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Brainwaves Activities during Resting State: A Neurofeedback Case Study

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ABSTRACT

Neurofeedback training (NFT) on a healthy participant was used to analyse brainwave activity during resting state. Electrodes were placed on the prefrontal cortex and at reference sites to conduct the experiment. The patient was asked to remain still and rest by sitting in a chair. The technology was then used to record the electrical waves emitted by brain activities. After ten cycles with a break interval, theta, alpha, and high beta brainwaves were discovered. There were statistically significant brainwaves in the prefrontal cortex. Remarkably, the ascending high beta oscillation range was the highest, while the alpha wave was the lowest, contradicting earlier results. Anxiety, excitement, and focus were thought to be associated with the highest range of high beta waves.

Keywords: resting state, neurofeedback, electroencephalogram

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1 INTRODUCTION

1.1 Definition and history of Neurofeedback Training (NFT)

Neurofeedback training (NFT) has contributed beneficially to the modern medical community. NFT is a subset of biofeedback based on the principle of operant conditioning. It is a learning method for establishing relationships between behaviours and effects which gain rewards and punishments (Cherry, 2020; Engelbregt et al., 2016; Strehl, 2014). Theoretically, biofeedback is a biological insight of the Automatic Nervous System (ANS). Before its origin, the term "a real-time physiological mirror" existed during World War II (Sattar & Valdiya, 2017). It is limited to physiological processes such as heart rate, blood pressure, skin temperature, digestion, respiration, and sexual arousal. All examples are involuntary and are controlled by ANS. In the 1950s, an opposition team of scientists disapproved of the idea of ANS potentially influencing human physiological and psychological states, which also function on biological processes (Jones, 2016). It remains questionable in operant conditions, information processing or skill learning. Furthermore, the hypothesis is inadequate as a foundation for pharmaceutical treatment (Sattar & Valdiya, 2017; Jones, 2016). Researchers discovered in the 1960s that ANS function might be altered analogously to operant settings. As a result, it is an opportunity to turn biofeedback into a proper therapy method that may be employed in medical practice.

Over the decades, many generations have evolved from the basic framework of biofeedback to highly specific neurofeedback, or NFT, which is helpful for training and improving brainwave activity. In their research, Sattar and Valdiya (2017) mentioned that Electroencephalogram (EEG) biofeedback focuses primarily on electrical activity in the brain and maps activity based on the region. NFT typically receives an audio or video of neurofeedback and uses EEG to record electrical waves of neuro signals from brain activity (Marzbani al., 2016). Figure 1 depicts some of the expected brainwave frequencies which appear in different neurofeedback treatments, such as alpha (8-13Hz), delta (1-4Hz), theta (4-8Hz), beta (15-20Hz), gamma (32-100 or 40Hz), alpha/theta, lower-alpha (8-10Hz), upper alpha (10-13Hz) and high beta (20-32Hz).

Each frequency has its characteristics that can benefit the training and treatment. Due to non-invasive therapy and low-cost procedure, it has been implemented for clinical applications of neurofeedback for drug addiction treatment (Sunder & Bohnen, 2017) and some mental disorders, such as depression (Cheon et al., 2016), autism spectrum disorder, obsessive-compulsive disorder (OCD) (Scheinost et al., 2014), attention deficit hyperactivity disorder (ADHD) (Eroglu et al., 2018) and anxiety (Zhao et al., 2019; Eroglu et al., 2018). Therefore, previous studies have found and conducted well with EEG to aid cognitive impairment (attention and working memory performance) (Wang & Hsieh, 2013)

Table 1. Brainwave frequency and characteristics.

Common brainwave frequency	Frequency range (Hz)	General characteristics
Delta	1-4	Sleep, repair, complex problem solving, unawareness, deep unconsciousness
Theta	4-8	Creativity, insight, deep states, unconsciousness, optimal meditative state, depression, anxiety, distractibility
Alpha	8-13	Alertness and peacefulness, readiness, meditation, deeply relaxed
Lower alpha	8-10	Recalling
Upper alpha	10-13	Optimal cognitive performance
SMR (sensorimotor rhythm)	13-15	Mental alertness, physical relaxation
Beta	15-20	Thinking, focusing, sustained attention, tension, alertness, excitement
High beta	20-32	Intensity, hyper-alertness, anxiety
Gamma	32-133 or 40	Learning, cognitive processing, problem-solving tasks, mental sharpness, brain activity, organising the brain

