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Article

Investigating the correlation between EEG brainwave patterns and English reading proficiency using biosensors

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Abstract: Reading ability is a complex cognitive activity affected by various neural mechanisms. This research aims to examine the relationship between brain activity, as measured by non-invasive biosensors, specifically an electroencephalogram (EEG), and English reading ability. Specifically, the research investigates how different brainwave patterns (alpha, beta, and theta waves) relate to reading speed, comprehension, and accuracy across different levels of reading proficiency. Biosensors, in EEG devices, suggest a non-invasive means of monitoring brain functions in real-time, giving extensive vision into cognitive functions correlated with reading performance. Seventy native Chinese-speaking university students in China were selected as participants for this research. Based on their performance in word recognition, sentence comprehension and abstract reading, the participants are divided into high, intermediate, and low proficiency groups. While participants are performing the reading tasks, their brain activity was recorded using a 32-channel EEG system. The three main frequency bands for EEG set up are, theta waves, 4–7 Hz; alpha waves, 8–12 Hz; and beta waves, 13–30 Hz. The EEG-based biosensor system offers high resolution data, allowing very precise measurements of brainwave activity, which are directly correlated with cognitive states during reading tasks. Correlation analyses, one-way ANOVA, and multivariate regression models were applied to check the associations between brainwave power and reading performance in the context of proficiency groups. The outcome suggests that higher alpha and beta wave activity was related to greater reading proficiency, with higher beta waves being related to higher speeds as well as better comprehension, while theta waves were again more pronounced in low-proficiency readers on complex tasks. These results suggest that EEG-based biosensors assessments should be used to measure cognitive states related to reading proficiency and may offer a new avenue for personalized educational intervention.

Keywords: English reading ability; brain activity; biosensors; brainwaves; electroencephalogram (EEG); cognitive processes

1. Introduction

Reading is a cognitive skill vital for learning and lifelong education. It involves several interrelated cognitive processes such as word recognition, sentence comprehension, and memory retrieval. Such processes require neural mechanisms that enable humans to read and decode written language. Understanding the cognitive mechanisms of reading may lead to making educational practices more tailor-made so that they maximize reading ability for individuals with problems in reading comprehension. These cognitive skills differ among the population of readers and constitute elements such as cognitive load, attention, and processing speed, which define reading performance [1]. Human information processing is done through frequency bands called brainwaves that represent various cognitive states or mental tasks to be done. Alpha waves fall within 8–12 Hz, beta waves range between 13–30 Hz, and theta waves fall between 4–7 Hz, all considered different stages of thought. Alpha waves are associated with relaxed attention or readiness for use in cognitive processing. Beta waves indicate more active tasks that must be done, such as solving a problem and making decisions. Theta waves are associated with states of intense focus, memory recall, and emotional regulation. These brainwaves may be recorded using electroencephalogram (EEG) as a non-invasive technique by which one can directly evaluate the real-time activity of the brain in the execution of a cognitive task, like reading [2].

Brain wave research suggests that in most focused attention cases, alpha waves increase, while beta waves dominate tasks involving active thinking. In general, tasks that involve deeper cognitive processing and are characterized by the significant retrieval of memory or comprehension are typically associated with theta waves. Such EEG investigations of reading ability have insightfully pointed out the kind of brainwave patterns involved with cognitive activities in reading, ranging from word recognition to fluency in reading, and comprehension [3].

The correlation between reading ability and EEG brain wave activity was explored in a lot of studies. It shows that specific brain waves are associated with a specific aspect of reading. For example, the association of alpha wave activity proved positive in reading comprehension. Higher levels of alpha waves have been associated with better concentration and relaxed cognitive processing. High levels of beta waves are correlated with higher reading speeds. Quite often, individuals with lower reading proficiency tend to record dominant levels of theta waves during complex or demanding reading tasks. It suggests that theta waves could indicate cognitive demands such as decoding or maintaining attention during reading tasks [4].

Different patterns of brain waves have also been established to be associated with the ease or difficulty of reading the text. For example, in children, increased beta wave activity was associated with rapid word recognition and improved comprehension compared with those instances exhibiting higher alpha wave activity that occurred during tasks that required more sustained attention or memory retrieval [5].

