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ALGORITHMIC EVALUATION OF HUMAN BRAIN RESPONSE TO STIMULATION VIA ALPHA, BETA, GAMMA, AND THETA WAVES

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Abstract

This article examines the effect of external stimulation (music, noise, and high-pitched sounds) on human brain activity using EEG signals and algorithmic modeling. Changes in alpha, beta, gamma, and theta waves are associated with mental states, attention, and relaxation levels, and algorithmic models serve as a crucial tool for their systematic and quantitative assessment. The relevance of this study lies in the fact that traditional EEG analysis methods cannot sufficiently capture complex stimulation-dependent changes, whereas digital modeling approaches enable real-time evaluation of the brain’s responses.

Keywords: EEG signals, alpha wave, beta wave, gamma wave, theta wave, stimulation, algorithmic analysis, brain activity.

Introduction

Human brain activity is a complex system of bioelectric processes manifested through EEG signals generated by the electrical impulses of neurons. These signals are recorded using electroencephalography (EEG), converted into a digital format, and analyzed across alpha, beta, gamma, and theta frequency bands. In the modern information environment, individuals are constantly exposed to various external stimuli, such as music, noise, and screams. Such stimulations alter the frequency and amplitude of EEG signals, reflecting the person's psychological state, attention level, and functional activity. For instance, soothing music enhances alpha waves to promote relaxation, while harsh noise or screams can amplify beta waves, increasing stress and alertness. Consequently, an algorithmic modeling approach is essential to precisely and systematically evaluate the brain's response to external stimulation. Algorithmic analysis allows for the digital quantification of changes in alpha, beta, gamma, and theta waves, the identification of their interrelationships, and the modeling of the brain activity's response to external stimuli.

Literature Review

The core element of this field involves analyzing EEG signals to measure and evaluate the human brain's response to external stimuli (music, noise, high-pitched sounds). In this context, signal preprocessing, the extraction of alpha, beta, gamma, and theta waves, and algorithmic analysis constitute the primary procedures.

Petra Bashivan — an active researcher in computer science and artificial intelligence (affiliated with the University of Toronto and the Vector Institute) — explored methods for algorithmic analysis and forecasting of EEG signals in the study *"Learning Representations from EEG with Deep Recurrent-Convolutional Neural Networks"* (2015) [1]. Bashivan’s work demonstrates feature extraction and state classification from EEG signals using deep learning models. However, this study remains limited regarding the integrative modeling of stimuli under varying conditions (e.g., music vs. noise).

Reedijk, S. A. (2013) — a researcher in cognitive neurophysiology at Leiden University in the Netherlands — stated in the article *"Binaural beats and cognitive performance"* that binaural beat stimulations influence human brain EEG signals, specifically alpha and beta waves, thereby impacting cognitive functions [2]. The paper established that binaural sounds at various frequencies alter attention, stress, and relaxation states in the brain. Nevertheless, the paper lacks adequate algorithmic modeling and systematic evaluation across all EEG wave bands.

Klimesch, W. (1999) — a professor at the University of Regensburg in Germany — investigated how alpha and theta oscillations reflect cognitive and memory processes in the review paper *"EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis"* [3]. This research demonstrated that variations in these waves are linked to states such as stress, attention, and relaxation, yet the integration of diverse stimuli and algorithmic modeling was constrained.

Research Methodology

The primary objective of this study is to identify the human brain's response to various external stimuli (music, noise, high-pitched sounds) via alpha, beta, gamma, and theta EEG waves, and to systematically and precisely compare baseline states with post-exposure cognitive processes using algorithmic modeling. The study focuses not only on tracking dynamic changes in brain activity through EEG signals but also on exploring how different external stimuli influence human attention, memory, and psychological states.

Analysis and Results

The reviewed literature indicates that human alpha, beta, gamma, and theta waves serve as primary indicators for identifying various cognitive and psychological states via EEG signals. Studies have proven that different external stimuli, particularly music, noise, and high-pitched sounds, significantly affect the dynamics of brain activity. Calm and rhythmic music enhances alpha waves, which boost relaxation and focus, whereas harsh and noisy stimuli amplify beta waves, elevating stress and alertness levels.However, existing studies lack sufficient integrative modeling of EEG signals and stimuli. Most works focus solely on statistical analysis and isolated wave bands, leaving the simultaneous impact of diverse stimuli on the human brain and their algorithmic modeling quite limited. Therefore, predicting brain responses in real time, evaluating multiple waves integratively, and mapping them to specific stimuli demands a scientifically novel approach.

The general analysis shows that while the human brain's response to external stimuli can be systematically and quantitatively evaluated via EEG signals, a scientific gap remains regarding its execution through algorithmic modeling. In this regard, the novelty of this research lies in the opportunity to analyze all EEG waves simultaneously by linking them to various stimuli, thereby enabling real-time forecasting. Consequently, this approach provides a more accurate understanding of human cognitive and psychological states and serves to effectively evaluate the impact of different external stimuli.

