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Spectral Topographic Brain Mapping in EEG Recording for Detecting Reading Attention in Various Science Books

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ABSTRACT

The electrical signals in the brain can be analysed by performing spectral topographic brain mapping via Power Spectral Density. This brain mapping analysis can show the brain's different parts. Knowing dominant part(s) of the brain during reading activities enable to describe their attention levels when reading various books. The higher their attention levels are, the more information they receive during reading. The researchers used a qualitative approach with laboratory research using a small-group study of random behavior analysis method. The researchers recorded EEG data from 16 respondents (aged 18-22 years; eight males and eight females). EEG recordings took 15 minutes via a Simblee-based brain computer interface. The highest sampling rate was 200Hz, and the largest impedance was limited to 10Ω. EEG data with Power Spectral Density were analysed by using EEGLab Matlab-based software. Power Spectral Density was exploited to determine the high and low amplitude. The amplitude of this research was measured for the frequency range 15-18Hz (Beta1) showing the attention span. This study performed EEG recordings forreading tasks with different genres of books (academic science nonfiction book, general science nonfiction book, and science fiction book) to identify various attention cases. Attention measurement in reading can be used to detect students' reading skills in understanding science. The recording results showed that different genres of the books produced distinctive brain activities. The differences were based on the dominant part of the brain, amplitudes, and frequency patterns.

Keywords: Brain mapping, EEG recording, power spectral density, reading attention, science book.

INTRODUCTION

Understanding the concept is a priority in science learning. The aim of science education is to meaningfully teach science concepts and increase students' awareness of associating these concepts with their daily lives (Çepni, Taş, & Köse, 2006). Reading, which involves complex mental processes, is an effort to understand the concept. The mental process depends on the performed activities, and the stimuli received by a person. Activities and

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stimuli affect the brain's certain parts, which have more dominant intensity than others or vice versa.

The dominant part(s) of the brain can particularly detect through brain mapping. Brain mapping through reading activities can show the experienced mental state. If a person is sleepy while reading, the alpha state or theta is more dominant than the beta state. Similarly, while reading different genres of books, brain mapping can also be performed for controlling the brain's part(s).

Fiction and nonfiction books may provide different stimuli to readers. Fiction books are more narrative and invite the readers to be more imaginative. In contrast, non-fiction books (e.g., textbooks) call for readers to think critically or include factual information. Mutha, Haaland and Sainburg (2012) reported that differences in stimulation allegedly affect the different dominant part(s) of the brain.

In addition, the attention factor plays a role in the quality and quantity of the received information during reading. The attention factor also makes certain frequencies more dominant than other frequencies. In view of Kropotov (2016), attention conditions indicate that the frequency of the 15 - 18 Hz (beta1) electrical signal is more controlled or powerful than any other frequency in the brain.

The emergence of electric signal frequencies in the brain is recorded and measured throughout electroencephalograph (EEG). EEG is an electrophysiological monitoring method for recording brain electric activity. The monitoring is non-invasive, with electrodes placed in some parts of the scalp, although invasive electrodes are sometimes used in some cases. The EEG is a unique and valuable measurement of brain electrical function that displays graphics of voltage difference between two functional brain locations over time (Tatum, Husain, Benbadis and Kaplan, 2008). EEG involves recording these electrical signals generated by the brain.

To convert EEG data into brain map, Power Spectral Density (PSD) analysis can be used. The results of this PSD analysis produce a visualization called spectral topographic. The PSD analysis can be used to measure the amplitude density of a particular frequency based on Fast Fourier Transform. This paper will describe the power spectral analysis of reading activity and investigate the effects of the different book genres on attention conditions.

EEG through Power Spectral Density analysis can produce the visualization of brain mapping, which show the most intensity part of the brain. The brain mapping with EEG through Power Spectral Density analysis can also indicate the reading attention of respondents and the process of cognition.

EEG recording identifies the power of concentration when a person performs a reading activity. This concentration power is determined based on the recorded brain waves, such as delta, theta, alpha, beta, and gamma. One analysis that might be an alternative in the EEG data processing is to perform an analysis of the Power Spectral Density. PSD is a very useful tool to know frequencies and amplitudes of oscillatory signals in the time series data. In a similar vein, the PSD shows the amount of energy per unit based on the frequency and output-frequency components of different outcomes (Kusmaryanto, 2013).