Most of the studies concentrated on specified tasks or on specific populations, leaving a gap in understanding how brainwave activity differs between various levels of reading proficiency. Few studies examine how brain activity changes with proficiency in reading across a broad range of proficiency levels, especially in non-native language learners. EEG has emerged as a very robust tool in the investigation of cognitive processes during reading. Compared with other brain imaging techniques, EEG is non-invasive, cost-effective, and provides real-time data on brainwave activity. This feature makes it suitable for the research of how the brain reacts to reading in general and focuses on specific aspects like word recognition, comprehension, and abstract reading. Analysis of brainwave patterns of tasks on reading serves to show how aspects such as attention, memory, and processing speed contribute to literacy [6].

Recent studies also suggest a fine-grained understanding of the relationship between brain waves and the skill achieved in reading during these phases of language acquisition. Non-native language readers may encounter cognitively very different loads when reading because of newly introduced complexities regarding the comprehension of vocabulary and grammar structures that are not native. For instance, the pattern of theta wave activity may be distinct for non-native learners while decoding since individuals often try to decode unknown words or translation for these people. Moreover, their cognitive processing may be much more haphazard and contain longer cycles of attention due to frequent switches of cognitive resources between linguistic comprehension and memory retrieval. These differences illustrate the possibility to make reading interventions nuanced and tailored toward addressing the special neural needs of non-native language learners [7].

However, research has recently started examining the connection between reading fluency and the synchronization of particular brainwave frequency combinations. For example, better reading comprehension in both native and non-native learners has been connected with a more coherent synchronization between alpha and beta waves, suggesting a smooth transition between relaxed cognitive processing and a more active analytical thinking activity. If there is an understanding of how these wave patterns interrelate, then that will offer great insights into designing learning tools that enhance reading speed, comprehension, and overall reading proficiency. Insights from EEG data could help develop the innovative strategies of enhancing reading interventions, which are not just about improving fluency but about making brainwave activity synchronous with effective outcomes [8].

Quite recently, EEG was applied to the examination of differences in brainwave patterns between readers of different skill levels. In other words, researchers compared poor readers and good readers by differences in EEG data between these groups. Besides becoming a diagnostic tool, EEG can be used to assist in delivering personalized educational interventions. If specific brainwave patterns are discovered for various reading tasks, then teachers may adapt interventions that target specific cognitive processes engaged in reading [9].

The main difference between a native and a non-native language learner is that the processing of the language, acquiring new vocabulary, and understanding while reading is processed differently. Thus, brainwaves may potentially be impacted in diverse ways. By linking brain activity to reading proficiency in non-native language learners, it may be possible to better understand the cognitive processes involved in second language acquisition and create educational interventions that are more successful in meeting the needs of these learners [10].

The reading proficiency and biomechanics are related through the cognitive and motor processes. The physical analysis of eye movement, postural dynamics, and brainwave patterns while reading can give view on how these physical components influence reading speed, comprehension, and accuracy. The knowledge can promote improvements in teaching techniques and instructional interventions [11].

1.1. Research objectives

Research aims to explore the correlation between brain activity and reading ability in native Chinese-speaking university students. The research determines how the differential types of brain wave, alpha, beta, and theta, might affect performance on a set of reading tasks, including word identification, passage comprehension, and abstract reading. The relationship will be taken into account in the context of supporting a better comprehension of cognitive processes occurring while reading and the development of targeted educational interventions catering to different levels of proficiency among students.

1.2. Key contributions

The primary contributions of the present research are as follows:

- To research EEG brainwave patterns about reading proficiency in non-native English speakers (Chinese-speaking university students).
- To classify participants into three proficiency groups (high, intermediate, low) and analyze EEG differences across reading tasks such as word recognition, comprehension, and abstract reading.
- To investigate the correlation between brainwave frequencies based on reading performance with speed, accuracy, and proficiency.

1.3. Paper organization

The paper is organized into six sections. Section 2 provides the detailed related studies. Section 3 reports the methodology, which covers the selection of participants, methods of data collection, and analysis techniques. Section 4 presents results, including EEG analysis and correlations between EEG and reading performance. Section 5 addresses the discussion of the research. And lastly, Section 6provides a conclusion for the paper with directions for future studies.

2. Related works

Biosensors have found applications in making better understanding of brain functions by integrating with other technologies such as functional Magnetic Resonance Imaging (fMRI) and thereby enhancing language interventions. A conceptual model developed in the research [12] expressed the basic theme of neuroplasticity in language recovery and the utility of biosensors for preoperative assessment and tailored therapy. The tools thus help in mapping language areas non-invasively, thereby providing a strategic framework for neurolinguistic intervention. Some studies of wearable EEG devices monitored the relationship between attention and academic performance. The existing single-person model of attention into interbrain coupling [13], which suggested that interpersonal attention dynamics in a class relate to academic performance positively. The approach emphasizes potential collective-level monitoring of attention, which may provide better results outcomes for predicting academic success relative to individual measures of attention.

