ORIGINAL ARTICLE

A Meta-analysis of Quantitative Electroencephalography (EEG) in Insomnia Sleep Disorder

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Unaiza Memon[1]
Muhammad Umair[1,2]
Anwara Khan[1,3]
Faisal R. Jahangiri [1,2,3,4]

[1]Global Innervation LLC, Dallas, Texas, USA.
[2]Neurocare.AI, Prosper, Texas, USA
[3]Department of Neuroscience, School of Behavioral & Brain Sciences, The University of Texas at Dallas, Richardson, Texas, USA.
[5]Labouré College of Healthcare, Milton, Massachusetts, USA.

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ABSTRACT

Electroencephalograms (EEG) can help detect sleep disorders, including insomnia and stress-related disorders. Analysis of sleep EEGs is essential for providing an objective and statistics-based assessment of EEG power spectra in patients with Insomnia Disorder (ID) using meta-analytic methods. It was characterized by increased high-frequency activity in the beta and/or gamma range and decreased activity in other frequency bands. The cause of these alterations was unknown, but cortical hyperarousal may be responsible. Benzodiazepine users exhibited increased sigma activity and decreased delta and theta activity overnight than did good sleepers, except for increased theta activity during wakefulness. This review of studies had several limitations, including inconsistent subdivisions of EEG spectral bands across studies, a small number of studies reporting data on EEG power during REM sleep, and a need for studies reporting results during daytime and sleep.

INTRODUCTION

The electroencephalogram, commonly known as EEG, has been used globally for recording electrical human brain activities for diagnosis and treatment purposes. One of the applications of EEG is to detect sleep disorders, including insomnia and stress-related disorders, depending on the severity of the disorders [1]. Insomnia disorder (ID) has been identified as a persistent difficulty initiating and maintaining sleep and waking up earlier than desired [1]. ID has become the second-most common mental disorder: approximately one-third of adults in the general population experience at least one symptom of insomnia, with about 10% meeting the diagnostic criteria for ID [2]. Insomnia is characterized by [3]. Frequently waking up during the night [4]. Waking up early [5]. A general feeling of exhaustion [1]. Deficit concentration prowess [6]. Feeling slow and not refreshed during the day [7]. The effects generated due to

insomnia are (i) Daytime sleepiness, (ii) Irritable mood, (iii) Increased possibility of workplace accidents, (iv) Inability to operate machinery effectively (v) Lapse in concentration while driving [7]. Sleep is a complex physiological process of restoration and renewal for the body [6]. The physiological condition depended on the findings of electroencephalogram (EEG), electro-oculography (EOG), and electromyography (EMG) [1]. The electroencephalogram (EEG) exhibited marked variations across the vigilance states and was a primary variable in sleep research [6]. Analysis of sleep EEGs is an essential research branch of medicine because of its clinical applications in brain dynamics research [3]. Some researchers have declared that spectral analysis might represent an objective method for examining insomnia's pathophysiological mechanisms [2]. Other studies compared EEG spectral features during rest state wakefulness, sleep-onset, non-rapid eye movement (NREM), and sleep between patients with insomnia and good sleepers. Most studies reported that ID is associated with significantly increased EEG activity in high-frequency bands (beta/gamma) during these periods, which might reflect cortical hyperarousal [2]. The present study pursued an objective and statistics-based assessment of EEG power spectra in patients with Insomnia Disorder (ID) using meta-analytic methods [4].

MATERIAL AND METHODS

Data sources

All the criteria for sleep disorder insomnia and techniques were researched through the study using PubMed, ScienceDirect ResearchGate, and Scholar Articles database sources.

Study selection

The population included males and females aged <18 and >65. Inclusion criteria were case-control design, international classification of sleep disorder (ICSD), and outcomes, including comparing the spectral power of six frequency bands: alpha, theta, gamma, delta, beta, and sigma. Also, statistical information. Exclusion criteria were under the following conditions focus on comorbid medical, psychiatric, and lack of corresponding control group.

