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Review Article

A review of the literature on the impact of acute and chronic stress upon brain waves

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Abstract

Background: The biological responses associated with stress originate in the brain and involve-different physiological and physical effects. The direct effect of stress on cortical responses can be visualized by recording the brain's electrical waves using an encephalograph. These waves are recorded by means of an electroencephalogram (EEG). EEG is the most commonly used neuroimaging technique to study the patterns of brainwaves and functioning of the brain. It also measures the variation of the electric field produced by neuronal activity a millisecond at a time. To systematically analyze published studies on the difference between brain wave patterns in terms of their frequencies among subjects with acute stress, chronic stress, and normal individuals.

Methodology: The data from published studies was arranged quantitatively and qualitatively by producing a planned summary measure. Studies that focused on brain wave analysis of the EEG of healthy adult subjects with no history of mental illness or head injury were included in the review. The selected literature included many types of stressors that are acute or chronic, and that affected the neuronal electrical activity. The only electronic database utilized to identify relevant studies was PubMed.

Result: Fifteen studies were included that were based on a variety of acute stressors to observe alterations in brain wave activity between stress-free and stressed states. These studies showed that stressors could be a causative factor to generate fluctuations in neuronal oscillations that also leads to significant psychological, physiological and neurobiological deteriorations to some extent. An additional sixteen studies were included, which showed the effect of chronic stress on the asymmetry of the amplitude in the frequencies of brain waves.

Conclusion: The most common change observed was in the alpha frequency (8-13Hz), followed by changes in beta waves (13-30 Hz) and theta (4-8Hz). Though, there is not always the same resultant pattern of waves explored with even the same type of stressors due to interpersonal differences in response to a stressful situation.

Keywords

Chronic Stress, Acute Stress, Brain Waves, Electroencephalography.

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Introduction

Everyone, at least once in their lifetime, faces a stressful situation. This stress can be beneficial if it motivates a person to do challenging tasks to achieve their goals. But it can be harmful when it begins to affect the physical or mental health of the subject. The term stress is defined as; when the equilibrium between internal and external environment is disturbed, it alters the bodily mechanisms[1]. This scenario casts a bad impact on the central, and peripheral regulatory systems that leads to deprived health and mental wellbeing[2]. Stress is also responsible for the progression of chronic disorders. Its long-term exposure is linked with several health problems, including obesity, peripheral vascular disease, diabetes, and depression. Therefore it is essential to evaluate stress levels at the early stage before they start to interfere with everyday routine. Stress can be evaluated based on physiological and behavioral responses. Traditionally, physicians tend to assess stress by using critically designed questionnaires[3], i.e. a subjective method. Stress can also be measured by assessing different biological indicators like cortisol[4], alpha-amylase levels, body vitals namely blood pressure[5] and skin conductivity[6]. The direct effect of stress on cortical responses can be obtained by using a neuroimaging technique, electroencephalogram (EEG)[7]. EEG is the electrophysiological technique used to assess the electrical activity of the brain[8]. It also measures the variation of the electric field produced by neuronal activity at the millisecond resolution.

Assessment of Acute and Chronic Stress Based on EEG Features

Biological responses associated with stress originate in the brain and involve different types of physiological and physical effects. Previous studies have investigated the variations in EEG signals during stressful conditions. The alpha frequency band ranges between 8-13 Hz[9]. Alpha waves are usually recorded in a relaxed, calm and tension-free condition[10], when a subject is exposed to a distress in a controlled laboratory setting a distinct reduction in power is observed[11]. During the stressful condition, the right hemisphere shows more frontal altered alpha waves then left hemisphere[12,13]. Other studies discuss the relationship between negative emotions, stress or depression with alpha frequency[12,14]. Marshall and Lopez Duran suggest a decline in the power of alpha frequency in the prefrontal cortex during a stressful situation[15]. As well, there is an increase in alpha power in the frontal cortex during fatigue[16]. Yi et al. reported that during chronic stress such as social isolation there is a decrease in the power of alpha frequency[17].

Methodology

Study Characteristics

This systematic review protocol is based on PRISMA guidelines[18]. The only electronic database involved in this study is PubMed and the records and data throughout the review is managed by M.S. Word.

Inclusion Criteria

- The studies conducted between 1st January 2000 to 31st March 2019.
- All the full-text original articles published in the English language
- Studies with the subject age range of 19-44 years.
- Studies that focus on brain wave analysis by EEG.
- Studies involving healthy subjects, without any history of mental illness or head injury.