Reading comprehension is a cognitive process that is associated with brain activity [14], most notably EEG brainwaves. The effects of yellow overlays upon brainwaves and the fluency of reading among children who have Autism Spectrum

Disorder (ASD) have been probed in several studies. These studies indicated that beta brainwave activity in the frontal and temporal lobes increased with the use of yellow overlays [15], which increased the fluidity of reading. Such visuals aid a good facilitator of cognitive processing while reading and are hence beneficial for children with ASD.

EEG tests on reading ability have been used to deduce the nature of wave patterns and how they are related to performance in reading. For the assessment of reading skills among a group of native Chinese speakers' university students [16], alpha, beta, and theta waves were used to reveal their relationship with reading speed, comprehension, and accuracy. There were positive correlations between reading proficiency and higher levels of alpha and beta activity. Theta was more common in lower-proficiency readers, so EEG was used to evaluate states of cognition relevant to the process of reading.

The relation of the interaction between physical activity and brainwaves has been studied as a cognitive performance issue among children. A positive association between daily physical activity and executive function increased the alpha and beta waves, which were associated with improved performances in executive tasks. The exercise strengthened cognitive functions in the child by activating the effects of brainwave activity [17]. Neural mechanisms of dyslexia and their relation to brainwave patterns were examined by comparing children suffering from linguistic and perceptual dyslexia with normal readers. It was interested in comparing the relative amounts of brainwave activity among these groups [18]. Results showed that power levels of alpha waves were highly differentiated between linguistic dyslexics and normal readers, thereby implying that certain specific patterns of brainwaves may tend to correspond to certain types of dyslexia. The approach sheds much light on how monitoring of brain waves can help in the early diagnosis and treatment of learning disabilities.

Neuroengineering tools have been used to predict the learning performance of students on different modalities. The application of EEG signals for text versus video-based learning to predict performance was examined [19]. It revealed that students' performance was better for video-based learning and negatively correlated with theta-to-alpha ratios related to the performance, and hence, mental fatigue was responsible for influencing the learning outcome. The research therefore contributes to the development of tools for predicting and improving the performance of students based on cognitive states. A conceptual framework that uses EEG and Virtual Reality-based learning activities to monitor early detection of Learning Disabilities (LDs) such as dyscalculia was developed [20]. By integrating through EEG and virtual reality can measure cognitive states such as attention, memory, and cognitive load to help in early detection and personalization of interventions for students with LDs, which is better for neurotechnology in special education.

Research focused on learning Arabic and Hindi and examined the brain mechanisms of second language acquisition [21]. It has indicated EEG signals in Indian and Yemeni participants when new words were first learned. Applying machine learning classification models to the data reveals interesting insights into how patterns of brain activity differ between languages so that such findings may be used in more effective language learning and intervention measures.

Research work [22] looked into inferring intent in human reader from EEG data and the eye movement data, to differentiate between normal reading and task-based English reading [22]. A quality improvement in the publicly sourced annotated data was made using cognitive load and reading intent. An extensive ablation experiment supported better improvements over other models on the dataset by utilizing spatial correlations between EEG signals and temporal characteristics from the dense graph neighborhoods.

Lab-based user research [23] presented a Unified EEG-based Reading Comprehension Modelling framework that examined brain activity during reading comprehension. EEG characteristics were utilized in extensive trials on two tasks: answer extraction and answer phrase categorization. The results revealed that brain signals can improve performance on both of the tasks indicating that brain signals yield valuable feedback for enhancing reading comprehension interactions between humans and computers.

Research discussed the wearable devices that can enhance engineering education; this research compared their benefits based on body locations in which they are worn: head, wrist, chest [24]. The head-worn devices, like eyeglasses, improved students' engagement and attention and even helped them develop spatial awareness. The other issues concerning implementation challenges were discussed and recommendations made to improve teaching and learning in engineering courses.

The synchronized multimodal neuroimaging (SMN4Lang) dataset [25] combined fMRI and magnetoencephalography (MEG) data to explore brain language processing with comprehensive linguistic annotations including word frequencies, grammatical structures, and embeddings. The information, which was gathered from the same subjects, provides information on time and position of linguistic elements in the brain as well as dynamic language understanding. It functioned as a superior standard for assessing and enhancing computational language models.