READING, ELECTROENCEPHALOGRAPHY, and POWER SPECTRAL DENSITY

a) Reading

Some experts have suggested various meanings of reading. In view of McGinnis and Smith (1982), "Reading is a complex process that involves a constant interaction between the reader and the author, each of whom have his or her own language pattern and experiences (p. 19)." Soedarso (2002) addresses that reading is a complex activity by mobilizing a large number of separate actions (e.g., understanding, imaginating, observing, and remembering).

The aforementioned notions have appeared two main components of reading activities: (a) visual ability, for example, the ability of the eye is to see graphic symbols, (b) cognitive ability, for example, the ability of the brain and mind is to understand and interpret graphic symbols.

Tarigan (1994) depicts that reading is also a language skill besides listening, writing and speaking skills. Each of these skills -including reading- is closely related to the thought processes that underlie language. At least, there are three skills that must be mastered in the reading process. The first skill, which requires an ability to recognize the forms of pictural modes, points to an orderly and neat patterned relationship. The second skill requires an ability to connect black marks on paper. That is, images are patterned with elements of language and such sound groups as phonemes, words, phrases, and sentences. A third skill that covers all reading skills is essentially intellectual skills.

b) Electroencephalography on Reading Activities

Studies, which have reviewed on reading activities through EEG recording and measurement, have focused on the following issues: “EEG Spectra in Dyslexic and Normal Readers During Oral and Silent Reading” (Galin et al., 1992); “Reading Activity Recognition Using an Off-The-Shelf EEG Detecting Reading Activities and Distinguishing Genres of Documents” (Kunze, Shiga, Ishimaru, & Kise, 2013); “Lateralization of posterior alpha EEG reflects the distribution of spatial attention during saccadic reading” (Kornrumpf & Sommer, 2017); “Influences of Visual Attention and Reading Time on Children and Adults” (Wei & Ma, 2017), and “Steady state visual evoked potentials in reading aloud: Effects of lexicality, frequency and orthographic familiarity” (Montani, Chanoine, Stoianov, Grainger, & Ziegler, 2019). Previous studies, which have employed the measurement and use of EEG, have focused on eye movements, comparison of readers with dyslexia and normal readers, language differences in reading, differences in reading source documents, saccadic reading, age difference in reading attention, and reading loudness. However, none of them has concentrated on attention measurement by distinguishing the genres of books (academic science nonfiction science book, general science nonfiction science book, and science fiction book) from read activities. Attention measurements show reading skills and the skills to understand the contents of reading, especially science reading. Investigating the level of reading attention, especially reading science books may be used as a basic guide to study reading skills or the readability of a book.

c) Power Spectral Density Analysis in EEG Recording

This study uses three main theoretical foundations: neurolinguistics theories, EEG theories, and power spectral density theories. Neurolinguistics theories presented by Stemmer and Whitaker (1998), Craver (2007), Whitaker (2010), and Nardi (2011) examine brain mechanisms and interpret the performance of the brain based on the dominant certain parts of the brain. Meanwhile, the theory described by Luck and Hillyard (1994), Nardi (2011), Stern and Engel (2005), Luck, Woodman, and Vogel, (2000) and Tatum et al. (2008) interprets the frequency patterns of electrical brain signals based on EEG recordings and Event Related Potential (ERP) of attention.

The implementation of power spectral density analysis, especially EEG analysis for different types of books rectruits the modified method described by Kunze et al. (2013). Meanwhile, analyzing the EEG as a monitoring and imaging modality requires to utilize Toga and Mazziotta’s (2002) model. PSD shows the strength of the variation (energy) as a function of frequency. In other words, it reveals which frequency variations are strong and weak (Cygnus Research International, 2017). If the unit of PSD is energy (variance) per frequency (width), an integrated energy within a specific frequency range appears. Meanwhile, in view of Valipour, Shaligram, and Kulkarni (2014), the power spectral density (PSD) is the power or energy of a distributed signal frequency.