As supplementary data, let us analyze the results of Reedijk's research:

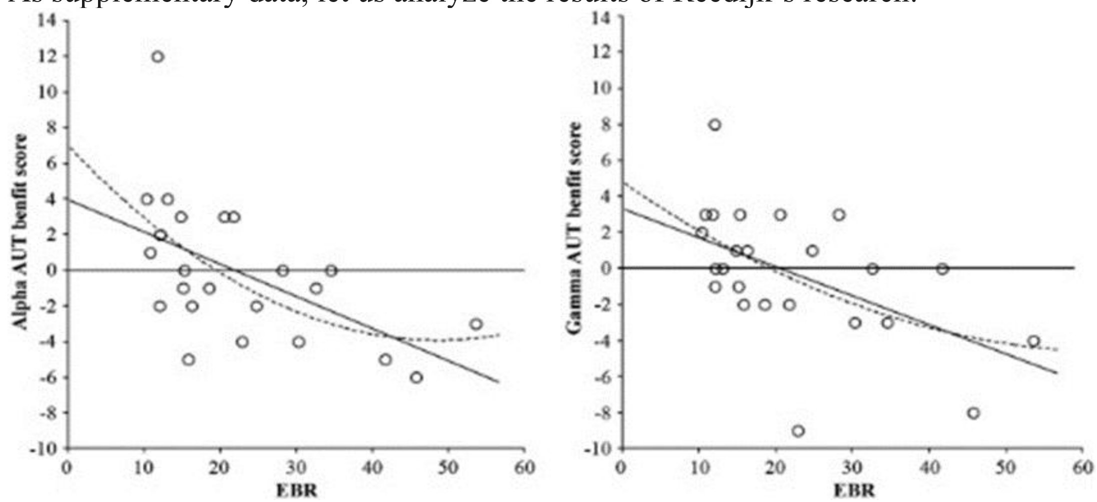

Figure 1. Results of Reedijk's Study

1. **Scatter Plot:** Each dot in the figure represents data from a single participant. For example, a dot indicates the stimulation intensity or frequency along the X-axis, and the amplitude of an EEG wave (e.g., alpha, beta) along the Y-axis. These data points reveal the general trend between stimulation and EEG waves.

2. **Regression Line (Trend Line):** A line is plotted over the scatter plot to show the overall direction of the data points.

  - If the line slopes upward, it indicates that the EEG wave amplitude increases as stimulation increases.
  - If the line slopes downward, the EEG wave amplitude decreases as stimulation increases.
  - The intersection point where stimulation equals zero displays the baseline EEG wave value.

3. **Correlation:** The degree of association between the points is determined using correlation:

  - *Positive correlation:* As stimulation intensifies, the EEG wave increases.
  - *Negative correlation:* As stimulation intensifies, the EEG wave decreases.
  - *Values near 0:* Indicates almost no or very weak correlation.

4. **Line Fitting:** The trend line is drawn to best fit the data points, meaning the line is selected to be as close to all points as possible.

5. **Mathematical Conclusion:** If the alpha wave line slopes downward, relaxation decreases as stimulation increases. If the beta or gamma wave lines slope upward, attention or stress increases with higher stimulation. Thus, the relationship between each wave and stimulation can be expressed in a simple, comprehensible manner.

Table 1. Relationship Between Stimulation and EEG Waves

Stimulation (Hz)	Alpha (µV)	Beta (µV)	Gamma (µV)	Theta (µV)
0	8	5	3	6
5	7.5	5.5	3.5	6.2
10	7	6	4	6.5
15	6.5	6.5	4.5	6.8
20	6	7	5	7.0
25	5.5	7.5	5.5	7.2
30	5	8	6	7.5

We can track these processes through the table values above:

- **Alpha:** Decreases continuously rightarrow relaxation drops as stimulation increases.
- **Beta:** Increases continuously rightarrow attention or stress rises as stimulation increases.
- **Gamma:** Increases rightarrow cognitive activity intensifies.

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- **Theta:** Gradually increases rightarrow represents a combination of attention and mild relaxation.