With the support of the Four Components of the Instructional Design (4C/ID) approach, the model was designed and piloted with children in an Abu Dhabi, United Arab Emirates public school [26]. The results showed how MILE successfully enhanced the comprehension of Arabic reading by cognitive techniques, self-generated exercise, and constructive learning. With retelling and paraphrasing being the easiest and summarization the hardest, the concept was aimed at enhancing development among low-level devoted students. It throws light upon integrating cognitive approaches with educational systems to enrich reading skills.

Research examined how students felt about five low-tech learning opportunities and how well they understood biomechanical principles [27]. The findings demonstrated that, especially in particular tasks, students' comprehension of biomechanical principles enhanced. The instructors of biomechanics could explain theeducation and progressively include both individuals and groups in learning activities.

Research gaps

In the development and maturation of brain activity relating to cognitive performance and reading ability, there is much that remains an open gap in the literature. While a body of research exists on the role of EEG in understanding reading comprehension and related cognitive processes, most of the work has focused on limited proficiency groups or aspects of reading such as word recognition or fluency. No previous research explored the relationship between brainwave patterns (alpha, beta, theta) and reading ability across different proficiency levels, especially among non-native language learners. With the promise of EEG-based interventions improving the individual's cognitive performance, the synergistic use of real-time EEG monitoring with educational tools, like tailored individualized reading interventions, is under-explored. Most research to date has involved either children or the general population; very little interest has been shown in university students, particularly those who are acquiring an additional language. This research intends to fill the research gaps by investigating how EEG relates with differing degrees of proficiency in reading in English among native Chinese-speaking university students, exploring the validity of EEG as a measure for personalized educational interventions. In addition, it aims at determining the capability of EEG data in developing the most promising language learning strategies that can improve the cognitive performance of the non-native learner and make valuable contributions to the understanding of how adaptable the brain is in second language acquisition.

3. Research design

The research design explores the relationship between students' brainwave activity during reading and their reading ability. It looks into how different frequencies of brainwaves, alpha, beta, and theta waves, are correlated with components of reading performance in terms of reading speed, reading proficiency, and comprehension accuracy. Utilizing EEG readings and reading tasks, this research examines the cognitive processes that occur during reading.

3.1. Data collection

The research consists of 70 native Chinese-speaking university students, by making them to perform a Standard English reading test. The aged between 18 and 25 years participants were selected through an invitation send to students in varying academic programs in the university. They were initially selected based on voluntary participation and informed approval. To categorize the participants into different proficiency levels, they performed a standard English reading test that measured word recognition, comprehension of passages, and abstract reading tasks. At this stage, the subjects were assigned to the groups of high, intermediate, and low proficiency according to the following cutoffs: 75th, 50th–75th, and below 50th percent. Each participant performed reading tasks suitable for their proficiency level, under EEG recording with 32 active channels to research the relationship between patterns of brainwaves and reading ability. The EEG signal integration tracking eye movements, body posture, and hand gestures with biosensors. Making association of these transformations with the brainwave signals can help in analyzing the motor-action and response systems affect brain cognitive steps while reading, thus explaining a better understanding of reading performance dynamics.

The validity test was examined by content validity test which was used to measure the dimensions of reading efficiency and to evaluate the test items based on the skills of interest. The reliability test was conducted by Cronbach's alpha which determines the various parts of the reading proficiency.

- High Proficiency Group: Participants who scored in the top 33% of the test for English reading.
- Intermediate Proficiency Group: Participants who scored in the middle 34% range of the test for English reading.
- Low Proficiency Group: Students who scored in the lower 33% of the English reading test.

Every participant had a vision history, whether it is normal or corrected and those vision details are mentioned in the demographic information. And none of the participant had a history of head injury or neurological disorder. Finally, no participants had any impairments within cognitive functions that would impact their reading performance.

Table 1 presents demographic details of participants grouped by reading proficiency levels. The high proficiency subject (*N* = 23) consisted of subjects aged 18–20, including 12 males and 11 females, with 20 having normal vision. The intermediate proficiency subjects (*N* = 24) were aged 21–23 and included subjects of matched gender distributions, with 19 subjects having normal vision. The Low Proficiency subject (*N* = 23) consisted of subjects aged 23–25, including 11 males, 12 females, with 17 having normal vision.