METHODS

a) Research Design

Through a descriptive research methodology, the current study described the brain mapping conditions of reading activities at various genres of the books. The researcher only reported the existing data of the brain mapping without controlling them (Kothari, 2004). This research utilized the assistant tools in a simple laboratory: (1) the EEG was used to record electrical stimuli in brain when reading various books, and (2) laptops, which were connected to the EEG through Bluetooth, were exploited to analyze the obtained data. As seen from Figure 1, the research steps started with loading the EEG signals. Then, Using the EEGLab emerged the obtained raw data and filtered the unwanted frequencies. The next step measured the EEG data in the form of power spectrum from all channels (4 channels) using Fast Fourier Transform (FFT). Then, the data were classified in regard to low/high attention. Finally, the differences in power spectrum patterns in fiction and non-fiction reading activities were analysed for attention and non-attention cases.

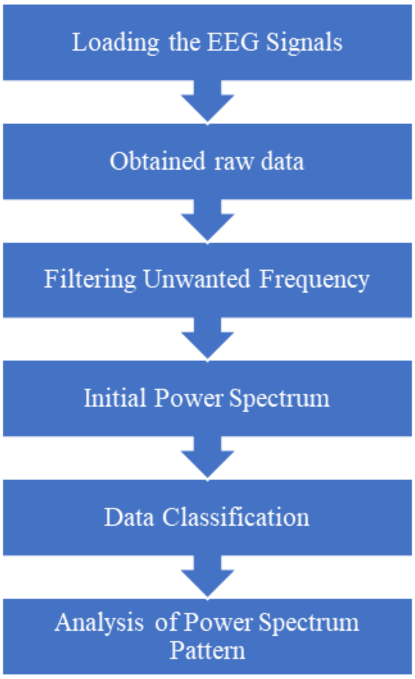

Figure 1. Flow graph of the research steps

b) Data Collection

The study was conducted in Indonesian University of Education, Bandung, Indonesia. The respondents were 16 students (aged 18-22 years; eight males and eight females). In selecting respondents, the researchers used several general criteria, e.g., having the normal reading ability or not having such reading disorders as dyslexia. Given the ethical rules, the respondents of the current study were volunteers and their personal data were kept in confidential. Before the data collection, the researchers ensured that each respondent had carefully understood the type of data in this study.

Data collection procedure included several stages. Firstly, each respondent had an opportunity to choose one genre of the books (academic science nonfiction book, general science nonfiction book, and science fiction book) according to his/her interest. Several titles from various books were prepared. The topics of the books were of interest in their studying fields, although 16 respondents claimed that it was the first time they had read the book. Secondly, each respondent possessed a chance to quietly read his/her chosen book for about 15 minutes per task. To ensure validity and reliability of the obtained data, each respondent repeated three times his/her reading activities with the same book. This repetition was expected to ensure validity and reliability of the data. Thirdly, each respondent freely chose a place and reading position that made them feel relaxed during the reading activities. The brain imaging process is presented in Figure 2.

Figure 2. Brain Imaging Process

Researchers recorded raw EEG data using Simblee-based Ganglion devices from the Open Brain Computer Interface from four electrodes at Fp1, Fp2, P3, and P4 sites. As seen in Figure 3, A1 and A2 mounted on the left and right ears of each respondent. The placement of these electrodes was based on the 10–20 International Systems for Electrode Placements. The sampling rates used were 200Hz. The impedance was maintained to be less than 10kΩ for each electrode to minimize noise. The EEG data were recorded for 15 minutes per task.

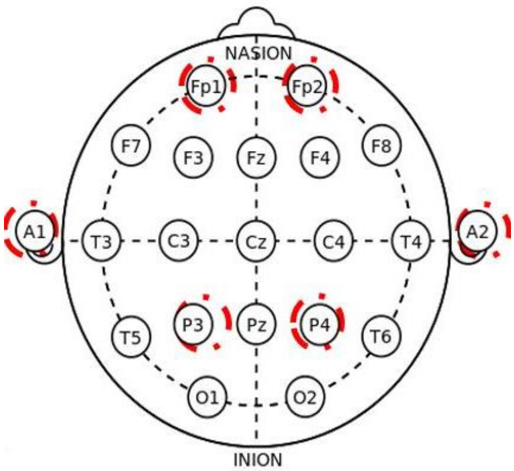

Figure 3. The electrode placement systems used the 10-20 International System.

c) Data Analysis

The researchers individually analyzed the respondents' data for later results. After obtaining the data, the researchers used EEGLab to process raw data (unfiltered EEG data) and calculate the EEG data using Fast Fourier Transform (FFT). Then, they classified the frequencies into the high attention case (high amplitude in 15–18 Hz range) (A) and low attention case (low amplitude in 15–18 Hz range) (B). Afterwards, the differences in power spectrum patterns in fiction and nonfiction reading activities were analyzed for attention and non–attention cases. Then, the data were described for one sample of the respondents with high and low attention levels in regard to each different book. The analysis consisted of the attention level based on the spectrum pattern and its tendency of the cognitive processes. For cognition patterns, the EEG data were analyzed based on the appearance of the most dominant positive currents from the signal occurrence point.