Exclusion Criteria

- Studies assessed depressive symptoms in healthy populations.

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- Studies on infants (pediatric studies), neonates, pregnant women.
- Studies focused on other electrophysiological techniques than EEG.
- Studies used EEG for evaluation other than stress.
- Studies involving diseased subjects.

Data Synthesis

The data was arranged quantitatively and qualitatively by producing a planned summary measure, reviewing original articles in the same aspects, extracting and screening the citation and studies, handling the studies, screening them and combining them according to the methods given by the following PRISMA flow diagram (Figure 1 & 2).

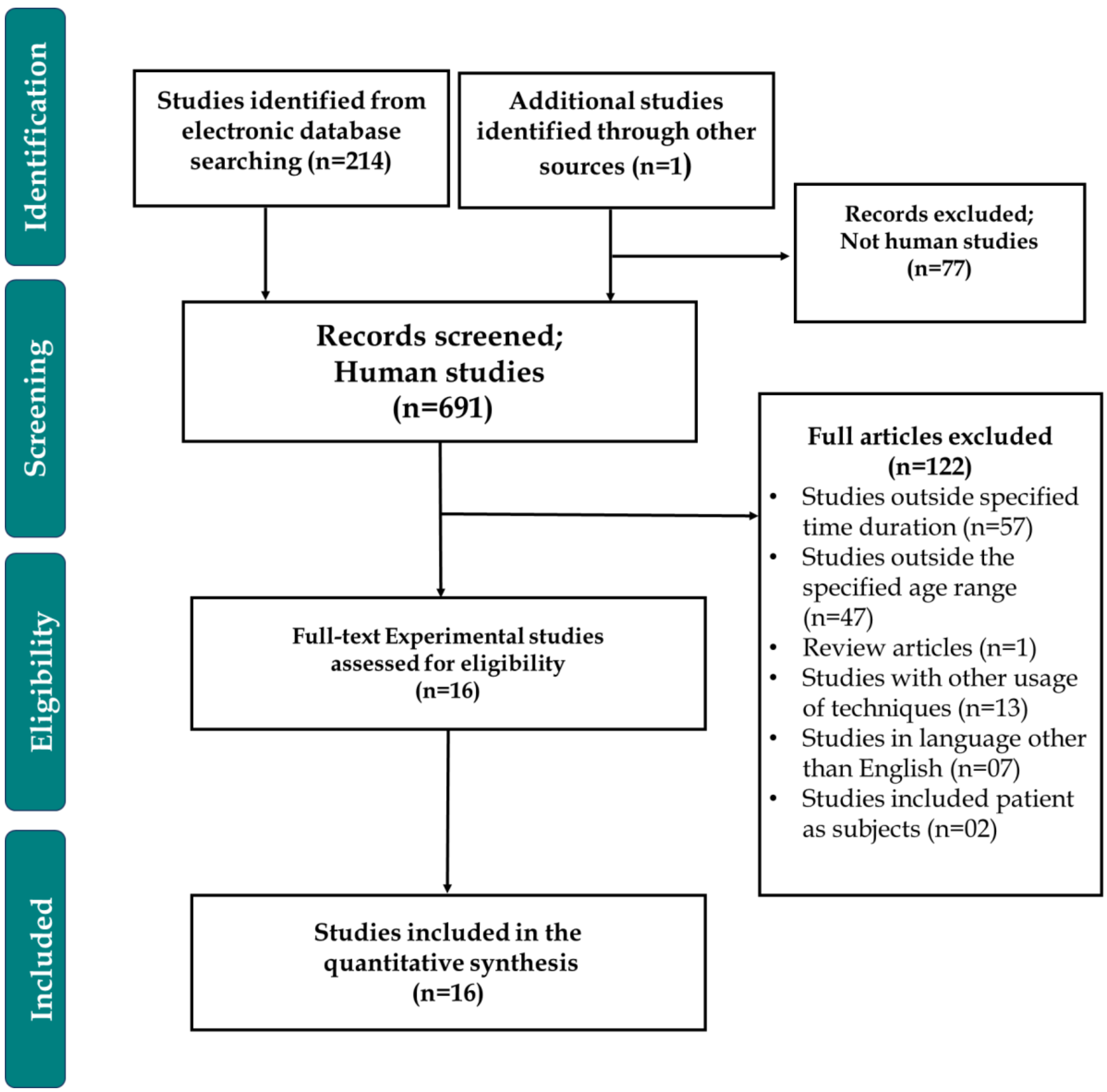

Figure 1: PRISMA Diagram for study selection of chronic stressors in systemic review.