Experiment setup

The EEG gold cup electrodes were placed on the scalp according to the 10-20 electrode placement at C3, C4, O1, O2, and A1 (mastoid area). EEG data were recorded for 5 mins. EEGs were derived from the C3-A2 (mastoid area) and C4-A1 (sensory-motor area). EEG signals were high-pass filtered with a time constant of 0.3 sec at 50 Hz and low-pass at 35 Hz.

EEG frequency bands range

Delta 0 to 4 Hz, Theta 4 to 8 Hz, Alpha 8 to 12 Hz, Sigma 12 to 15 Hz, Beta 13 to 30 Hz, and Gamma 30 to 100 Hz. Rapid Eye Movement (REM) sleep and Non-Rapid Eye Movement (Non-REM) sleep. The average power spectrum was computed for every 30 epochs, and REM sleep accounts for 20-25% of total sleep time. NREM sleep was divided into three stages, accounting for 40-50% of sleep time.

Empirical Mode Decomposition (EMD) features

EMD (Empirical Mode Decomposition) is a method that can adaptively decompose any complicated data set into an Intrinsic Mode Function component (IMF). IMFs functions provided two conditions [4]:

a) In the complete time series, the number of extrema and zeros must be crossed equal or different at most by one.

b) At any moment in the time series, the mean value of the envelopes-local maxima (upper envelope) and local minima (lower envelope) is equal to zero.

For the EMD method, the screening process is repeated until an IMF is derived. 'Stopping criteria' diagnoses the number of sifting steps to initiate the IMF. The concept was to identify the local extrema defined by local maxima and local minima. All the local maxima will be connected and obtain the upper envelope. At the same time, the local minima will also be linked to each other to produce the lower envelope [1].

RESULTS

The following PRISMA flow chart (Figure 1) shows the number of exclusion and inclusion paper criteria along with all the data sources. Duplicate papers and reports assessed eligibility were also excluded because of needing accurate information, data collection, and adequate sample sizes. Finally, eighteen (18) studies met the inclusion criteria.

Characteristics of the included studies

The eighteen (18) studies recruited 577 participants, where 63% were ID patients, 101 effect sizes at six frequencies band during wakefulness or sleep. Over six months, patients with ID experienced insomnia. Most studies conducted Polysomnography (PSG) recording in a sleep laboratory. Of the seven studies investigating waking EEG power, nine assessed resting-state EEG data during eyes-closed conditions, two studies during wakefulness after sleep onset, one study during eyes-open conditions, and one during both eyes-open and eyes-closed conditions. Thirty-five percent (35%) used the central EEG leads referenced to A1/A2 for power spectral analysis, and one study failed to report the electrode montage used clearly.

Publication bias analysis

Egger's regression test, Duval, and Tweedie's trim-and-fill method were performed to assess the possible effect of publication bias. First, we estimated publication bias across all retrieved effect sizes and then separately for each frequency band during wakefulness, NREM sleep, and REM sleep. Although obvious publication bias was observed when all effect sizes were combined, separate analyses revealed no significant evidence of publication bias for each frequency band during different periods.

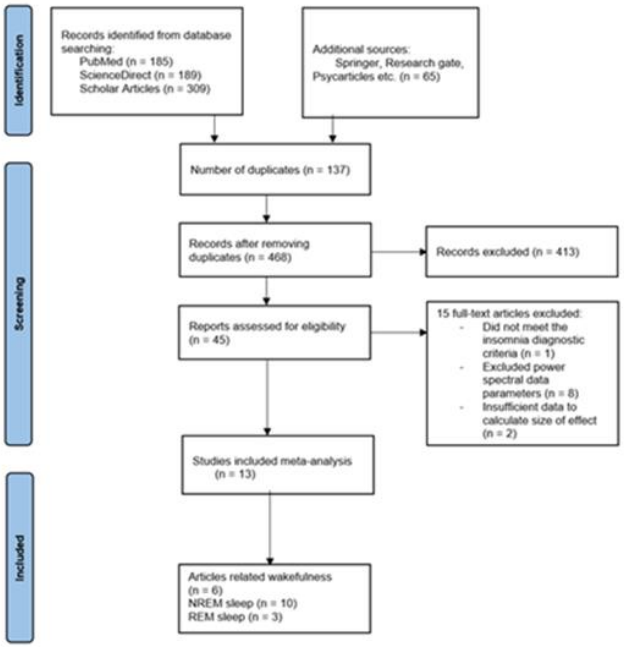

Figure 1. PRISMA flow chart of the study selection process.