RESULTS AND DISCUSSION

a) Amplitude Measurement

The results from the analysis of the power spectrum density are displayed in respect to the respondents' attention powers of the reading activities.

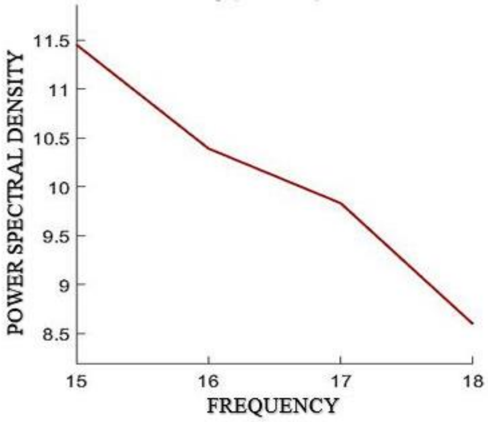

Figure 4. The respondent's (M-7) sample analysis for high amplitude at frequencies 15–18 Hz indicating attention cases while reading an academic science book

As can be seen from Figure 4,the respondent M-7 had a decreased spectral line at 15Hz with 11.40, 16Hz with 10.30, 17Hz with 9.80, and 18Hz with 8.60. This means that the respondent M-7 had a high attention in high Beta1. Figure 5 illustrates a sample low amplitude at frequencies 15–18 Hz indicating a low attention in Beta1.

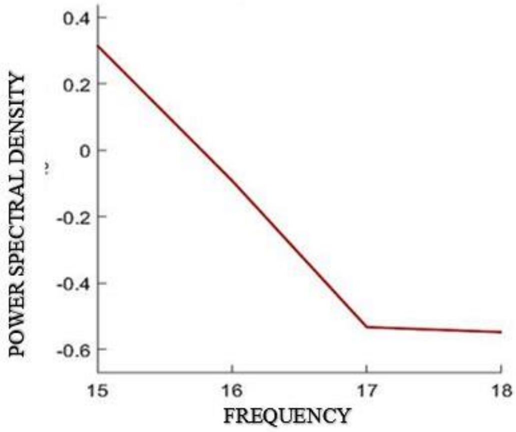

Figure 5: The respondent's (F-5) sample analysis with low amplitude at frequencies 15–18 Hz indicating non-attention cases while reading an academic science book

As observed in Figure 5, the respondent F-5 had a smaller power spectrum value at 15Hz with 0.30, 16Hz with –0.10, 17Hz with –0.55, and 18Hz with –0, 56 as compared with the respondent M-7.

The analysis of power spectral density showed different attention levels for frequencies 15–18 Hz using Fast Fourier Transform (FFT). Given Xizheng, Ling and Weixiong’s (2011) statement “Fourier's transformation has been used to analyse the pattern of EEG characteristics and non–transient EEG activity, a higher amplitude at the frequencies 15–18 Hz indicates a higher attention power in the reading activity.

b) Spectral Topographic Map

This study filtered the spectral power analysis at frequencies 15-18 Hz. Then, the amplitude was measured for this range. A higher amplitude in the range shows a higher attention level. On the contrary, a lower amplitude in this range indicates a lower attention level. The results converting raw EEG data into spectral topography using EEGLab are dispaled in Figure 6.