This method was used as a medium for extractions and simplification of the combined data and rate it in its quality and quantity.

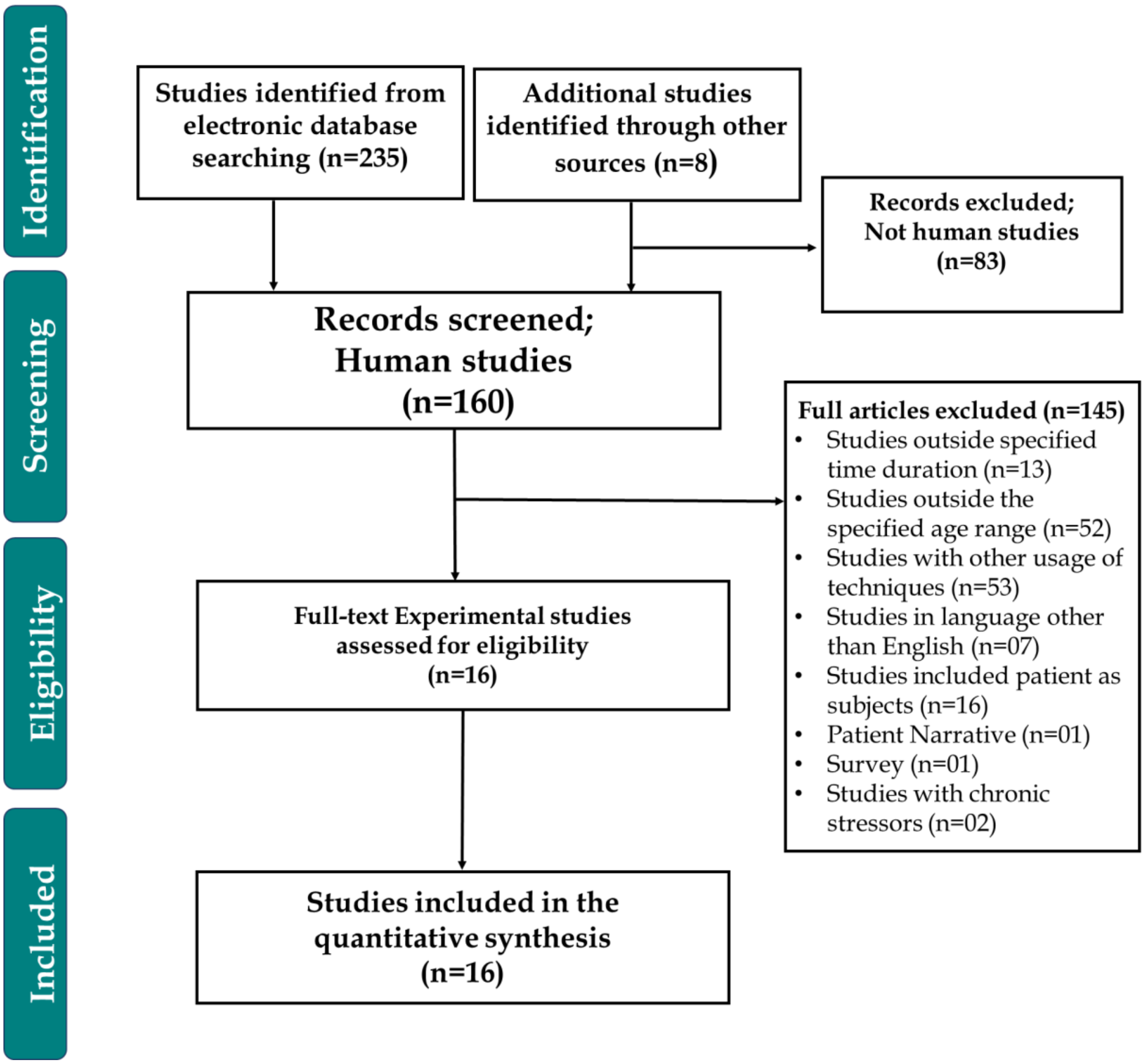

Figure 2: PRISMA Diagram for study selection of acute stressors in systemic review.

