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Exploring Background Noise During Learning: A Neurofeedback Study

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ABSTRACT

Distinguishing effective background noise during learning is crucial for students. This study was conducted to determine the effective noise background during learning. Two healthy female subjects were recruited for this experiment. They were put in separate brainwave recording sessions for learning tasks without noise and with background noise. Their theta and alpha brainwave readings showed higher activity while learning with background noise. The finding indicated that both brainwaves represented insight and alertness were more dominant during active learning tasks than without noise. However, there was no statistically significant difference in both learning conditions for theta (p = 0.09) and alpha (p = 0.07) brainwaves. The higher activity level during the learning process with background noise could be interpreted as a sign of enhanced cognitive insight and alertness. Nonetheless, the magnitude of the difference observed did not reach a statistically significant level, thus necessitating further investigation and analysis.

Keywords: neurofeedback training, brainwaves, background noise, learning

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1 INTRODUCTION

Many generations have evolved and innovated from the basic framework of biofeedback to highly specific neurofeedback training (NFT), which is helpful for training and improving brainwave activity. Sattar and Valdiya (1999) stated that electroencephalogram (EEG) biofeedback focuses primarily on electrical activity in the brain and maps activity based on region. NFT typically receives audio or video neurofeedback and employs EEG to record electrical waves from brain activity (Marzbani et al., 2016).

NFT is a type of biofeedback in which individuals learn to regulate their brain activity deliberately and, therefore, gain control over processes that are typically not subject to conscious manipulation (Holtmann et al., 2014). Cognitive performance, symptoms, and behaviour are expected to improve due to altered brain activity. This is feasible through online feedback on changes captured by several technologies, most notably the NFT system of EEG (Weber et al., 2020). Table 1 explains the brainwave frequencies and characters that represent each wave.

Background noise, a ubiquitous environmental factor, has long been acknowledged for its potential influence on cognitive function and learning outcomes (Ke et al., 2021). Although silence has traditionally been viewed as the optimal environment for educational activities (Ollin, 2008), background noise has illuminated its impact on learning performance and brainwave activity (Söderlund et al., 2007). A thorough comprehension of the ramifications of background noise during the learning process can offer valuable insights into refining learning environments and enhancing cognitive processes to yield improved learning outcomes.

This study investigated the effects of background noise on brainwave activity and its potential implications for learning and memory retention. This study also provides valuable insights to improve the quality of educational services by proposing an effective and conducive background noise environment. It can enhance students' attention and focus during their learning process.

Table 1. Brainwave frequencies and characters.

Brainwave	Frequency	General characteristics
Delta	1-4	Sleep, obliviousness, deep unconsciousness
Theta	4-8	Imagination, insight, depth states, meditative state
Alpha	8-13	Alertness and peacefulness, readiness, deeply relaxed
Lower alpha	8-10	Recalling
Upper alpha	10-13	Optimal cognitive performance
Sensorimotor rhythm	13-15	Mental alertness, physical relaxation
Beta	15-20	Thinking, focusing, attention, alertness, excitement
High beta	20-32	Intensity, hyper-alertness, anxiety
Gamma	32-133	Learning, cognitive processing, problem-solving tasks

1.1 Problem Statement

Numerous NFT studies have been conducted on patients with various auditory stimuli. Among the studies are training on selective attention (Kim et al., 2021), learning-disabled children with auditory reinforcement (Bucho et al., 2019), and auditory stimuli to increase cortical activity and training for auditory hallucination. However, studies on the effects of noise on student's learning and attention are scarce. Brainwave data can support researchers in the learning science field and university students in seeking the connection between attention and background noise.

A quiet setting-up area has been developed for years to provide a learning environment. However, Gordon-Hickey & Lemley (2012) proposed that an acceptance level of background noise while reading and listening to speech is connected to study setting selection. The study demonstrated that students accurately self-assessed their acoustic learning environment demands. Due to this output, this study investigated the effect of background noise on learning attention. The subjects were asked to perform attention tasks with background noise for the brainwave emission to represent the subject's physiology and cognitive condition. It is significant for the students to adopt the outcomes of this study while learning in class or at home.