Table 1. Demographic information of participants.

Demographic Characteristic	**High Proficiency (*N* = 23)**	**Intermediate Proficiency (*N* = 24)**	**Low Proficiency (*N* = 23)**
Age Range	18–20 years	21–23 years	23–25 years
Gender	12 Male, 11 Female	13 Male, 11 Female	11 Male, 12 Female
Native Language	Chinese	Chinese	Chinese
Vision	20 Normal, 3 corrected	19 Normal, 5 corrected	17 Normal, 5 corrected

The results in **Table 1** outline demographic information about the participants. The information includes age range, gender, native language and vision status. Participants were divided into one of three groups (high, intermediate, or low proficiency) based on their performance on the English reading. **Figure 1** shows the experimental design for data collection, thus describing the procedures for analysis of brainwave patterns (alpha, beta, theta) during reading tasks. The biosensors measures the frequencies of brainwaves and their correlation. It directly captures the real-time activity of the brain in reading tasks. Using these sensors that can measure brainwave patterns precisely and correlate with reading performance to help identify underlying cognitive processes.

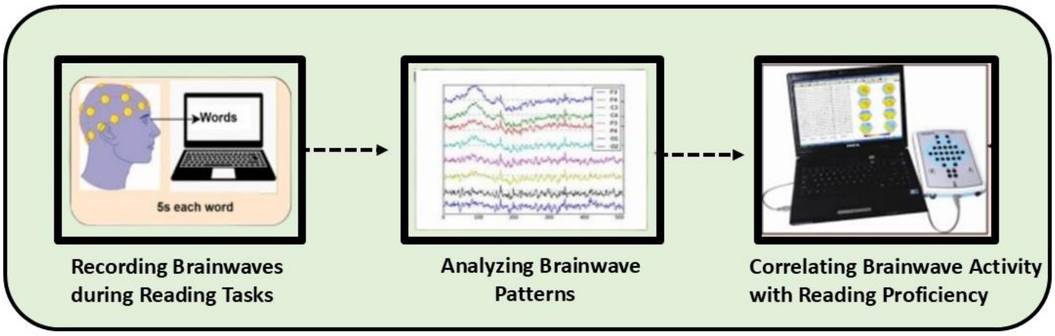

Figure 1. Experimental design for data collection.

3.2. Reading tasks

Reading tasks have been prepared for this research to check various aspects of reading ability in the English language, including word recognition, sentence comprehension, and abstract reading. Each of the tasks was designed so as to involve cognitive processes used in the basic reading skills and the higher-level reading comprehension.

(1) Word Recognition Task

In this word recognition task, participants were shown a list of English words. Each was displayed for a fixed duration (e.g., 2000 ms) and then disappeared. The task for the participants was only to indicate whether the word that appeared on the screen was a real English word or a non-word. Randomly generated non-words were created so that they looked like phonologically plausible words but had no semantic significance. Participants were elicited to respond using one of two keys of the keyboard, for words and for non-words. This is used to test the reaction time in differentiating between the familiar and unfamiliar words.

(2) Sentence Comprehension Task

The sentences in this task had numerous English sentences that were varied as regards complexity. From such simple declarative sentences to more complex syntactic structures with a requirement for greater-order comprehension, the range of sentences ranged from the former to the latter. Each line was followed by a set of multiple-choice questions designed to assess understanding of the text’s basic premise, important details, and particular conclusions. The task was performed to test reading comprehension skills and the ability to understand written text in English.

(3) Abstract Reading Task

The abstract reading task is given to assess the participants’ ability to comprehend abstract texts, metaphors, idioms, and grasp abstract concepts. The participants are asked to read a set of sentences that included nonliteral expressions. After reading every sentence, participants are asked to answer questions referring to the meaning of the nonliteral expressions; hence, it was possible to test a participant’s ability to understand nonliteral language. This later task gave insight into how participants processed complex or figurative language in print.

3.3. EEG data acquisition during reading tasks

EEG data was captured during reading tasks to obtain brain activity and analyze the related activity and reading performance.

EEG Setup

Brain activity was recorded with the help of a 32-channel EEG system during the English reading tasks. The system recorded the brainwave activity in three main frequency bands, such astheta (4–7 Hz), alpha (8–12 Hz), and beta (13–30 Hz). Participants are asked to sit in a sound-attenuated and electrically shielded room to avoid interference from external noises. For accurate data capture, the sampling rate of the EEG system was set at a very high-rate of 1000 Hz. **Figure 2** depicts the environment for the EEG system, which is designed to record brain activity in the reading tasks.