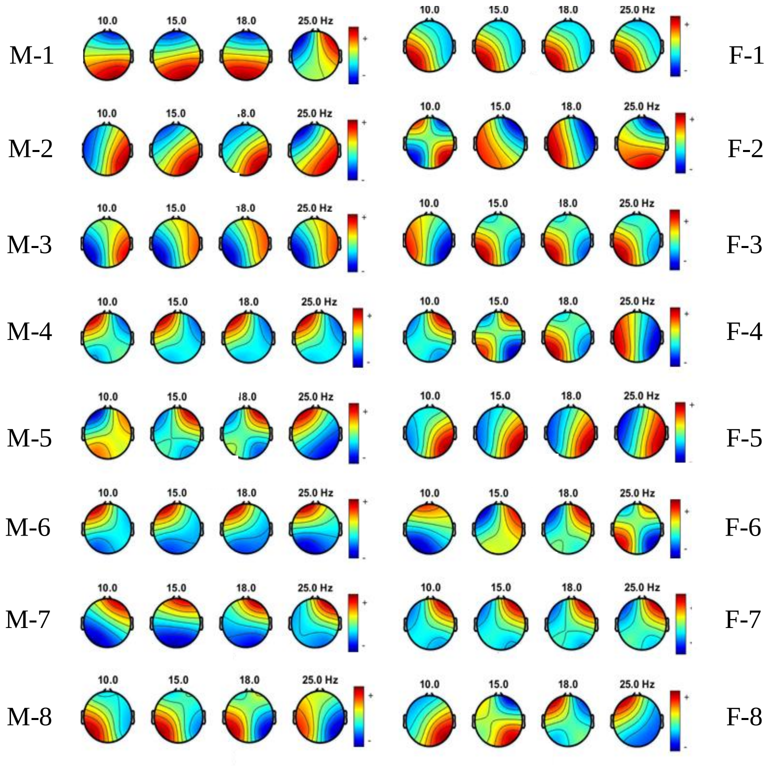

Figure 6. A sample Spectral Brain Imaging for Reading Various Science Books

The red color indicates a positive electric current, while the blue color reveals a negative one. Positive current points that electrical signal activity occurs in the area with a higher amplitude, whilst the negative current shows that the electrical signal activity in the area is very low. Table 1 presents the attention levels in the specific book genres given the results in Figure 6.

Table 1. *Attention levels in accordance with book genres*

SUBJECT	ATTENTION LEVEL	BOOK GENRE
M-1	LOW (B)	SCIENCE FICTION
M-2	LOW (B)	GENERAL SCIENCE NONFICTION
M-3	LOW (B)	ACADEMIC SCIENCE NONFICTION
M-4	HIGH (A)	SCIENCE FICTION
M-5	HIGH (A)	ACADEMIC SCIENCE NONFICTION
M-6	HIGH (A)	SCIENCE FICTION
M-7	HIGH (A)	GENERAL SCIENCE NONFICTION
M-8	LOW (B)	SCIENCE FICTION
F-1	LOW (B)	SCIENCE FICTION
F-2	LOW (B)	GENERAL SCIENCE NONFICTION
F-3	LOW (B)	SCIENCE FICTION
F-4	LOW (B)	SCIENCE FICTION
F-5	LOW (B)	ACADEMIC SCIENCE NONFICTION
F-6	HIGH (A)	ACADEMIC SCIENCE NONFICTION
F-7	HIGH (A)	GENERAL SCIENCE NONFICTION
F-8	HIGH (A)	SCIENCE FICTION

Figures 7-9 display the visualization results of brain mappings at nonfiction and fiction reading activities.

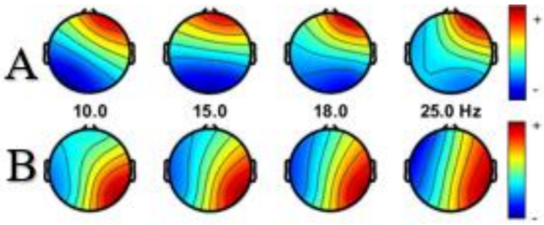

Figure 7. A Sample Power Spectra Difference in Academic Science Nonfiction Reading in Cases (A) Attention from the Respondent M-7 and (B) Non–attention from the Respondent F-5

As seen from Figure 7, nonfiction academic reading activity in attention case emerged the high amplitudes from anterior precisely on Frontal Polar 2 (Fp2). Meanwhile, high amplitudes were located in Parietal 4 (P4) and partially in Frontal Polar 2 (Fp2) (on 25 Hz) for non–attention case.

