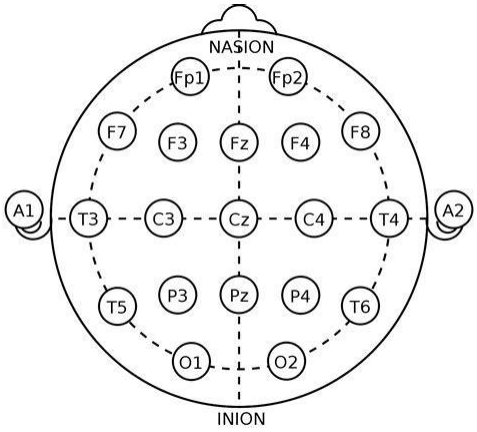

Figure 2. EEG channels selection

Table 2. Demographic and clinical characteristics of participants (Mean, Standard Davison)

	PPI (n = 16)	GS (n = 20)	T-Values	P-Value
Male	9	11		
Female	9	7		
Age	43 ± 5	40 ± 6	-0.32	0.55
PSQI	11.88 (3.98)	3.75 (0.85)	8.90	<0.0001 ***
ISI	15.75 (2.05)	2.95 (1.23)	17.02	<0.0001 ***
ESS	7.03 (3.28)	6.32 (3.56)	2.16	0.05
BAI	7.33 (2.89)	3.20 (2.01)	4.04	0.02 *
BDI	11.01 (4.27)	5.35 (3.20)	4.61	0.009 *

Note: The data is given in terms of mean (SD). PSQI, Pittsburgh Sleep Quality Index; ISI, Insomnia Severity Index; ESS, Epworth Sleepiness Scale; BDI, Beck Depression Index; BAI, Beck Anxiety Index;
* p < 0.050, *** p < 0.0001.

Table 3a. The Absolute power of frequency Bands in the EO condition.

PPI (n = 16)	GS (n = 20)	Group x^2	Group*Region x^2	Post-Hoc Test
Delta Band		151.85 *	621.75 **	
Frontal	27.52 (8.75)	20.55 (4.13)		$p < 0.001$
Central	14.50 (7.21)	14.80 (6.41)		
Parietal	13.33 (5.90)	14.09 (4.62)		
Theta Band		2.21	11.54 *	
Frontal	10.63 (5.71)	8.70 (3.97)		$p < 0.050$
Central	9.45 (2.73)	8.98 (4.74)		
Parietal	8.35 (3.34)	8.29 (3.09)		
Alpha Band		15.85	548.2 **	
Frontal	7.76 (4.05)	8.35 (3.46)		
Central	9.91 (2.69)	11.29 (8.74)		
Parietal	15.29 (6.64)	20.87 (10.02)		
Beta Band		0.15	15.1 *	
Frontal	7.72 (3.90)	7.87 (3.21)		
Central	9.49 (4.64)	9.10 (3.60)		$p < 0.050$
Parietal	8.26 (5.50)	9.74 (3.43)		$p < 0.050$
High Beta Band		4.15 *	11.28 **	
Frontal	2.38 (1.39)	2.66 (2.05)		
Central	2.30 (1.79)	1.72 (1.52)		
Parietal	1.12 (0.72)	0.95 (0.41)		

Note: Difference between PPI and GS groups in the eyes-open (EO) condition.
* p < 0.050, ** p < 0.001

Table 3b. The Absolute power of frequency Bands in the EC condition.

PPI (n = 16)	GS (n = 20)	Group x^2	Group*Region x^2	Post-Hoc Test
Delta Band		0.001	3.43	
Frontal	21.29 (10.31)	21.03(9.72)		
Central	13.74 (5.73)	13.11 (۶.34)		
Parietal	16.03 (5.97)	15.99(7.98)		
Theta Band		0.418	1.02	
Frontal	12.14 (4.29)	10.08(4.45)		
Central	10.18 (4.94)	9.23 (4.94)		
Parietal	12.92 (3.76)	11.58 (4.59)		
Alpha Band		0.045	2.05	
Frontal	18.71 (10.07)	17.14 (11.۴8)		
Central	21.66 (10.66)	21.98 (10.00)		
Parietal	48.59 (21.13)	47.33(20.25)		
Beta Band		0.008	2.25	
Frontal	7.21 (2.16)	7.01(2.81)		
Central	7.27 (4.34)	7.64(۲.01)		
Parietal	13.67 (5.70)	13.15 (5.94)		
High Beta Band		355.202*	456.472*	
Frontal	1.10(0.51)	0.97 (0.57)		p < 0.001
Central	1.62 (0.90)	1.11 (0.56)		p < 0.001
Parietal	1.45 (0.73)	1.24 (0.63)		p < 0.001

Note: Difference between PPI and GS groups in the eyes-closed (EC) condition.
* p < 0.050, ** p < 0.001

Daytime qEEG and Nighttime PSG characteristics correlation

Table 4 indicates the correlation between Daytime qEEG and Nighttime PSG characteristics in patients with PPI. Results of the Pearson correlation represent that there is a significant small negative relationship between Frontal Delta and Frontal Theta band in eyes open condition and the Frontal High Beta band in eyes closed condition from daytime qEEG characteristics and Sleep Efficiency, Microarousal, N1 sleep stage, and REM sleep stage from PSG characteristics.