This study of background noise in learning poses a few factors to encounter due to the different types and sources of noise and its interaction with task complexity. It is crucial to bridge research and practical applications, as an example, to enhance learning outcomes and well-being in various educational and classroom settings. The rationale and implications are wide-ranging for education, cognitive science and learning design. It allows for creating more effective learning environments and tailored educational practices to individual needs. Contribution knowledge and ideas about background noise during learning can help shape educational practices, classroom design, and technology development for better learning outcomes. The idea of learning and background noise lies in finding the optimal noise that enhances the learning experience. This entails creating an environment where background noise contributes positively to concentration and engagement during active learning activities. Therefore, educators and learners must carefully consider the background noise to foster an environment that maximises the effectiveness of active learning.

1.2 Research Question

1. What is the frequency of brainwaves produced during relaxation and performing tasks with background noise?
2. Can background noise improve attention and the learning process?

1.3 Hypothesis

H_0: Background noise has no significant effect on student's attention.

H_A: Background noise has significantly disturbed and distracted student's attention.

1.4 Objectives

1. To determine brain activity during learning tasks in silence (without noise).
2. To determine brain activity during learning tasks with background noise.
3. To differentiate brain activity with and without noise.
4. To propose effective background noise during learning tasks.

2 LITERATURE REVIEW

Studies of NFT brainwaves are essential to understand psychological and social situations, encompassing stress, mental exhaustion, and mental fatigue (Jebelli et al., 2018) as well as cognitive performance, such as attention and working memory (Da Silva & De Souza, 2021; Wang, 2017). Due to EEG ability and capacity, a study related to NFT was proposed. Subjects can monitor changes in their brain activity audibly, tactilely, or visually on a computer screen in real-time via auditory tone, screen exhibiting a display, moving the ball, or plane moving across the screen. Based on trials, participants receive feedback (e.g., verbal feedback from a trainer, tactile feedback from a vibrating pad, or visual feedback from a visual sign on a screen) as reinforcement for changes in activity in the correct direction (Arns et al., 2014).

NFT is an effective and significant tool for brain imaging techniques. Electric energy produced by the brain is known as brainwaves. It consists of four main groups, from the most active to the least active: alpha, beta, delta, and theta. NFT records electrical activity generated by firing along the scalp. Brainwaves are defined as arrhythmic, electrically captured by EEG equipment between brain cells called neurons (Ciccarelli et al., 2023). In a clinical context, EEG monitoring over a certain period of the brain's spontaneous electric activity. NFT helps train people's brains based on sensory input from real-time EEG data processing during a cognitive or mental function. It is a rehabilitation strategy, as training will develop cognitive skills through constructive learning. The brain, for example, learns to control itself and controls executive functions, such as attention, focus, concentration, and impulse control. The benefits are high time resolution and NFT when noninvasively monitoring the physiological responses of the brain. In an NFT session, data are processed in real-time to monitor or influence stimulus and sensory (Paret et al., 2019).

Using background music in educational contexts is a widespread pedagogical strategy; nonetheless, its impact on learning achievements has engendered substantial scholarly discourse and inquiry, according to Caviola et al. (2021), experimented on middle-school students the age of 11 to 13 years old by measuring their performance on mental calculation tasks. The background noise was manipulated to reflect further the actual classroom environment – quiet, traffic and classroom noise. The study found that the youngest children were negatively impacted and performed poorly in classroom noise conditions, while in the older children, the differences were relatively indistinguishable; no significant difference. Previous studies have demonstrated that younger children exhibit a heightened tendency, compared to older children and adults, to become disengaged from tasks when confronted with ambient noise, irrespective of the inherent characteristics of the task (Klatte et al., 2013). The data of the findings are most distinct when the math task is moderately difficult. A more complex task implicitly encourages children at any age to actively focus their attention on the task at hand (Dockrell & Shield, 2006). Hence, Caviola et al. (2021) concluded that younger children are more sensitive to the noise in school classrooms than older children, and their academic performance can be affected.