Statistical analysis

The outcomes were reported as $p < 0.05/0.01$, and two-tailed p values were assumed to be 0.05/0.01. The reported results were insignificant, and no statistical values were provided to compute the exact p-values, so this study took a one-tailed p-value of 0.50.

DISCUSSION

In the current study, we performed a systematic review and meta-analysis to assess the EEG spectral power in patients with ID, NREM sleep, and REM sleep. During wakefulness, patients with insomnia disorder exhibited significant and robust increases in absolute and overall theta power, relative beta power, and absolute gamma power. During NREM sleep, patients with ID demonstrated significant and strong

alterations in EEG power across all frequency bands except for gamma. In these patients, NREM sleep was associated with decreases in relative and overall delta power and increases in absolute and overall beta power, the relative power of theta, alpha sigma, and beta bands. A significant increase in absolute alpha power, absolute sigma power, and overall beta power was observed in patients with ID during REM sleep. These findings showed that insomnia disorder relates to increased beta activity during wakefulness and sleep. Based on EEG data during wakefulness and REM sleep, absolute and relative power had similar sensitivity in distinguishing ID patients from HCs. During NREM sleep, relative power differences were more homogeneous than absolute power differences.

Insomnia-related alterations in waking EEG spectral features

Although existing narrative reviews of EEG in insomnia have discussed spectral features around sleep onset and during sleep, few studies have focused on resting-state EEG data obtained during wakefulness. The present study estimated the overall effect across six frequency bands and the effect sizes of case-control differences for absolute and relative power in separate and integrated analyses. Early studies reported inconsistent results for the alpha activity during wakefulness. Here, we observed significant and moderate to high heterogeneity in the dispersion of effect sizes for both absolute and overall power. Patients with ID do not fall asleep quickly, even when napping opportunities are provided during the day. Cortical hyperarousal, characterized by relative beta and absolute gamma power increases, may explain difficulties falling asleep throughout the day. Researchers found that patients with ID were more likely to exhibit hyperarousal mental states after beta increases than the average sleeper.

NREM sleep alters EEG spectral features across frequency bands.

Numerous studies have demonstrated that ID was characterized by increased high-frequency activity, primarily in the beta and/or gamma range. Studies had also reported abnormal activity in other frequency bands, but none had examined whether such spectral alterations were consistent. No apparent publication was found in the above outcomes. During NREM sleep, beta activity was increased, reflecting cortical hyperarousal. Much less attention had been paid to frequency bands below beta, which might provide some hypothetical interpretations [8]. Extended cortical hyperarousal might be responsible for alterations in almost all frequency bands during NREM sleep in individuals with ID. Such changes may co-exist with either decreased thalamocortical hyperpolarization during N3 or a shorter duration of N3 relative to N2 during the NREM period.

Increased high-frequency activity during REM sleep.

In previous studies, EEG spectral features in ID during sleep were studied during NREM sleep. REM sleep could distinguish patients with ID from HCs. A significant increase in absolute alpha and sigma power was observed during REM sleep in people with ID and overall beta power [9]. No apparent heterogeneity or publication bias was observed for the above outcomes. Since REM sleep was associated with enhanced

emotional memory and regulation, altered EEG activity during REM sleep in patients with ID might be critical to understanding their characteristic difficulties in regulating emotional distress and hyperarousal.

Study comparisons with and without hypnosis

The benzodiazepine users exhibited significantly increased sigma activity. They decreased delta and theta activity overnight than good sleepers—however, the significant effect of medication status on theta activity during wakefulness only. Therefore, the above results are reliable, except for increased theta activity during wakefulness, which might relate to hypnotic medication use.