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Result

Table 1 summarizes the sample size, gender, included brain frequencies, altered oscillations, and type of chronic stressor measured. The stressors mentioned in Table 1 discuss the disturbance in neuronal oscillations. Many studies discuss several reasons for the asymmetry in brain waves that can be a result of continuous exposure to a stressful situation. Different stressors have been reported; one of the stressors is sleep deprivation, which increases alpha waves[19]. Another stressor is isolation; during 520 days, isolation shows the increase in beta waves at the frontal region while alpha and delta remain unaffected[20]. Loganovsky et al. found an increase in alpha at the temporal and frontal area, delta at the anterior brain, and theta at the anterior brain and right temporal region and beta increase at anterior brain while decrease at the temporal region due to workload[21]. Jacubowski et al. considers two stressors, one is isolation and the other is exercise, and both stressors resulted in high alpha and beta waves[22]. Hu concluded the influence of different stressors caused by unemployment, and the frequent examination on students and mothers of disabled children[23]. They found alpha, beta and theta frequencies increase anteriorly. Luijcks et al. used electro-shocker as a chronic stressor and reported an increase in alpha and slow beta waves frequency at central and parietal-temporal areas, spectrum of gamma wave's decrease at frontal, central and occipital regions[24]. Vanneste et al. assessed chronic tinnitus and reported that alpha 1 and beta are altered[25]. However, in this condition, alpha 1 at the subgenual anterior cingulate cortex, beta 3 at dorsal anterior cingulate cortex, delta, theta, alpha 2, beta 1 and 2 remain unaffected. When extreme isolation was studied by Yi et al. they found a decrease in alpha and beta frequency[17].

Table 1: Chronic Stressors That Alter Brain Wave Symmetry.

Author	Year	Sample size	Waves	Result	Brain region	Stressor
Begić et al [26]	2000	18 veterans with PTSD and 20 healthy non-veterans	delta, theta, alpha 1, alpha 2 beta 1 & beta 2	theta ⬆ beta ⬆ alpha and delta no significant change	Theta: Central region Beta: Frontal, central and left occipital-al	PTSD
Hall et al[27]	2000	14 subjects with primary insomnia	delta, alpha and beta	During non-REM sleep: delta ⬆ beta ⬇ alpha ⬆	-	Last 6 months depression.
Brady et al[28]	2000	6 subjects	Theta	theta ⬆	Frontal	Binaural beat sound tape
Neylan et al[29]	2003	24 PTSD patients and 18 control	Delta	delta ⬇	-	PTSD

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Hall et al[30]	2007	30 patients of insomnia	beta and delta	beta ↑ delta ↓	-	Perceived stress
Baumeister et al[31]	2008	16 right-handed healthy subjects	theta alpha1 alpha2 beta1 and beta2	beta-1 ↓ alpha-1 ↑	Frontal region: Alpha 1 Right Hemispheric frontal brain beta 1	Supplementation of phosphatidylseri-ne
Todder et al[32]	2012	10 right handed PTSD patients+ 10 healthy hospital staff member	Theta	qEEG: No statistical difference between PTSD and control subjects for theta band LORETA: ↓Theta band	Low on right temporal-al lobe, higher theta band patients with PTSD showed lower activity over both the right and left frontal lobes	PTSD
Glos et al[33]	2014	12 healthy young volunteer	Alpha	alpha ↑	-	Sleep deprivation
Yi et al[20]	2015	6 subjects	alpha, beta, and delta	beta ↑	Frontal region	Chronic stress burden of 520-d isolation
Loganovsk et al[21]	2015	196 subjects	alpha, beta, theta and delta	alpha ↑ beta ↑ theta ↑ delta ↑	Anterior brain: beta, theta, delta Right Temporal: theta, beta, alpha Frontal: Alpha	Work load
Jacubowski et al[22]	2015	6 subjects	alpha and beta	post isolation alpha, beta ↑ exercise alpha, beta ↑	Limited number of channels, no further details of brain regions	Isolation.
Hu et al [23]	2015	18 unemployed, Students and Mothers of disabled children	alpha, beta and theta	alpha ↑ beta ↑ theta ↑	Anterior and frontal region	Unemployment, Frequent examination and graduation, Disabled children

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Luijcks et al[24]	2015	69 right handed subjects	delta, theta, alpha, slow beta and fast beta, gamma	alpha ⬆ fast, slow beta gamma ⬍	Central, parietal- temporal area: alpha, slow beta Frontal, central , occipital: Gamma	Electro-shocker
Vanneste et al[25]	2015	55 patients with constant chronic tinnitus	delta, theta, alpha 1, alpha 2, beta 1, beta 2, beta 3 and gamma	Sinificant effect on alpha 1 ⬇ beta 3 ⬆	Subgenual anterior cingulate cortex: alpha 1 Dorsal anterior cingulate cortex: beta 3	Tinnitus
Giannakakis et al[9]	2015	18 healthy subjects	theta, alpha, beta and gamma θ, alpha 1,2 beta 1,2,3,4 , low and high gamma	alpha and beta feature ⬇	Frontal	Video
Yi et al[17]	2016	6 healthy subjects	alpha and beta	beta ⬇ alpha ⬇	No further differentiation due to limited no. of channels	Mars voyage subjects lived in extreme social isolation