Recently, there has been an escalating scientific curiosity in exploring the intricate interplay between brainwave frequencies and dynamics of attention and cognitive acquisition (Boer & Krumbholz, 2018). Various investigations have been undertaken to dissect the impact of diverse brainwave frequencies on cognitive operations, with the overarching objective of delineating a discernible threshold or critical juncture that underpins augmented attentional focus and enhanced learning capabilities. The body of research has yielded diverse outcomes certain studies have posited a nexus between distinct brainwave frequencies and realms of attention and learning (Alaros et al., 2021; Herweg et al., 2020; Klimesch et al., 2011; Wagner & Tilney, 1983), whereas others have encountered outcomes that lack a decisive correlation between these variables (Ede et al., 2014).

Drawing upon a comprehensive literature review conducted by Wagner and Tilney (1983), inspired by the pioneering work of Dr. Georgi Lazanov on optimal brainwave states for effective learning, it was revealed that students immersed in an alpha state, characterised by a state of relaxed concentration, and exhibited heightened learning efficacy. In this context, Klimesch et al. (2011) explored the role of alpha oscillations (8-12 Hz) in shaping attentional processes. They revealed a positive correlation between heightened alpha power and enhancements in attentional focus, concurrently resulting in diminished susceptibility to distraction. However, the study did not definitively delineate a precise threshold or cut-off point indicative of the pinnacle of attentional performance.

In addition, Alaros et al. (2021) delved into the intriguing connection between theta waves and focused attention. Their findings illuminated an intriguing relationship, where an elevation in theta wave activity was identified as a potential indicator of heightened attentional focus. This implies that theta waves, typically associated with more relaxed cognitive states, may also play a pivotal role in facilitating sustained concentration during tasks that demand attentive engagement. Further insights into the ramifications of theta oscillations on learning and memory emerged from the comprehensive study conducted by Herweg et al. (2020). They meticulously examined the effects of theta oscillations in successful learning and memory in human episodic memory. The results were compelling, revealing that a successful memory is correlated with an augmentation in both focused theta oscillations within a specific frequency range and a more general elevation across the power spectrum. This suggests that the theta waves play a distinct role in supporting associative memory, while the overall power spectrum's tilting effect reflects a broader measure of cognitive activation.

However, few studies have found an explicit link between brainwave frequency and attention and learning. For example, a study conducted by Ede et al. (2014) found no correlation between alpha waves and attention, as the data from the study revealed that alpha oscillations are not always required for attention. The lack of a clear consensus on the relationship between brainwave frequency and attention and learning is likely because the brain is a complex organ, and many factors can affect its function. Additionally, previous studies have used different methods and sample sizes, making it difficult to compare the results. While no specific threshold or cut-off point exists for improved attention and learning process brainwave frequencies, the existing literature provides evidence of the relationship between specific frequency ranges and cognitive enhancement. Alpha, theta, and beta waves have been consistently associated with improved attention, memory, and learning outcomes. However, it is essential to note that individual variations in brainwave patterns and the complexity of cognitive processes make it challenging to establish a universal threshold.

3 METHODOLOGY

NFT was conducted on the first floor of the Counselling Laboratory, Faculty of Cognitive Sciences and Human Development, Universiti Malaysia Sarawak. Participants were recruited by screening through a set of inclusion and exclusion criteria. The inclusion criteria are, first, participants are aged between 20 and 25 years old, and secondly, no medical history of significant neurological disorders, such as epilepsy, multiple sclerosis, Parkinson's disease, Alzheimer's disease or traumatic brain injuries. The exclusion criteria are, firstly, individuals who are currently taking medications that could affect neurological functions, such as antipsychotics, antiepileptics or other drugs known to impact the nervous system, and secondly, individuals with a history of substance abuse or addiction.

Prior to the commencement of the experimental protocol, subjects were presented with an informed consent assessment document. After that, the subjects were explained about the learning task, which involved comprehension and puzzles of cognitive tasks comprising different mental processes and skills. Comprehension refers to understanding and interpreting information, and puzzles are structured tasks designed to engage cognitive skills and promote learning. These tasks played crucial roles in cognitive development and learning in various aspects.