1.2 Resting-state and brainwave activity

The definition of rest is widely subjective and used based on a person's understanding, which is often confused with sleep. According to the website organisation, resting is a part of behaviour that ceases involvement in any external activity (Sleep.org, 2021). Scientifically, Huang (2019) defined resting, or intrinsic activity, as a neural spontaneous activity or condition that does not involve any external stimuli and is generated by the brain. Helvig and his colleagues reported the importance of resting which will impact physical, mental, spiritual and cognitive responses in an individual (Helvig et al., 2016). Nonetheless, this category of passive resting remains debated to observe and measure brain activity in various conditions. For instance, previous studies have conducted eyes-closed (EC) and eyes-opened (EO) (Diaz M et al., 2019; Choi et al., 2018), both using blood-oxygen-level-dependent (BOLD) (Patriat et al., 2014) or mind-wandering (Son et al., 2019; Son et al., 2019; Huang, 2019). BOLD, from previous studies, is associated with the resting state network and occurs during calm consciousness, sleeping and under anaesthesia care (Rogala et al., 2020; Pizoli et al., 2011; Huang, 2019). In addition, there is a physiologically significant weakness with resting conditions (Patriat et al., 2014; Pizoli et al., 2011).

The association between brainwave activity and resting state, as well as cognitive assessment, has been demonstrated in several prior studies. Prior to the EO and EC cases with BOLD, Patriat et al. (2014) hypothesised that this would disturb the alpha wave range during the resting state in EO and EC situations. Repetitive transcranial magnetic stimulation, or rTMS, was found to influence cortical activity by Qiu et al. (2020). Theta and alpha brainwave occurrences were discovered in the study, which yielded varied results. With the eyes open, the alpha band waves changed their pattern before rTMS and increased significantly after rTMS.

Theta frequency was found to be more suited for the effects of inhibition on cortical activity in the ipsilateral frontal lobe; hence, the alpha frequency dropped. In the ipsilateral frontal and contralateral centroparietal areas, however, theta band waves increased statistically. Local efficiency deteriorated during the transition from EC to EO due to inconsistency with alpha and theta waves, and fascinatingly, no beta waves were identified between EC and EO (Tan et al., 2013). On the other hand, other experiments were successful in obtaining significant beta waves on the EC with alpha waves (Greer et al., 2021).

In conclusion, the exploration of brainwave activity at a resting state is still ongoing. Current research has reported significant correlations of theta and alpha waves in pairs and negatively correlated with the beta band, consistent with previous findings where the oscillation ranges were substantial under the control group (Engelbregt et al., 2016; Strehl, 2014). The theta, alpha and beta present in the prefrontal cortex (Engelbregt et al., 2016; Wu et al., 2021; Scally et al., 2018; Eroglu et al., 2018; Azizi et al., 2017; Verweij et al., 2014). Several literature reviews stated specific names for similar experiments under resting state activity, such as the medial prefrontal cortex and ventral lateral prefrontal cortex (Chai et al., 2011), ipsilateral frontal (theta and beta waves) and frontoparietal (alpha and beta waves) (Qiu et al., 2020; Rogala et al., 2020).

2 METHODOLOGY

The neurofeedback session was conducted at University Malaysia Sarawak's Counselling Laboratory. There were ten sessions, each lasting 3 minutes with a 15-second rest in between, totalling 1 hour and 30 minutes. A female patient volunteered to take part in this experimental experiment. Two electrodes were inserted on the forehead of the prefrontal cortex and labelled Fp1 and Fp2, while the reference electrode was placed on the left earlobe and labelled Fp3 (A1). Cotton and gel substances were used to put the electrodes. This experiment was carried out while the subjects were at rest. The neurofeedback training system's video was shown. The patient must watch the movie while relaxed—the film is presented as a game.