Table 2. Summarizes the sample size, their gender, included brain waves, altered oscillations, and type of acute stressor. The stressors mentioned in Table 2 discuss the disturbance in neuronal oscillations. Acute stressors can be beneficial as these stressors make the body able to adapt according to their surroundings. Alonso et al., applied two psychological and physical stressors, a Stroop test and sleep deprivation in which the Stroop test resulted in an increase in alpha 1 and beta whereas in sleep deprivation, theta increased and there was a decline in alpha 1, finally high alpha decreases and high beta increases in stress responses[34]. Zambotti et al., applied the Trier social stress test on insomniac patients and compared them with a control group, beta 1 increases in the control group showed no change in brain wave symmetry[35]. Acute mental arithmetic tasks cause a decrease in alpha and increase in beta and delta and theta stay unchanged[36]. Allen et al., used a socially evaluated cold presser test (S.E.C.P.T.) and found an increase in theta at the frontal midline and that alpha1, 2 and beta 1, 2 and delta did not responded to the stressor[37]. Banis et al., used the Distressing Video and Monetary Incentive Delay Task and found alpha power increase in reward cues, which was unaffected during a stressful situation. They also found that theta increased in on reward signal[38]. In Julien Modolo et al., study, alpha remains unchanged at the occipital region in magnetic frequency (60 Hz) stressor[39].

Table 2: Acute Stressors That Change Brain Wave Symmetry.

Author	Year	Sample size	Waves	Result	Brain region	Stressor
Muttray et al[40]	2000	12 subjects	Alpha 1, Alpha 2, Beta 1, Beta 2, Theta And Delta	alpha 1 : ⬇ alpha 2 : ⬇ beta 1 : ⬇ beta 2: no change	Tempor-o-parieto-occipital: Alpha 1 and beta 1 Temporooccipital: Delta Parietal & temporal regions: Theta	200 ppm 1,1,1-trichloroethane + Color Word Stress test
Tops et al[41]	2004	11 subjects	Alpha	alpha : ⬇	Frontal activity	Acute cortisol
Hewig et al[42]	2008	37 subjects	Alpha	alpha : ⬇	Frontal	Exam
Master et al[43]	2009	54 subjects	Alpha	alpha asymmetery	Frontal EEG. Asymmetry	Trier social stress test
Rozhkov et al[44]	2009	11 subjects	Theta & Delta	theta : ⬆ delta : ⬆	Temporospatial	Hypoxia
Scholey et al[45]	2012	31 subjects	Theta, Alpha And Beta	theta : ⬆ alpha : ⬆ beta : ⬆	Midline frontal and central region	Epigallocatechin gallate (E.G.C.G.)
Lithari et al[46]	2012	26 right handed healthy subjects	Alpha Beta, Gamma, Delta Theta	theta : ⬆ alpha : ⬆ beta : ⬆	Regions not mentioned	Alcohol intake
Quaeflieg et al[47]	2014	70 subjects	Alpha	alpha not effected	Frontal	Maastricht acute stress test

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Alonso et al[34]	2015	30 subjects	Delta Theta Alpha And Beta	Stroop test: alpha1↓ beta : ↑ sleep deprivation: theta : ↑ alpha 1: ↑ stress response high alpha: ↓ high beta: ↑	-	Stroop color word test chronic: Sleep deprivation
de Zambotti et al[35]	2015	22 subjects with insomnia & 18 without insomnia	Alpha Beta1 Beta2 Delta Theta And Sigma	Insomniac subjects: beta1: ↑ Control: beta 1 no change	-	Trier social stress test.
Al-Shargie et al[35]	2016	22 healthy right handed subjects	Delta Alpha Beta And Theta	beta : ↑ alpha : ↓ alpha waves responded more significantly to stress	-	Mental arithmetic task
Allen et al[37]	2016	22 subjects	Alpha1 Alpha 2 Beta 1 Beta 2 Delta & Theta	theta : ↑	Frontal midline representing prefrontal cortical activity.	Socially evaluated cold presser test (S.E.C.P.T.)
Banis et al[40]	2017	17 subjects	Alpha & Theta	alpha : ↑ in reward cues No effect in stressed condition theta : ↑ in non reward cue.	-	Distressing video+ Monetary Incentive Delay Task
Modolo et al[39]	2017	25 subjects	Alpha	alpha not effected	Occipital region	Magnetic frequency 60 Hz

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Discussion

The conditions that are associated with stress produce significant psychological, physiological and neurobiological deteriorations. Distress affects neuronal circuits that further disturb the normal propagation of brain waves; these interruptions can be analyzed by EEG with precision and efficacy.