There were ten periods, each lasting three minutes with a 15-second break, for 32.5 minutes. Two healthy female subjects volunteered for this laboratory experiment. They sat for separate brainwave neurofeedback recording sessions. Two learning tasks, as explained above, were conducted in two conditions, namely, without noise and with background noise. The setup for the session is depicted in Figure 1. Before the session began, two electrodes were placed on the forehead of the prefrontal cortex and labelled as Fp1 and Fp2, and another was placed on the left earlobe and labelled as A1. Ten20 conductive gel was used to place electrodes on the skin to obtain close contact and eliminate air between them. After that, the session started, and the brainwaves were recorded accordingly. The band waves on the screen indicated the recorded brainwave frequency. The frequency, expressed in the number of waves per second (Hz), indicates how fast the waves oscillate, whereas amplitude, measured in microvolts (µV), represents the power of the waves.

This study employed The Brain Trainer: Spectrum Learning Software as a training tool for cognitive enhancement, while Statistical Package for the Social Sciences (SPSS) was used for data management, statistical analysis, and reporting of research findings. These two software tools served different but complementary roles in this study.

Figure 1. Set up of the neurofeedback experimental session.

4 RESULTS AND DISCUSSION

Figure 1 depicts the results obtained from ten experiments on healthy female subjects according to the task given in conditions without noise and with background noise. Two types of brainwaves were recorded in the prefrontal cortex: alpha and theta. The brain activity was measured in microvolts (µV). In Table 2 and Figure 2, each brainwave activity has a unique pattern representing the range value from the first to the last period. The results showed that alpha has a lower mean value of 27.086 than theta of 30.717. In addition, the alpha-band frequency showed non-data dispersion due to lower standard deviation values of 13.115 and 6.938 for theta and alpha, respectively. For brainwave activities with background noise, theta and alpha brain activities were 41.172 and 36.596, respectively. Higher brain activities demonstrated that the brain area of the prefrontal cortex recorded more theta and alpha waves while the subjects conducted a learning task with background noise.

Table 2. Brainwave activities of theta and alpha during learning in silence (without noise) and with background noise.

Period	Brain activities in silent		Brain activities with background noise	
	Theta	Alpha	Theta	Alpha
1	52.345	36.759	36.988	28.815
2	20.181	19.891	14.098	18.307
3	57.526	36.707	39.124	15.201
4	26.922	19.489	45.887	49.672
5	23.414	23.877	42.074	34.622
6	22.744	24.268	43.715	42.094
7	30.510	21.802	28.652	37.413
8	25.777	35.197	51.716	41.007
9	23.07	22.912	47.184	34.826
10	24.679	29.956	62.279	64.000
Mean ± SD	30.717 ± 13.115	27.086 ± 6.937	41.172 ± 13.056	36.596 ± 14.268

