Analysis of brain activation and wave frequencies during a sentence completion task: a paradigm used with EEG in aphasic patients (#78572)

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Analysis of brain activation and wave frequencies during a sentence completion task: a paradigm used with EEG in aphasic patients

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Aphasia is a language disorder that occurs after brain injury and directly affects an individual's communication. The incidence of stroke increases with age, and one-third of people who have had a stroke develop aphasia. The severity of aphasia changes over time and some aspects of language may improve, while others remain compromised. Battery task training strategies are used in the rehabilitation of aphasics. The idea of this research is to use electroencephalography (EEG) as a non-invasive method, of electrophysiological monitoring, with a group of aphasic patients in rehabilitation process in a prevention and rehabilitation unit of the person with disabilities of the Unified Health System (SUS), of reference in the state of Bahia-Brazil. In this study, the goal is to analyze brain activation and wave frequencies of aphasic individuals during a sentence completion task, to possibly assist health professionals with the analysis of the aphasic subject's rehabilitation and task redefinition. We adopted the Functional Magnetic Resonance Imaging (fMRI) paradigm, proposed by the American Society for Functional Neuroradiology as a reference paradigm. We applied the paradigm in the group of aphasics with preserved comprehension, right hemiparesis, and left hemisphere injured or affected by stroke. We analyzed four electrodes (F3/F4 and F7/F8) corresponding to the left/right frontal cortex. Preliminary results of this study indicate a more robust activation in the right hemisphere (average of aphasics), with a difference of approximately 14% higher in Theta and Alpha frequencies, with 8% higher in low Beta (BetaL) and with approximately 1% higher in high Beta frequency (BetaH), Gamma frequency was higher by approximately 3% in the left hemisphere of the brain. The difference in electrical activation may be revealing to us a migration of language to the non-language dominant hemisphere. We point to possible

evidence suggesting that EEG may be a promising tool for monitoring the rehabilitation of the aphasic subject.

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ABSTRACT

Aphasia is a language disorder that occurs after brain injury and directly affects an individual's communication. The incidence of stroke increases with age, and one-third of people who have had a stroke develop aphasia. The severity of aphasia changes over time and some aspects of language may improve, while others remain compromised. Battery task training strategies are used in the rehabilitation of aphasics. The idea of this research is to use electroencephalography (EEG) as a non-invasive method, of electrophysiological monitoring, with a group of aphasic patients in rehabilitation process in a prevention and rehabilitation unit of the person with disabilities of the Unified Health System (SUS), of reference in the state of Bahia-Brazil. In this study, the goal is to analyze brain activation and wave frequencies of aphasic individuals during a sentence completion task, to possibly assist health professionals with the analysis of the aphasic subject's rehabilitation and task redefinition. We adopted the Functional Magnetic Resonance Imaging (fMRI) paradigm, proposed by the American Society for Functional Neuroradiology as a reference paradigm. We applied the paradigm in the group of aphasics with preserved comprehension, right hemiparesis, and left hemisphere injured or affected by stroke. We analyzed four electrodes (F3/F4 and F7/F8) corresponding to the left/right frontal cortex. Preliminary results of this study indicate a more robust activation in the right hemisphere (average of aphasics), with a difference of approximately 14% higher in Theta and Alpha frequencies, with 8% higher in low Beta (BetaL) and with approximately 1% higher in high Beta frequency (BetaH), Gamma frequency was higher by approximately 3% in the left hemisphere of the brain. The difference in electrical activation may be revealing to us a migration of language to the non-language dominant hemisphere. We point to possible evidence suggesting that EEG may be a promising tool for monitoring the rehabilitation of the aphasic subject.

Keywords: brain activation; aphasia; electroencephalography; language rehabilitation;

Introduction

Due to a focal brain lesion, the person may not be able to speak and understand the people around him, or he may understand, but not be able to make himself understood. In other cases they can make sentences, but do not use articles and connecting terms, which leaves the message confusing, or they lose the ability to name things, objects, and have no command of the word, for example to name an object (table) or an animal (horse). This means that the brain lesion has affected the area responsible for language control, and the symptoms vary from person to person.

This is aphasia, defined as a language disorder that affects a person's ability to communicate, which limits his or her social interaction, contributes to his or her isolation and depression, and strongly impacts the individual's quality of life.

The most common cause of aphasia is stroke and traumatic brain injury (TBI), mainly in the left hemisphere, where language function is usually located. Approximately one-third of people who have had a stroke develop aphasia (Brady et al., 2016; Mattioli, 2019).

"The incidence of stroke increases with age and is higher in men than in women" (Mattioli, 2019) and the severity of aphasia "can change over time and single aspects of language impairment may improve while others remain compromised," aphasia dramatically impacts functional communication, daily activities, and social skills of patients and their families, with that it is essential to have effective rehabilitation.