This review reveals how the different stressors could be a causative factor in generating fluctuations in neuronal oscillations. It should be noted that gamma is the least observed wave in the above-included studies. Above all, only Luijcks et al. reported a decrease in gamma waves at the frontal, central and occipital regions while others reported no change [9,24,25]. Slow-wave delta least shows the deflection when influenced by chronic stressors; in many studies, delta waves remain unchanged before and after the stressor applied[20,24-26]. Few studies mentioned the increase in delta waves during chronic stress[9, 12, 21]. However, Neylan et al. and Hall et al. suggested a decrease in delta waves[29,30]. Like delta, theta also in some studies reported to not be a respondent of a stressor [9,24,25,31]. While Begic et al.[26], Brady et al. [28] and Hu et al. [23] observed a decrease in theta rhythms at central, frontal and anterior regions, respectively. However, Todder et al.[32] use QEEG and Low Resolution Electromagnetic Tomographis Analysis (LORETA) techniques and report that there is no difference observed. At the same time, LORETA reveals some other results; they distributed the theta band into higher and lower frequency band, both bands show low activity at different brain sites, the low band found at right temporal lobe while the higher band at the right and left frontal lobe. Now, beta waves are more involved in brain-specific tasks. Most of the studies reported an increase in beta oscillations at frontal, central, left occipital, anterior, right temporal and parietal temporal regions of the brain [18,20,21-23,26,30]. Some detect a decline in this rhythm at the frontal and right hemispheric frontal site of the brain[8,9,17]. Also, Vanneste et al. observed alteration in frequency bands of beta 3 waves at the dorsal, anterior cingulate cortex[25]. Finally, the alpha wave remains unchanged in very few cases [20, 26]. Mainly, the alpha oscillations were reported to be increased during or after chronic stressors were applied, and the regions indicated were frontal, right temporal, parietal temporal, central and anterior[18,22,25,28,29,31].

On the contrary, Giannakakis et al. [9] and Yi et al. [17] suggested the decline in beta frequency in the frontal region of the brain. Additionally, Vanneste et al. found fluctuations in alpha 1 waves after the extensive exposure to stress[25]. Acute stressors are the second parameters in this review. Lithari et al. [46] included gamma wave in his study, but the rhythms remain un-deflected. Now, the delta waves mostly reported being unchanged during acute stress[34-37,46]. Whereas, Muttray et al. [40] and Rozhkov et al. [44] observed an increase in the frequency of the delta waves at temporo-occipital and temporospatial regions of the brain. Theta oscillations are not respondents of acute stressors observed by Massimiliano de Zambotti[35] and Al Shargie et al.[36] But most of the studies mentioned an increase in theta wave and the regions are parietal and temporal, temporospatial, midline frontal and central part of the brain[34,40,44,46]. Allen et al.,[37] suggested no change in the beta wave. Though, Muttray et al.[40] mentioned a decrease in beta rhythm at the temporoparietal occipital. On the other hand, most of the studies reported an increase in the beta wave at midline frontal and central regions[34-36,46]. Lastly, the alpha

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waves are the most considered wave to study stress. Some studies reported that alpha remains unchanged[27,35,37,47]. In acute stress, it is reported that alpha wave increases at frontal, midline frontal and central sites[34,38,43,46], while other studies reported a decline in alpha waves at temporoparietal-occipital and frontal regions of the brain[41,42].

Conclusion

The literature reviewed for this study shows the effect of numerous stressors on brain oscillations that change their frequency, affecting normal functions of the brain. These fluctuations in the power of brain waves could lead to some severe consequences if persisted for too long. Multiple interventions and therapies especially biofeedback techniques are making the mark and are now being tested and successfully applied to train the subject to revert the effect of stress. Most significant one amongst these were biofeedback and behavioral structuring techniques with high efficacy rates. Awareness in this regard is highly recommended.

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