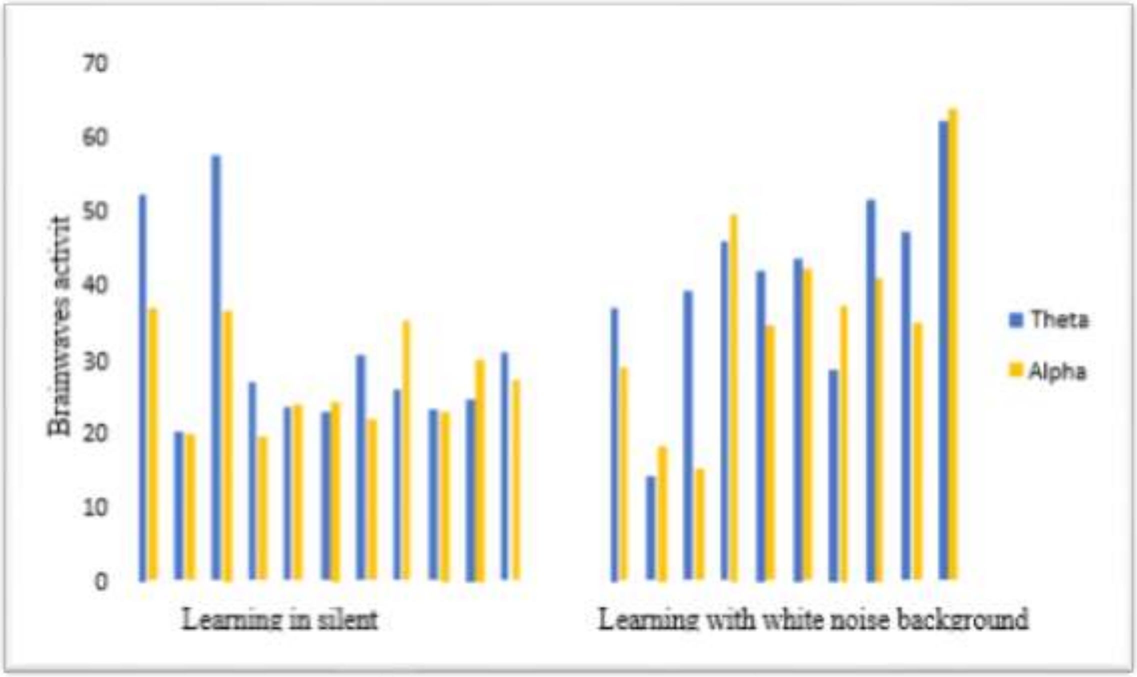

Figure 2. Brainwave activities of theta and alpha during learning in silence (without noise) and with background noise.

A simple t-test was performed on both theta and alpha (brainwave activities to test the results obtained. The results showed $p = 0.09$, representing no significant difference for theta brainwaves in conditions without noise and with background noise. A similar trend was observed for alpha brainwave. The value of $p = 0.07$, representing H_O, was accepted as it demonstrated no significant difference between alpha waves during learning without noise and background noise. The results are summarised in Tables 3 and 4.

Table 3. Sample t-test for theta brainwaves for conditions without noise and background noise.

	Theta (without noise)	Theta (with background noise)
Mean	30.717	41.172
Variance	172.013	170.421
Observations	10	
df	18	
t-Stat-	-1.78655	
P(T<=t) two-tail	0.09087	
t Critical two-tail	2.10092	

Table 4. Sample t-test for alpha brainwaves for conditions without noise and with background noise.

	Alpha (without noise)	Alpha (with background noise)
Mean	27.086	36.596
Variance	48.134	203.572
Observations	10	
df	18	
t-Stat	-1.89554	
P(T<=t) two-tail	0.07419	
t Critical two-tail	2.10092	

This study investigated the brainwave activities of two healthy subjects while performing two learning task activities. Two types of brainwaves, theta and alpha, were recorded in the prefrontal cortex. The findings revealed no statistically significant difference between theta and alpha brainwave learning conditions. The subject's brain was observed in the prefrontal cortex with the learning process condition as vigorous cognitive task involvement. The range increased from theta to alpha waves, according to the results.

The non-significant disparities in this study could be attributed to diverse factors, including individual differences in response to environmental stimuli, sample size restrictions, and specific features of the learning tasks employed. It is essential to acknowledge the exploratory nature of this study, and further investigations with larger sample sizes and controlled experimental designs are imperative to elucidate the subtle implications of background noise on brainwave dynamics during the learning process.

This study makes a valuable contribution to the expanding research on the effects of environmental variables on cognitive performance. It emphasises the potential advantages of incorporating background noise as an unobtrusive background auditory stimulus in learning environments. This aspect may be particularly pertinent in educational settings where optimal engagement and cognitive performance are paramount.

According to Jeon and Oh (2019), background noise listening concentration revealed a statistically significant difference between background noise listening experience ($p = 0.001$), caring for the construction of a noisy environment ($p = 0.004$), and noise helps concentration ($p = 0.000$). Their findings contradict the outcomes of this study. They also perceived that designing the environments and programs using background noise is crucial to improving nursing students' learning attitudes.

The observed increase in theta brainwave activity suggests that the participants may have undergone an amplified cognitive processing state, marked by an increased capacity to establish connections and obtain insights during their learning process. Similarly, intensified alpha brainwave activity indicated that background noise may have stimulated a state of augmented attentiveness and concentrated cognitive engagement among the participants.

These findings are of particular significance as they provide insight into the potential of background noise as a facilitating environmental factor for cognitive tasks. Background noise creates an atmosphere that fosters a state of heightened cognitive vigilance, which could be advantageous in educational settings where sustained focus and cognitive processing are indispensable (Al-Shargie et al., 2021). A study by Al-Shargie et al. (2021) on cognitive vigilance enhancement using audio stimulation proposed that 250 Hz audio could increase attention and cognitive efficiency due to the multisensory process integration. Multisensory integration is when input from one sensory enhances the perception of stimuli in another.