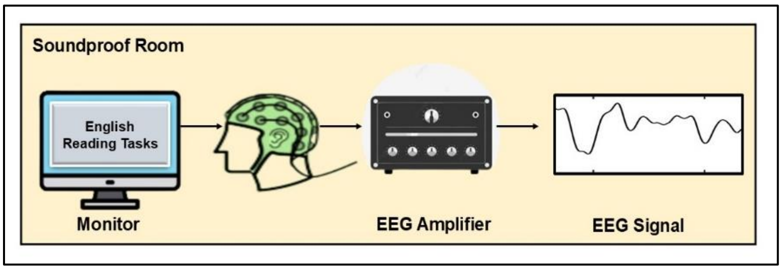

Figure 2. EEG system setup.

It is clear that recording takes place in a controlled environment with minimal interference, and thus, this ensures high-quality signals in alpha, beta, and theta recordings from the brain activity.

3.4. Performance variables

The relationship between brainwave activity and reading performance is evaluated using three types of brainwave frequencies. The independent variables in this analysis are the brainwave activities. It includes Alpha Wave Power, Beta Wave Power, and Theta Wave Power. These various frequency bands of the brainwaves, as recorded by EEG, are used as independent variables to see how they relate to reading performance.

3.5. Statistical analysis

Therefore, SPSS version 28 offers methods for guaranteeing the correct use of statistical techniques, eliminating doubts regarding the reliability and validity of results. The statistical procedures contain correlation analysis, one-way ANOVA, and multivariate regression for analyzing the relationships between brainwave activities and reading performance. Consequently, the data is processed with the use of appropriate methods to identify the common patterns representing reading speed, comprehension accuracy, and total achievement. The correlation analysis presents results regarding the strength and the direction of the relationships between the rhythmic brainwave patterns and reading performance.

Correlation analysis

Correlation analysis is applied to determine the course and intensity of the association between two continuous variables. It measures the change in one variable compared to others. In this research, a correlation analysis was adopted to examine the alpha, beta, and theta wave activities of the brain about the reading performances, which included reading speed, comprehension and accuracy.

(1) One-Way ANOVA

To compare the means of the groups independently and to find out if the means of three or more groups differ significantly from one another, One-way ANOVA is used. Essentially, it determines whether the variance between groups is less than the variance within groups. The alternative hypothesis suggests at least one mean differs from the null hypothesis, which implies that all the group means are the same. In this experiment, one-way ANOVA was applied to the comparison of brainwave activity and reading performance across three levels of proficiency: high, intermediate, and low.

(2) Multivariate Regression

The multivariate regression method is essentially a kind of statistical analysis, which involves the interaction of several independent variables with an equal number of dependent variables to measure the relationship between them. It enables the researcher to understand how several factors tend to affect outcomes together, rather than isolating variables. In this research, multivariate regression was applied to uncover which brainwave frequencies (alpha, beta, and theta) predict the following reading performance variables, such as speed, comprehension accuracy, and overall accuracy, with their combined effects.

4. Statistical results

The statistical results section presents the result of analyzing the association between brainwave activities and reading performance. The result features some of the outcomes of correlation analysis, one-way ANOVA, and multivariate regression, which set out the main trends and differences in brainwave frequencies in relation to levels of reading proficiency.

4.1. Correlation analysis results

Correlation analysis express at the relationships between brainwave activity (alpha, beta, theta) and three key aspects of reading performance speed, comprehension, and accuracy. The analysis in this research has the assessing of how brainwave frequencies relate to the reading efficiency of participants by scoring the strength and direction of these associations.

From the analysis in **Table 2**, the findings of strong positive correlation are provided below. Alpha waves on reading proficiency (r = 0.68), meaning higher alpha activity is most closely linked to better proficiency in reading. Beta waves show a higher positive correlation with comprehension accuracy (r = 0.70), meaning beta waves are mostly influential to enhance reading accuracy. In contrast, theta waves correlate negatively with all reading measures and relate most strongly and negatively to comprehension accuracy (r = −0.41), meaning that heightened activity of theta waves is linked to lower levels of accuracy while reading. Generally, the table indicates that alpha and beta waves are facilitative of reading performance, whereas theta waves are detrimental, particularly for comprehension accuracy.

Table 2. Correlation coefficients between brainwave activity and reading performance.