Limitations

This review of studies has several limitations. First, due to inconsistent subdivisions of EEG spectral bands across studies, the analysis was based solely on semantic categories. Although this approach may have limited precision with respect to the borders of the significant case-control differences, our results provide an overall indication. Moreover, future EEG spectral analyses should divide the frequency bands according to some standard guidelines or, preferably, present results across all individual frequency bins. Second, only a small number of studies reported data on EEG power during REM sleep, so any inference based on the results during REM sleep should be cautious. Third, studies have demonstrated the existence of different ID subtypes, which might affect EEG spectral characteristics, along with age, gender, and time of night (Figure 1).

CONCLUSION

In conclusion, this research study demonstrated that patients with insomnia disorder (ID) exhibit significant increases in beta band power during wakefulness and sleep that extend to neighboring frequency bands, suggesting a phenomenon of continuous cortical hyperarousal. Patients with ID also exhibit significant decreases in delta power during NREM sleep. Thus, they hypothesize that ID may result from the abnormal activity of wake-promoting and sleep-promoting neural structures during daytime and sleep. In future studies, spectral analyses should include more measures for reporting results, focusing on potential differences among insomnia subtypes in EEG spectral features. Also, future EEG spectral analyses should divide the frequency bands according to some standard guidelines or, preferably, present results across all individual frequency bins.

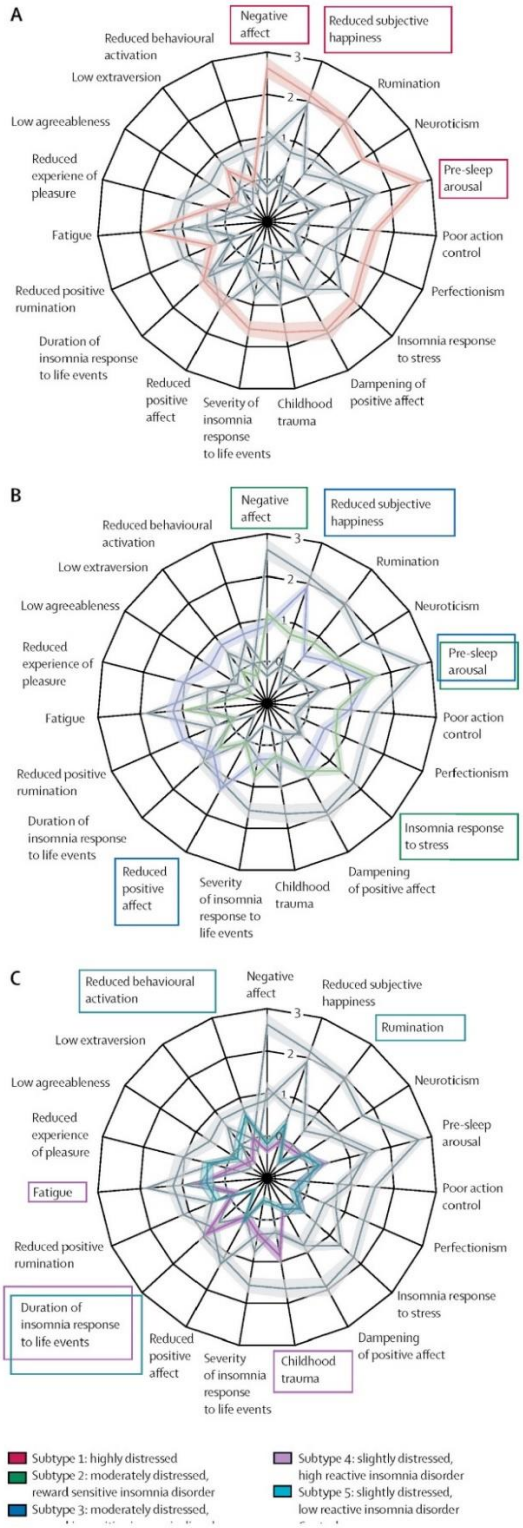

Figure 2. Multivariate profile plots of insomnia subtypes. (Reprinted from The Lancet Psychiatry, Vol 6/Issue 2, Blanken TF et al. Insomnia disorder subtypes derived from life history and traits of affect and personality, P151-163., Copyright (2019), with permission from Elsevier) [10].