However, it is imperative to accentuate that the absence of statistically significant variance in brainwave frequencies between learning with background noise and without noise environment necessitates meticulous contemplation. The non-remarkable outcomes imply that background noise may elicit noticeable modifications in brainwave activity, but these modifications may not attain statistical significance. Hence, one cannot definitively affirm that background noise profoundly influences brainwave activity during learning tasks.

Successful implementation of NFT leads to the desired increase in SMR activity. Although effects on learning were inconclusive in the preliminary study, the active neurofeedback group exhibited significantly improved attention, speed, and attentiveness in cognitive tasks compared to the sham controls (Kim et al., 2021). These findings are promising and support the need for additional research incorporating more NFT sessions. This study presents preliminary evidence of the potential of EEG neurofeedback in enhancing outcomes with intelligent tutoring systems. More extensive exploration of the link between SMR, attention, and academic performance is warranted.

This study also revealed that background noise successfully increased attention and focus. According to Awada et al. (2022) and Othman et al. (2019), background noise levels of 45 dB improved cognitive function in terms of sustained attention, accuracy, and speed of performance, as well as improved creativity and reduced stress levels. They also proposed setting the groundwork for incorporating background noise to improve workplace productivity.

Furthermore, another study by Rush (2023) examined the NFT method's effectiveness in improving auditory attention and speech perception in normal-hearing individuals. Participants underwent pre- and post-training speech-in-noise tests. EEG signals provided neurofeedback on attentional modulation during two attention training sessions. Results showed that the training improved speech-in-noise performance. Interestingly, individuals with poorer hearing thresholds at 250Hz showed the most significant improvement. The study suggested that neurofeedback attention training is a promising approach to enhancing speech-in-noise abilities in both standard and hard-of-hearing individuals.

According to Domingos et al. (2021), exposing athletes to intermittent noise during NFT can enhance their working memory, reaction time, and focus despite distractions, challenging the assumption that minimal noise is best for learning. These findings suggested that training in realistic conditions may optimise real-world performance more than silent protocols. The study contributes new knowledge about using neurofeedback in noisy conditions to help athletes improve skills. The impact of environmental context on neurofeedback outcomes highlights the need to consider personalisation.

Although this study made some original contributions to the literature, it is also subject to certain drawbacks. To ascertain the effect of the connection between background noise levels and cognitive function, this study proposes providing adequate variation in noise level, age and gender. Further studies are needed with a larger sample size and personalised training.

5 CONCLUSION

This study supports the notion that integrating background noise during learning activities could increase theta and alpha brainwave activities, corresponding to elevated cognitive insight and vigilance. The findings are consistent with prior literature on the modulating effects of environmental stimuli on neural oscillations during cognitive processes.

Given the lack of conclusive evidence regarding the superiority of one learning setting over another, the decision to utilise background noise in a learning environment or not may ultimately depend on individual preferences and subjective experiences. Students, educators, and policymakers should consider learners' diverse preferences and sensitivities when creating learning environments.

It is noteworthy to acknowledge that variances in auditory sensitivity among individuals and the potential impact of the learning context on cognitive performance may affect the efficacy of background noise in various educational settings. Therefore, an adaptable approach that caters to individual preferences for optimal learning conditions may be most conducive to promoting effective learning experiences.

Although this study presents preliminary insights into the effect of background noise on brainwave activity during learning tasks, more comprehensive research is entailed to establish a robust causal correlation between background noise and cognitive performance. The results of this study emphasised the significance of considering individual preferences while organising favourable learning environments. As the discipline of educational neuroscience progresses, an in-depth comprehension of how environmental factors, such as background noise, affect cognitive processes will undoubtedly emerge, leading to more informed educational practices and improved learning outcomes.

These dual-subject studies can serve as a starting point for investigating new ideas or new interventions. These preliminary results can give a sense of this method's possible pros and cons. More comprehensive studies could further explore the potential value or hazards suggested by these early data. These dual-subject experimental designs involved extensive and repeated measurements of one individual over time. Although limited in their generalisability due to a single participant, it is valuable for generating new hypotheses and revealing novel or counterintuitive findings that merit further research in larger samples.

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