Brainwave Frequency	Reading Proficiency	Reading Speed	Comprehension Accuracy
Alpha Waves (8–12 Hz)	0.68	0.54	0.61
Beta Waves (13–30 Hz)	0.49	0.42	0.70
Theta Waves (4–7 Hz)	−0.35	−0.28	−0.41

Figure 3 indicates the correlation coefficients between the brainwave frequencies (Alpha, Beta, Theta) and the measures of reading performance-speed of reading, comprehension accuracy, and overall accuracy. These relationships indicate the strength and direction of how each brainwave frequency affects various performance indices of reading ability.

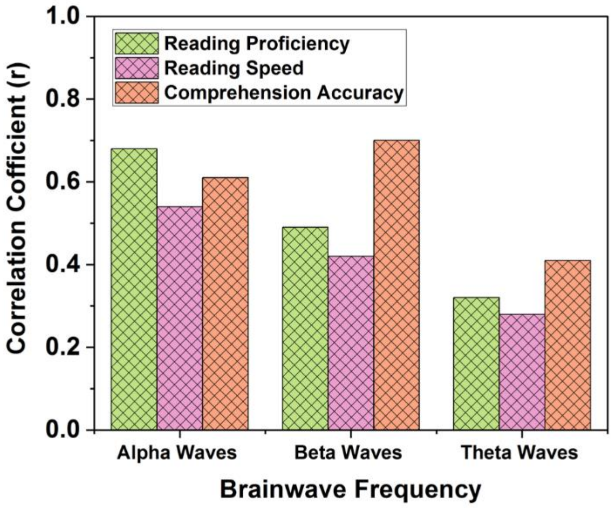

Figure 3. Correlation between brainwave activity vs reading performance.

4.2. One-way ANOVA results

One-way ANOVA was conducted to compare brainwave activity and reading performance across the three proficiency levels. **Table 3** presents the differences in brainwave activity and reading performance between the three groups (high, intermediate, and low).

Table 3. Comparison of brainwave power and reading performance.

Variation Source	Mean Square (MS)	*p*-value	*F*-value	The sum of Squares (SS)	Degrees of Freedom (df)
Alpha Wave Power	17.56	0.009	4.92	35.12	2
Beta Wave Power	21.28	< 0.001	8.27	42.56	2
Theta Wave Power	14.23	0.002	6.56	28.45	2

Significant differences were present in both brainwave power and reading performance in the results of **Table 3** across the three proficiency groups. Alpha wave power was higher in the high proficiency group compared to the two other groups (4.92), while beta wave power (8.27), also represented better cognitive efficiency. Theta wave power was stronger in the low-proficiency group 6.56, indicating that these readers expended more cognitive effort during reading tasks.

The results also suggest that elevated alpha and beta wave activity go with higher reading proficiency but that higher amounts of theta activity may indicate more effortful processing in lower proficiency readers.

Figure 4 depicts the MS values in high-proficiency readers for the Alpha, Beta, and Theta power of waves. The MS value that Beta wave power possesses is relatively high (21.28), indicating that Beta's relationship to cognitive efficiency is much bigger than that of Alpha (17.56) and Theta (14.23) waves. Significant differences related to wave powers are there and established by a *p*-value, as these would relate to proficient reading.

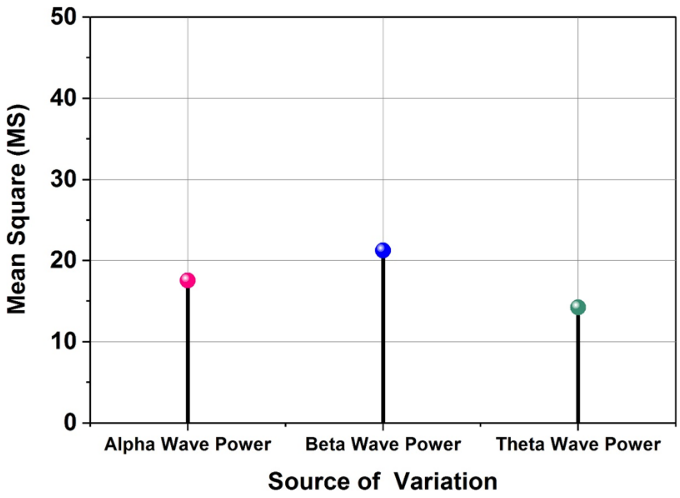

Figure 4. Brainwave power across proficiency groups.