3 RESULTS

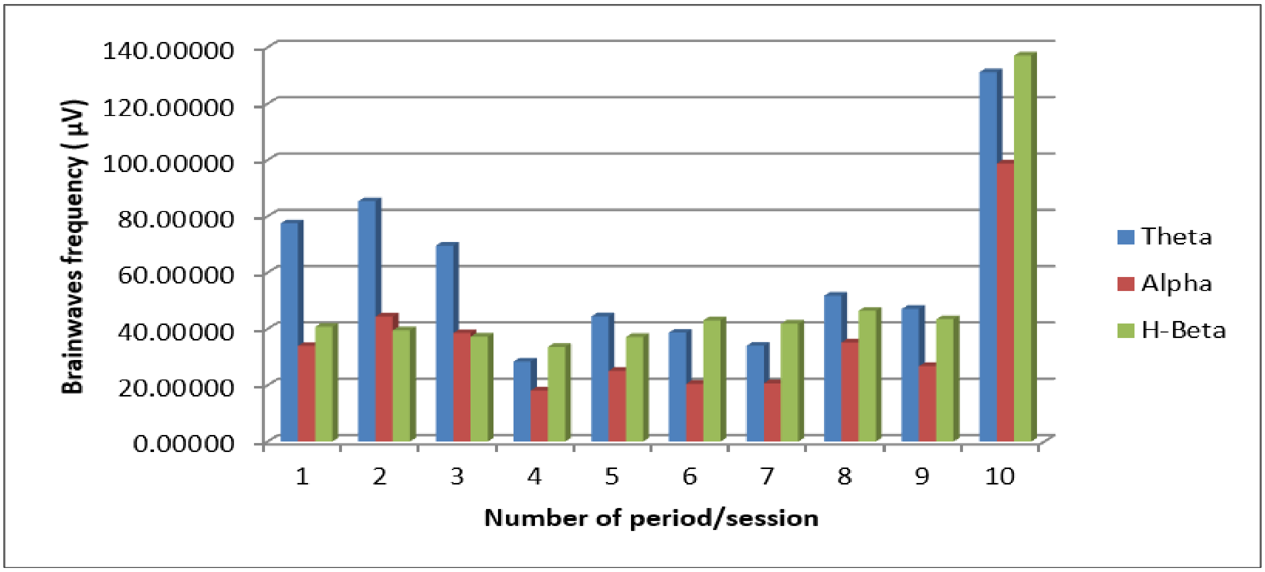

Figure 1. Bar chart representing theta, alpha and H-beta after the experiment.

This experiment exhibited disturbing statistics (Figure 1) over ten sessions conducted on a healthy female patient. Three brainwaves appeared in the prefrontal cortex, namely alpha, theta and high beta, and the measurement of frequency was recorded in microvolt (µV). Each frequency wave has a different pattern representing the range value from the beginning to the last. The distance of alpha-band frequency ranges from 1st to 9th sessions was not consistent but slightly separated between sessions until 10th sessions, more considerable number gap compared to the previous. Based on the findings, the alpha-band frequency indicated non-data dispersion due to a lower standard deviation value (*SD* = 23.61) compared to theta (*SD* = 31.11) and high beta (*SD* = 30.82). In addition, alpha demonstrated the lowest mean value (36.19 ± 23.61), followed by high beta (50.01 ± 30.82) and theta (60.81 ± 31.11).

Table 2. Normality test for brainwave frequencies.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
THETA	.189	60	.000	.851	60	.000
ALPHA	.247	60	.000	.707	60	.000
HIGH_BETA	.337	60	.000	.508	60	.000

a. Lilliefors Significance Correction

Before brainwave frequencies produced mean and SD values, the normality test procedure was continuously conducted to find out whether the sample collection was normally distributed or not (Ghasemi & Zahediasl, 2012; Laerd Statistics, n.d). From the results of Shapiro=Wilk's test (p<.05) and a visual inspection of histograms as shown in Table 1, normal Q-Q plots and box plots exhibited that the number of sessions conducted was not normally distributed for brainwave types (theta, alpha and high beta). It was revealed that the theta wave obtained a skewness of 1.350 with a standard error (*SE*) of 0.309 and kurtosis of 1.213 (*SE*= 0.608), and the alpha wave recorded a skewness of 2.178 (*SE*= 0.309) and kurtosis of 4.416 (*SE*= 0.608). For high beta, it recorded a skewness of 3.124 (*SE*= 0.309) and a kurtosis of 9.238 (*SE*= 0.608). The *p*-values of the normality test for all types of brainwave frequencies were lower than 0.05 (p<0.00); therefore, the null hypothesis was rejected.

Table 3. Friedman test for brainwave frequencies

N	60
Chi-Square	60.933
df	2
Asymp. Sig.	.000

a. Friedman Test

From the non-normal data distribution, the appropriate brainwave frequency for the activity conducted in the resting state has not been decided. Friedman test is an appropriate assessment for testing the differences between groups of brainwave activity (Laerd Statistics, n.d). According to Table 2, there were statistically significant differences in each brainwave type (theta, alpha and high beta), X^2 (2) = 60.933, *p*=0.000. The *p*-value signified that the null hypothesis was rejected. From the mean rank obtained from the Friedman test, the theta score (*M*= 2.57) in mean rank was higher than the alpha score (*M*= 1.20) and high beta score (*M*=2.23).