Table 4: Correlation

Variables		NIGHTTIME			
		SE	MA	N1	REM
DAYTIME	Frontal Delta(EO)	r = -0.96 *p* < .001	r = - 0.78 *p* < .001	r = -0.91 *p* < .001	r = -0.94 *p* < .001
	Frontal Theta(EO)	r = -0.97 *p* < .001	r = - 0.49 *p* < .04	r = -0.92 *p* < .001	r = -0.97 *p* < .001
	Frontal High Beta(EC)	r = -0.85 *p* < .001	r = - 0.70 *p* <.001	r = -0.95 *p* < .001	r = -0.96 *p* < .001

SE: sleep efficiency, SL: sleep latency, N1: stage one, REM: rapid eye movement stage HR: heart rate, MA: Spontaneous Micro-Arousal, EO: Eyes Open condition,

4. Discussion

This study intended to address the question that whether psychophysiological insomnia may cause hyperarousal during the daytime and how the nighttime PSG and daytime qEEG correlate. The purpose was to identify neurophysiological factors in the brain region and the most common frequency bands in patients with PPI. The results suggest these patients experience neurophysiological hyperarousal during the day [30].

It should be noted that the frontal region of patients with PPI showed higher activity in the delta and theta bands and central and parietal regions showed higher beta band activity in the eyes open conditions [30].

These consequences corroborate previous findings with regard to high-frequency EEG activity during the

sleep-start time and Non-REM sleep stage [14,19,20,32-36].

In total, these findings suggest that hyperarousal continues during the daytime. The waking-state EEG data were collected in the late evening [27]. However, lower power is found in the alpha band in the Eyes open condition and higher power in the beta band in the eyes closed condition in patients with insomnia. In this research, the goal was to address the probability of this situation in patients with PPI specifically.

The connection between subcortical and cortical brain regions is correlated to slow and fast wave activity which is called cross-talk [37,38]. It is noted that higher slow-fast wave coupling considers a higher control of attention [39] and level of cortisol [40].

In this regard, the findings imply that patients with PPI possess higher cognitive activity.

All brain regions showed significantly higher beta band activity in the eyes closed condition compared with the eyes open condition.

The control of attention process (such as inhibition control) or perception and sensation correlation is integrated to increase fast wave activity [41,42]. Since the majority of patients with insomnia face difficulties suppressing their unwanted thoughts and concerns [43,44], significant high-frequency activity may point to cognitive impairments at the different neurophysiological levels. The high-frequency activity in the eyes closed condition, as well as slow-fast frequency association in the eyes open condition, were found.

Based on the findings of this study, patients with PPI might encounter various difficulties under both eyes closed and open conditions. For instance, in eyes opened conditions, they are vigilant to external stimuli that are caused by higher perceptual load exposed to a state of high tension and anxiety as exhibited in their cortical activation.

By contrast, closing eyes is an attempt not to be aroused by blocking the external stimuli entry.

Nonetheless, this effort may fail because of internal arousals or stimuli same as pre-sleep state difficulties at night.

All in all, daytime hyperarousal refers to the condition of those individuals who have unusual sleep-arousal regulation causing them to go to sleep with difficulty [45]. This situation arises from daytime cortical alertness and it covers sleep stages and the pre-sleep period. Patients with PPI have a hyper-aroused brain, which turns the sleep process from a requirement to a challenge. This complication is recognizable by a simple daytime EEG test [46].

5. Conclusion

The hyperarousal model results suggest that patients with psychophysiological insomnia were undergoing daytime neurophysiological hyperarousal since upregulation in arousal and low-frequency band fluctuation in the frontal region in eyes closed condition is the most effective index.

This study perceived an EEG pattern during the day and it recommended a reasonable measurement approach for evaluating psychophysiological insomnia. Previously, polysomnography (PSG) was the main method to identify all subtypes of insomnia which is costly and time-consuming. Furthermore, the correlation between PSG and qEEG characteristics indicates that there is a small negative correlation between sleep efficiency as the main factor of night sleep monitoring and daytime unregulated hyperarousal.

However, this study had some limitations. First, it focused on patients with psychophysiological insomnia and it may be difficult to distinguish PPI from the other subtype of insomnia disorders such as chronic insomnia. Further, other physiological characteristics like heart rate might be investigated to compromise more variables. In addition, the Gamma brain wave has the highest brain frequency and is associated with peak concentration and high levels of cognitive functioning; this should be taken into account in future research.

In closing, this study contributed to underestimating daytime and nighttime biological markers correlation and effectiveness in patients with psychophysiological insomnia.

Ethical Considerations

Compliance with ethical guidelines

The procedures used in this study adhere to the tenets of the Declaration of Helsinki. Approval was obtained from the ethics committee of University of Tehran, Institute of cognitive science. (No: IR.UT.IRICSS.REC.1401.021).

Funding

Informed consent was obtained from all individual participants included in the study.

Author's contributions

CAP, Cyclic alternating pattern

EEG, Electroencephalogram
GS, Good Sleeper
ICSD, International Classification of Sleep Disorders
ID, Insomnia Disorder
ISI, Insomnia Severity Index
MA, Micro arousals
N-REM, nonrapid eye movement
PPI, Psychophysiological Insomnia
PSG, polysomnography
PSQI, Pittsburgh Sleep Quality Index
REM, Rapid eye movement
SE, Sleep Efficiency
TST, total sleep time
SMO, Sequential minimal optimization
BDI, Beck Depression Inventory
BAI, Beck Anxiety Inventory
ESS, Epworth Sleepiness Scale

Conflict of interest

The authors declare no competing interests.

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