4.3. Multivariate regression results

Table 4 reveals a strong positive relationship between brain wave frequencies (alpha, beta, and theta) and reading performance. Beta wave power is the most significant predictor, contributing to faster and more precise reading. Alpha wave power has a weaker association, while theta wave power may indicate cognitive strain in poorer readers.

Table 4. Multivariate regression results for brainwave frequencies and reading performance.

Variables	SE (Standard Error)	Coefficients (B)	*t*-value	*p*-value
Alpha Wave Power	0.12	0.29	2.92	0.005
Beta Wave Power	0.10	0.45	5.20	< 0.001
Theta Wave Power	0.11	−0.24	−2.73	0.080

Figure 5 depicts the summary of results for the regression multivariate analysis of brainwave frequencies alpha, beta, and theta. It shows both unstandardized coefficients (B) and standardized coefficients (Beta) in predicting measures of reading performance speed, comprehension, and accuracy.

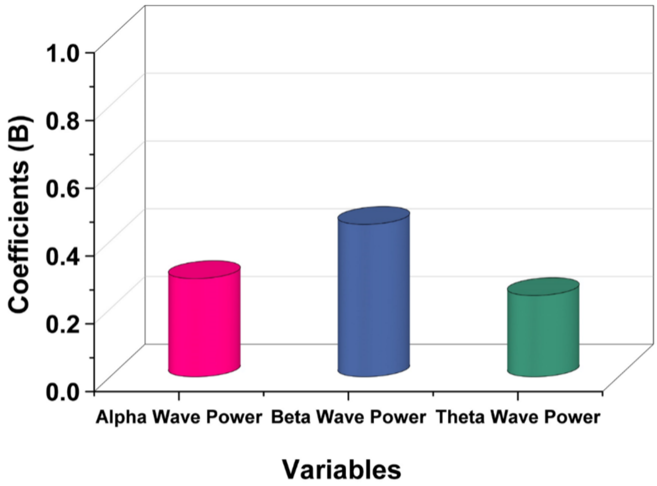

Figure 5. Multivariate regression coefficients for brainwave frequencies and reading performance.

5. Discussion

The findings of this research give important insight into the relationship between brainwave activity and reading performance. The research explored the relationship between brainwave activity, and reading performance among Chinese-speaking university students learning in English medium. Alpha waves, within the 8–12 Hz frequency range, were positively correlated with reading performance, indicating that higher levels of alpha activity are associated with effective reading through the development of a relaxed state of mind. Beta waves, between 13 and 30 Hz, emerged as the most significant predictor of reading success. Higher beta activity is positively associated with faster reading speed, good comprehension, and a greater accuracy level. This shows that there's a relationship between beta waves and active thinking and concentration components that constitute effective reading. Conversely, theta waves (4–7 Hz) manifested negatively to reading performance. High theta activity correlated with poor reading rates and low accuracy, indicating that high-skilled readers experience relatively low cognitive load and more efficient processing, whereas low-skilled readers struggle with reading tasks because of the elevated level of theta activity. These findings are supported by the results for One-Way ANOVA and multivariate regression, indicating that high-proficiency readers have significantly higher scores in comparison to low-proficiency readers on reading tasks. In general, low-proficiency readers demonstrated more theta activity and had worse scores. In relation to reading proficiency, alpha and beta waves were generally highly correlated, and greater theta activity is most likely indicative of increased cognitive effort and poorer performance.

6. Conclusion

Research analyzed the relationship between brain activity wave and reading skills in students at university levels. The research dwelt on alpha, beta, and theta waves. EEG records taken during three different reading tasks were used in assessing the link between brain wave frequencies and reading performance. Correlational analysis, ANOVA, and multivariate regression were used to assess the brain activity across different proficiency groups. The brainwave activities were highly correlated with the reading proficiency, meaning that alpha and beta waves were associated positively with reading proficiency, while theta showed negative correlations. Alpha and beta wave activity were associated with the high-proficiency group, while elevated theta waves were associated with the low-proficiency group. Regression analysis revealed that beta waves had the highest association with reading proficiency. This research is limited by the fact that input from EEG to accurately assess cognitive states is complex, with inter-individual variability in terms of brainwave patterns, which might affect the outcome. More future research may need to look into larger and more diverse samples and refine EEG-based interventions that work for native and non-native language learners. Such research can lay the foundation for the development of effective customized learning strategies for improving reading performance.

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