A study conducted to evaluate the effects of speech and language therapy (SLT) for aphasia after stroke (Brady et al., 2016) concluded that there is an indication that "high-intensity, high-dose, or longer-term therapy may be beneficial", however, it notes that these "high-intensity, high-dose interventions may not be acceptable for everyone".

There is a wide variability of language tests that can be applied in the rehabilitation process of aphasics; however, current evidence suggests that monitoring the aphasic is very difficult to achieve. This only leaves open the question of which method to use.

In the study by Sreedharan et al., 2020, real-time functional magnetic resonance imaging (RT-fMRI) was used as a neurofeedback training strategy, aiming to improve neural activation in the language areas of post-stroke patients with expressive aphasia to improve language deficits. For the author, this strategy is very expensive; there are many hours for training, and the system is not portable, making the cost very high. However, he claims that it is possible to adjust neurofeedback training to activate specific study regions using less expensive and portable methods, such as EEG-based systems, which may be feasible for rehabilitation.

Another essential strategy for studying the brain, according to Black et al., 2017 is the "sharing, comparison and generalization of results." According to the author institutions perform fMRI in markedly different ways. With this challenge, a task force of American Society of Functional Neuroradiology members from various institutions came together and created "2 sets of standard language paradigms that strike a balance between ease of application and clinical utility. An adult language paradigm for pre-surgical language assessment that includes the sentence completion task and another paradigm geared toward children (Black et al., 2017).

Given this scenario, the present study proposes to apply the fMRI paradigm, developed in the study of Black et al., 2017 with EEG, to analyze the brain activation of aphasic individuals with the task of "completing sentences or phrases". This study was developed in the Center for Prevention and Rehabilitation of the Person with Disability (CEPRED) which is a unit of the Unified Health System (SUS) of reference in the state of Bahia-Brazil.

With the perspective of application in other rehabilitation and clinical settings, the research has in its essence three pillars: daily accessibility (cost and mobility of the equipment), usability (ease of use of the therapy equipment), and whether the technology is invasive or not for the patient.

We hypothesize that by tracking the electroencephalographic signals of aphasic patients, post stroke with right hemiparesis and in the rehabilitation process, it is possible to investigate the brain electrical activation and wave frequencies. Our approach aims to support the rehabilitation process of aphasics.

Literature Review

Aphasia

It is a language disorder caused by an encephalic lesion or dysfunction, accompanied or not by cognitive changes. It is considered "one of the most common neurological alterations following focal lesion acquired in the central nervous system, in areas responsible for comprehensive and/or expressive language, oral and/or written" (Kunst et al., 2013).

For Brady et al., 2016 aphasia is "a language impairment acquired after brain damage affecting some or all language modalities: speech expression and comprehension, reading, and writing." Other diseases can also cause aphasia, such as tumors, trauma, degenerative or metabolic diseases.

Aphasia has been "a historical target of investigation and scientific debate in the areas of medicine, neuropsychology, and linguistics" (Mineiro et al., 2008). There are eight types of aphasia: Broca's aphasia (or expressive aphasia), Wernicke's aphasia, conduction aphasia, global aphasia, transcordial motor aphasia, transcordial sensory aphasia, mixed transcordial aphasia, and anomic aphasia.

For Mineiro et al., 2008, the classification of aphasias is based on the patient's "performance in certain parameters that are evaluated through batteries of tests", and the most used parameters are: speech fluency, ability to understand orders, ability to name objects, and ability to repeat words.

As for the prognosis (prediction) of aphasia, Plowman, Hentz & Ellis (2012) clarifies that this is a "daunting" task because one must consider variables that are interrelated, such as: age, gender, motivation, depression, family support, and attitudes toward health care and access to medical treatment, and variables specific to stroke include "location of injury, size of injury, type of aphasia, and pattern of recovery and initial severity of aphasia".

Regarding lesion location associated with aphasia type, Bocquelet et al. (2016) states that "lesions of ventral temporal lobe flow regions result in Wernicke's aphasia characterized by impaired speech comprehension, while lesions of frontal areas result in Broca's aphasia characterized by impaired speech production".

Diagnoses of aphasia are obtained through neurological evaluation and also through brain imaging tests, such as magnetic resonance imaging (MRI) or computed tomography (CT) (Pommerehn, Delboni & Fedosse, 2016). The assessment process involves the use of linguistic examination instruments and should address different levels and linguistic components, including comprehension and expression and the use of language at the levels of word, sentence, and speech" (Pagliarin et al., 2013).