ORCID

Unaiza Memon https://orcid.org/0000-0002-2489-5182

Muhammad Umair https://orcid.org/0009-0006-6928-1594

Anwara Khan https://orcid.org/0009-0001-8118-6286

Faisal R. Jahangiri https://orcid.org/0000-0002-1342-1977

REFERENCES

1. Dennis E.B. Tan; Ren Sin Tung; Wai YieLeong; Joel Chia MingThan, (2012, August 25). *Sleep disorder detection and identification*. Volume 41. Procedia Engineering. Retrieved December 1, 2022, 289-295. doi: 10.1016/j.proeng.2012.07.175.
2. Zhao, W., Van Someren, E. J. W., Li, C., Chen, X., Gui, W., Tian, Y., Liu, Y., & Lei, X. (2021). EEG spectral analysis in insomnia disorder: A systematic review and meta-analysis. *Sleep medicine reviews*, *59*, 101457. Doi: 10.1016/j.smrv.2021.101457.
3. Acharya U, R., Faust, O., Kannathal, N., Chua, T., & Laxminarayan, S. (2005). Non-linear analysis of EEG signals at various sleep stages. *Computer methods and programs in biomedicine*, *80*(1), 37–45. doi: 10.1016/j.cmpb.2005.06.011.
4. A. Malik, S. Z. H. Naqvi, S. Aziz, M. U. Khan, T. Hussain and F. Hasan, "Detection of Insomnia using Electrocardiography and Electromyography," 2021 International Conference on Artificial Intelligence (ICAI), Islamabad, Pakistan, 2021, 234-239, doi: 10.1109/ICAI52203.2021.9445241.
5. Hamida, S. T., Penzel, T., & Ahmed, B. (2015). EEG time and frequency domain analyses of primary insomnia. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference*, *2015*, 6206–6209. Doi: 10.1109/EMBC.2015.7319810.
6. Dijk, D. J., Shanahan, T. L., Duffy, J. F., Ronda, J. M., & Czeisler, C. A. (1997). Variation of electroencephalographic activity during non-rapid eye movement and rapid eye movement sleep with phase of circadian melatonin rhythm in humans. *The Journal of physiology*, *505 (Pt 3)*(Pt 3), 851–858. doi: 10.1111/j.1469-7793.1997.851ba.x.
7. Maroof Siddiquia, M., a, Geetika Srivastavab, b, Hasan Saeedc, S., c, & (2016, July 21). *Diagnosis of insomnia sleep disorder using short time frequency analysis of PSD approach applied on EEG Signal Using Channel Roc-Loc*. Sleep Science. Retrieved December 1, 2022, from https://www.sciencedirect.com/science/article/pii/S1984006316300487
8. Pereda, E., Gamundi, A., Rial, R., & González, J. (1998). Non-linear behaviour of human EEG: fractal exponent versus correlation dimension in awake and sleep stages. *Neuroscience letters*, *250*(2), 91–94. Doi: 10.1016/s0304-3940(98)00435-2
9. Siddiqui, M. M., Srivastava, G., & Saeed, S. H. (2016). Diagnosis of insomnia sleep disorder using short time frequency analysis of PSD approach applied on EEG signal using channel ROC-LOC. *Sleep science (Sao Paulo, Brazil)*, *9*(3), 186–191. doi: 10.1016/j.slsci.2016.07.002.
10. Blanken TF, Benjamins JS, Borsboom D, Vermunt JK, Paquola C, Ramautar J, Dekker K, Stoffers D, Wassing R, Wei Y, Van Someren EJW. Insomnia disorder subtypes derived from life history and traits of affect and personality. Lancet Psychiatry. 2019 Feb;6(2):151-163. doi: 10.1016/S2215-0366(18)30464-4.