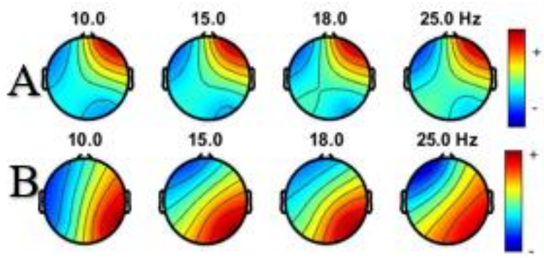

Figure 8. A Sample Power Spectra Difference in General Science Nonfiction Reading in Cases (A) Attention from the Respondent F-7 and (B) Non–attention from the Respondent M-2

Figure 8 illustrates the differences in attention and non–attention cases of the general science nonfiction readings. Similar to the academic science nonfiction readings, high amplitudes were located in Frontal Polar 2 (Fp2) and Parietal 4 (P4) for attention state and non–concentrated case respectively. Figures 7 and 8 showed that the high amplitudes in the right hemisphere were dominant for nonfiction readings. Meanwhile, the low amplitudes appeared in the left hemisphere.

According to Nardi (2011) Stern and Engel (2005) and Tatum et al. (2008), Frontal Polar 2 (Fp2) primarily shows three brain processes: (a) admitting a novelty, (b) managing negativity, and (c) managing a process. Meanwhile, the emergence of signals on Parietal (P4) indicates that the respondents: (a) weigh many factors and (b) integrate inner sensations.

The fact that the dominant amplitudes in the right anterior showed attention casesmean indicated that the respondents were receiving a new information. In contrast, the dominant non–attention cases in Parietal 4 (P4) showed a substantial amount of consideration. This revealed that the respondents had difficulties at receiving a new information. It means that there are some electrical activities in visual processing area while receiving the new information. This is consistent with Luck, Woodman and Vogel's (2000) idea depicting that some attention conditions modulate the initial feedforward volley of neural activity in intermediate visual processing areas.

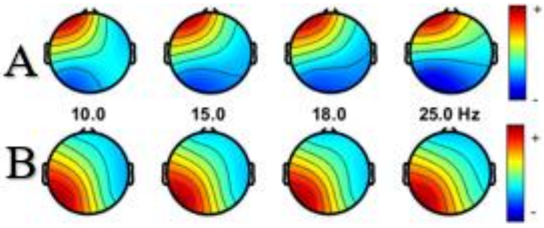

Figure 9. A Sample Low Power Spectra Difference in Science Fiction Reading in Cases (A) Attention from the Respondent M-6 and (B) Non–attention from the Respondent F-1

Figure 9 shows the various attention cases in fiction readings. As seen from Figure 9, the left hemisphere was dominant for the brain signals of the respondents with high and low attention levels in reading science fiction books. In contrast, the right hemispheres outweighed for nonfiction readings.

In the attention cases in the fictional readings (see Figure 9), high amplitudes appeared in the Frontal Polar 1 (Fp1) and Parietal 3 (P3) for non–concentrated cases. In view of Nardi (2011), Stern and Engel (2005) and Tatum et al. (2008), the emergence of signals in Fp1 addresses that the brain performs to: (a) filter input, (b) explain and decide, and (c) notice errors. Meanwhile, the appearance on Parietal 3 (P3) shows to: (a) integrate vision/sensation, (b) identify objects, and (c) do rote math or reading.

When the respondents concentrated on fictional reading, they paid more attention to the things that came into their minds and tried to describe them. Meanwhile, when they did not concentrate on reading fictional book, they identified what they had read, memorized them, and integrated them with their experiences/knowledge. Hence, it took longer time to continue reading. It means that attention may be influenced by memory or response process. This is in a harmony with Luck and Hillyard's (1994) view claiming that attention involves in a many kind of cognitive subsystems, e.g., early sensory analysis, object recognition, working memory, and response selection.

CONCLUSION

In light of the results, it can be concluded that the differences between the book genres, i.e., academic, general science nonfiction and science fiction readings, produce a different brain map. The right hemisphere was more controlled for nonfiction readings than the left one. Meanwhile, the left hemisphere was more controlled for fictional reading than the right one. In addition, various cases of attention also affected the amplitude on the brain map. Attention and non-attention conditions showed high amplitudes located in the anterior and posterior sites respectively. The differences in mental cases occurred during the reading activities. The results of this study may be used as guidelines for education practitioners, policymakers, and related institutions in terms of planning, implementing, and assessing language education/learning, especially language related competencies, namely reading.

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