Also according to Pagliarin et al. (2013) in a study conducted to evaluate the panorama of national and international literature about language examination instruments used after left hemisphere brain injury (LHE), it concludes that "efforts are needed for the development and standardization of language instruments for the assessment of adult patients with LHE and other neurological conditions suitable to the Brazilian sociocultural reality" and draws attention to the scarcity of studies with such instruments specifically involving patients with LHE.

The study developed by Casarin et al. (2011) also revealed a scarcity of instruments (or assessment tools of functional language components) in the national context and concludes that there is a need for new studies to fill this gap. He adds that "even at the international level, there seems to be an unmet demand for clinical tools for brief assessment of functional language components, such as pragmatic-inferential and discourse".

The study by Hill, Kovacs & Shin (2015) points to the challenge of promoting the interconnection of Brain Computer Interface (BCI) with augmentative and alternative communication (AAC), using brain signals as an alternative for a "non-invasive approach to access assistive technologies". According to the same author conventional alternative communication is not a satisfactory option when it requires a certain degree of voluntary muscle control, although CAA is "vital for helping people with complex communication."

Brain-controlled technologies appear to be even more promising in aiding communication for the aphasic individual, minimizing the consequences of the physical limitations that many of them have. Brain computer interfaces (BCI) can aid communication in disabled populations by utilizing neurobiological signals (Brumberg et al., 2010).

Strategies are being developed for BCI such as "letter selection" systems, which is an indirect way of establishing communication that considers, for example, the movement of the hand or arm, or of the eyes that are decoded. For Bocquelet et al. (2016) "the creation of a BCI speech to restore continuous speech directly from the neural activity of speech selective brain areas, is an emerging field in which increasing efforts need to be invested".

Brain-computer interfaces seem to hold promise for "enabling artificial speech synthesis from continuous decoding of neural signals underlying speech imagery" (Bocquelet et al., 2016). These interfaces, according to the same author do not exist yet and for their design it is essential to consider three points: "the choice of appropriate brain regions to record neural activity, the choice of an appropriate recording technique, and the choice of a neural decoding scheme in association with an appropriate speech synthesis method".

Testing, Techniques, and Language Paradigm

Speech therapy treats language disorders and their therapy. Speech and language therapy (SLT) is a "complex rehabilitation intervention aimed at improving language and communication skills (verbal comprehension, spoken language, reading, writing), activity, and participation" (Brady et al., 2016).

A study conducted by Altmann, Silveira & Pagliarin (2019) on "Speech therapy intervention in expressive aphasia" reveals that “among the traditional therapies found, the following were observed: word retrieval therapy, melodic therapy, and conversational therapy”. The author concludes that "word retrieval therapy was the most used traditional method" and "figure naming and figure/word relationship were the most used strategies", the author emphasizes that "the majority used figure naming, and the use of tablets and computers was frequent, mainly as a means of presenting the stimuli".

Research developed by Pagliarin et al., 2013 sought to identify "language investigation instruments used for the evaluation of sudden onset neurological pictures involving the left hemisphere (LHE)" and also sought to analyze which linguistic components are the most evaluated. As a result of this study, the authors identified "nine internationally used instruments that assess different language components in patients with LHE", highlighting the Boston Diagnostic Aphasia Examination (BDAE) as one of the "most internationally used instruments for aphasia detection". The most investigated linguistic components were "naming and listening comprehension, respectively". Finally, the authors reveal that the "instruments used internationally present appropriate adaptations and standardizations for the social, cultural and linguistic reality of the evaluated population".

In general, for speech and language evaluation, to confirm a diagnosis of aphasia, the phonoaudiologist analyzes the following areas: naming, repetition, language comprehension, reading, and writing. In addition to speech and language evaluation, diagnostic imaging tests can be performed using an MRI or CT scan.

Black et al., 2017 proposed the adoption of a standard language paradigm, to be used with fMRI as "the first step" to advance knowledge sharing. The authors hope that by adopting the reference paradigm, with a battery of language tasks, among them the "complete sentences" task, validated by a committee of experts, it will be possible to improve patient care.

Also, according to Black et al., 2017 the Sentence Completion Task(T1) produces greater activation in both temporal and frontal regions, "suggesting a more robust activation of language networks because it combines language comprehension as well as production in a naturalistic way."

For Zapata et al., (2018) the main challenges lie in the uneven learning pace of each individual and the effective operation of BCI devices, which use many techniques, e.g. fMRI, fNIRS, EcoG, MEG and EEG, for recording brain activity. Some of these techniques (or methods) are very expensive to implement or are very robust, making mobility difficult.

However, electroencephalographs (EEG) represent the basis of about 60% of the systems tested. Electrophysiological recording can offer adequate temporal resolution to track brain activity at the scale of speech production dynamics (Bocquelet et al. (2016).