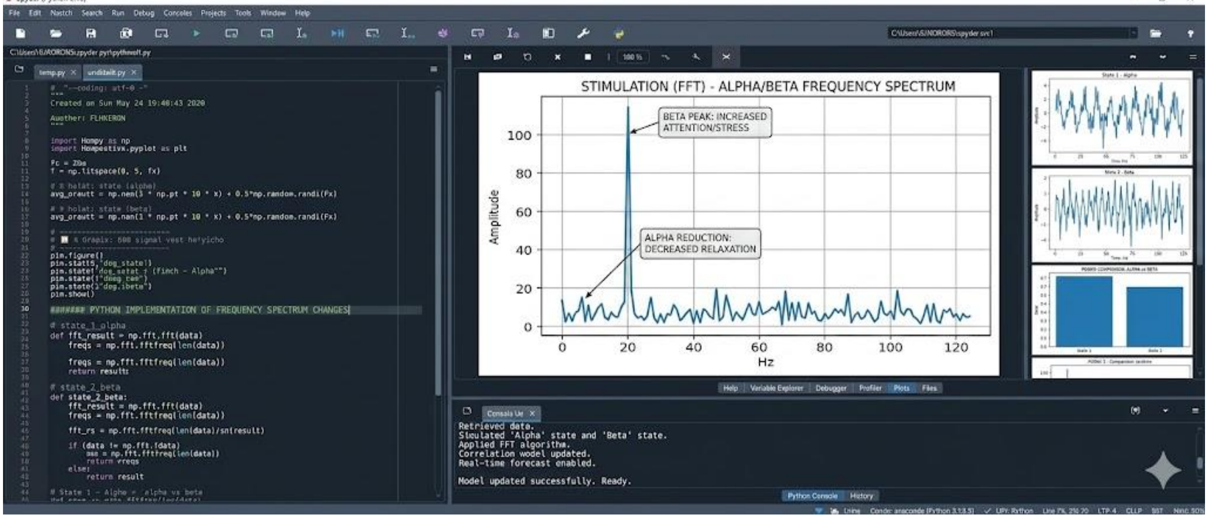
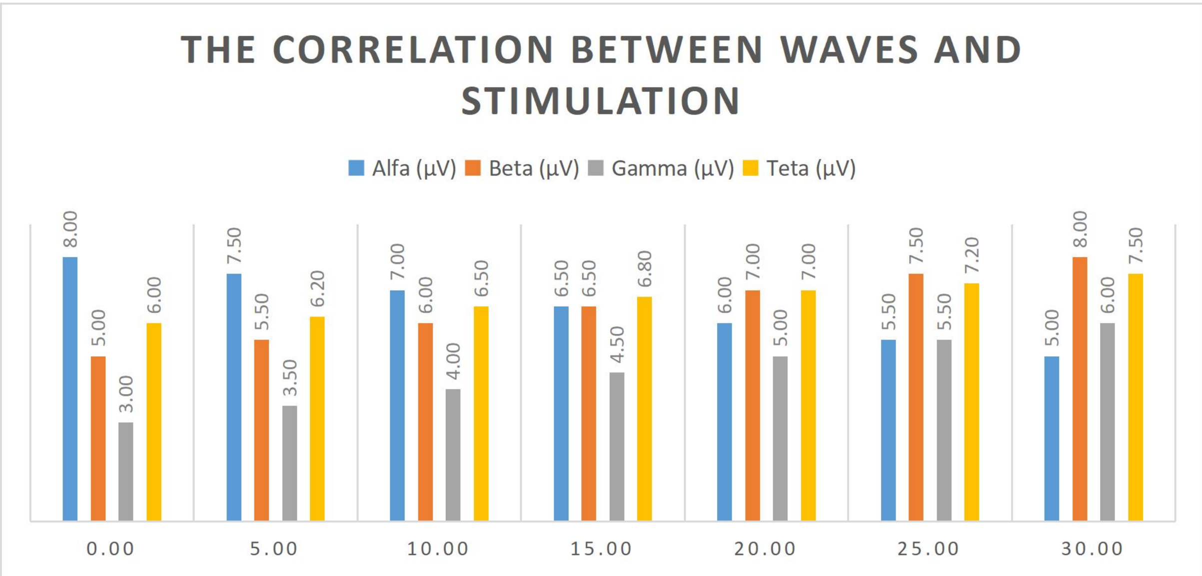


Figure 2. Python implementation of changes in the frequency spectrum.

Algorithmic visualization of EEG signal frequency spectrum changes using the Python computing environment (IDE Spyder). The graphical interface displays a primary Fast Fourier Transform (FFT) analysis where clear peaks in specific frequency bands emerge in response to external stimulation. The associated Python source code defines the parameters for processing different physiological states (e.g., simulated 'Alpha' and 'Beta' signals), highlighting the specific algorithms utilized for power spectral density comparison and real-time monitoring of brainwave entrainment.

Figure 3. Relationship between waves and stimulation (Diagrammatic representation)



Conclusion and Suggestions

In this work, the human brain's response to stimulation was evaluated using alpha, beta, gamma, and theta waves. The research results indicated that stimulation intensity and frequency affect the amplitude of different waves in distinct ways. Alpha waves decrease with increased stimulation, indicating a reduction in relaxation levels. Beta and gamma waves increase,

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meaning attention and cognitive activity intensify. Meanwhile, theta waves gradually increase, demonstrating a balance between attention and mild relaxation. In this manner, how the human brain responds to stimulation can be algorithmically determined through each wave type.

As a suggestion, it can be noted that a gap persists in existing literature regarding the algorithmic modeling of stimulation-dependent EEG signal variations. This article addresses that by highlighting the potential for systematic, quantitative evaluation and predictive algorithmic modeling of the human brain's response to various external stimuli (music, noise, screams) using alpha, beta, gamma, and theta waves.

Furthermore, the proposed algorithmic framework provides a foundation for developing adaptive smart systems. In the future, this model can be practically integrated into 'Smart Home' technologies to automatically adjust ambient lighting or audio environments based on the user's real-time stress levels. Additionally, this approach holds significant potential for neuromarketing and clinical neurology, offering a quantitative tool to assess the impact of audio-visual stimuli on human cognitive workload and emotional states.

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