Since the Friedman test showed statistically significant results, the data distribution was proceeded to a post hoc test to determine which brainwaves were significantly different (Galili, 2010; Laerd Statistics, n.d). The post hoc test through Wilcoxon signed-rank tests was conducted by applying Bonferroni correction and found that the theta and alpha had statistically significant changes in brainwave activity in the resting state (*Z*= -6.412, *p*= 0.000). Meanwhile, the alpha and high beta indicated statistically significant differences in brainwave activity in the resting state (*Z*= -5.418, *p*= 0.000), as shown in Table 3. In contrast, high beta and theta in Table 4 showed statistically significant (*Z*= -2.599, *p*= 0.009) similar result was demonstrated by alpha and high beta in Table 5 (*Z*= -5.418, *p*= 0.000).

Table 4. Post-hoc test for alpha-theta brainwaves.

	ALPHA - THETA
Z	-6.412[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.

Table 5. Post-hoc test for high beta-theta brainwaves.

	HIGH_BETA - THETA
Z	-2.599[b]
Asymp. Sig. (2-tailed)	.009

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

Table 6. Post-hoc test for high beta-alpha brainwaves

	HIGH_BETA - ALPHA
Z	-5.418[b]
Asymp. Sig. (2-tailed)	.000

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

4 DISCUSSION

This study looked at a single healthy person's brainwave activity while she was resting. Theta, alpha, and high beta brainwaves were recorded in the prefrontal cortex. Even though the sample collection was not normally distributed, the results demonstrated that the frequencies of brainwaves were statistically significant. Intriguingly, the statistics in Figure 1 showed that the number of high-beta was the largest in the resting state, which contradicted earlier research from 2019. The study looked at the subject's brain in distinct hemispheres and alterations in a transitional state from closed eyelids to active cognitive task involvement. According to the data, the range increased from low beta to high beta waves. High beta waves occur significantly in high pressure, anxious, excitement and low attention conditions (Diaz M et al., 2019).

The preceding statement suggested that the low beta band is a healthy range of beta frequency associated with cognitive processing, attention and decision-making. Meanwhile, high beta waves are commonly associated with mental health (Azizi et al., 2017; Cheon et al., 2016) and cognitive processing (Diaz M et al., 2019; Sugata et al., 2020). While performing an activity, our subject may probably be under pressure or with low attention, causing high beta waves and increasing rapidly in 10 sessions (Diaz M et al., 2019). Other frequently reported cases of beta bands have generally been found to be negatively correlated to resting conditions, despite being targeted in the prefrontal cortex (Diaz M et al., 2019; Qiu et al., 2020; Karamacoska et al., 2017).

Surprisingly, alpha waves are present in the electroencephalogram (EEG) but lower than theta and beta waves. Alpha band waves are more likely to appear in sleep deprivation (Wu et al., 2021; Verweij et al., 2014) and cognitive processing (Sammer et al., 2007). According to Diaz M et al. (2019), the alpha frequency range often appears in EEG due to natural traits. The finding is supported by Barry et al. (2007) that the alpha waves are present in resting conditions, specifically in eyes-closed and eyes-opened states. Furthermore, Choi et al. (2018) reported a similar outcome. The alpha frequency range inclined strongly in the eyes-closed condition when developing an authentication system and inversely to passive resting (Gutmann et al., 2015). This study assumed that the patient might have difficulty focusing on the task while opening her eyes, resulting in a slower oscillation range in the alpha wave. Moreover, theta waves are positive in closed and open eye states (Qiu et al., 2020). However, theta band waves were undetected in other frontal regions in the resting state (Scheeringa et al., 2007). The closest finding was discovered in pairs or, in other words, theta/beta ratio (TBR) correlated with the resting state in the frontal area (Zhang et al., 2018). Theta bands appear during sleep deprivation (Verweij et al., 2014), the mental calculation (Sammer et al., 2007) and predominantly in the stimulus-response process (Karamacoska et al., 2017). Thus, all brainwave types occurred in the resting condition in the prefrontal cortex.

5 CONCLUSION

Three brainwaves were recorded: theta, alpha, and high beta, which were monitored and analysed in this investigation. The beta, theta, and alpha waves were formerly stated to occur in the resting state, with the theta and alpha band frequencies prevalent during intrinsic activity. On the other hand, the antecedent assertion should validate the findings on resting activity. Due to the subject's condition, the maximum range of high beta waves was thought to be nervous, eager, and focused. On the other hand, the alpha wave is the smallest, which explains sleep deprivation. Many activities were carried out in various groups of healthy control subjects and control subjects with a sizable population for resting-state but not passive resting. In addition, a small number of researchers experimented on a single subject in a resting state regardless of gender, age and health condition. The implications of brainwave studies provide many advantages to the modern days. For example, alpha bands have been used for individual identification, where the alpha band waves benefit the authentication system. In future research, all brainwave frequencies of theta, alpha and high beta are suggested to be utilised as indicators for resting state activity.

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