Given this scenario, it is understood that it is essential to seek a method that will support health professionals in the ongoing rehabilitation process of aphasic people, considering the applicability in rehabilitation centers.

Materials & Methods

Aphasic Participants (Ap)

The present research was approved by the Ethics Committee on Human Research of the Integrated Manufacturing and Technology Campus (CIMATEC) - Senai/ Bahia (CAAE: 29622120.2.0000.9287) and approved by the Health Secretariat of the State of Bahia - SESAB (CAAE: 29622120.2.3001.0052) with the Center for Prevention and Rehabilitation of People with Disabilities -CEPRED, as a coparticipant center.

The sample consisted of eleven aphasic participants (Ap = 8 women, 3 men, mean age 54 years), 10 people with brain injury in the left hemisphere and one person with injury in the right hemisphere, all with hemiparesis (difficulty to move half of the body). Description of the voluntary participants is shown in table 1. None of the participants had hearing impairment, and all had normal or corrected-to-normal vision. They all signed informed consent to participate in the study.

Sentence Completion Task

We used the fMRI paradigm for adults, with adaptations for the Portuguese language. We will present in this study the results of the "Sentence Completion Task", here called Task 1 or simply T1, with duration of 4 min (240 sec), where each volunteer participant performed one experimental session.

About the T1 stimuli, the patient sees, on a video monitor, an incomplete sentence (example: Whales and dolphins live at ....) and is asked to mentally respond, just think the word (without speaking or moving lips). While the sentence is on the screen (5 sec), the patient must continue to think of alternative words that complete the sentence until the next sentence appears. Then, there are three more phases to be completed mentally.

After the end of the stimulus time (20sec), the "control" of the task begins, where the participant sees nonsense sentences (a set of letters separated by spaces), with the same time and quantity of repetitions. Thus, there are 4 stimulus sentences and 4 control sentences, interleaved in this order, until the 4 minutes (240secs) are completed. The task has a total of 24 stimulus sentences and 24 control sentences.

For the participant with low schooling, the researcher read the sentence aloud, for the participant to complete with words mentally. This procedure activates Wernicke's area which is located in the left hemisphere, specifically in the temporal lobe, and is the area responsible for understanding and receiving language, meaning that "we can activate it without necessarily speaking or communicating, simply by listening or reading for it" (ARDILA, 2016). Performing the "Sentence Completion" task has increased activation in the temporal and frontal region, thus activating both Wernicke's area and Broca's area (Black et al., 2017).

Proposed Model of Brain Activation Analysis

This section presents the structure of the proposed brain activation analysis mechanism. The scheme model is shown in Figure 1. The proposed scheme uses the standard paradigm developed by the American Society for Functional Neuroradiology (Black et al., 2017), with EEG, to analyze the brain activation of aphasic individuals with the sentence completion task.

In the first stage we applied the pre-test. The second stage starts with positioning the EEG device (wireless), then with connection settings and electrode hydration (when necessary). The "Baseline" protocol, parameterized in the EMOTIVPRO tool, is executed, and then the execution of the task itself begins. Once the task is finished, the file of electroencephalographic signals can be exported.

In the third and fourth stages we use Mathlab for data processing. The details of the data processing scheme are shown in figure 3 and include pre-processing and post-processing.

Experimental procedure

For the execution of the experiment, the participants were comfortably seated in front of a computer screen. The research protocol was read, informing that the participant is there voluntarily to participate in the study, which aims to investigate aphasia, hoping to support rehabilitation.

Next, it was confirmed that the participant signed the Free and Informed Consent Form (ICF), which contains the research details, the researcher's contact information, and information about the confidentiality of personal data, so as not to identify the participant. The experiment procedure has 5 stages, as shown in figure 1.

The stage called "Pre-Test" was created to explain to the volunteers how the task would be executed. We used a PowerPoint presentation with examples of the task, so that the participant had the opportunity to test and clarify any doubts about the paradigm, before starting the collection of electroencephalographic signals.

The time to put on the headset and check the electrode connection depended on the volume of the participant's hair. The hair was pulled back to facilitate contact between the electrodes and the scalp. We were previously instructed not to use creams on the hair, such as moisturizers, oils, or similar cosmetics. For people with a lot of hair, it was requested that, if possible, they wear their hair braided to facilitate the placement of the headset and electrode contact.

EEG Data Acquisition

A 16-channel Emotiv EPOC+, EEG Brainwear with Brain Computer Interface (BCI) technology was used as the data acquisition device. Designed for human brain research, from Emotiv based in San Francisco, USA, to acquire EEG signals, sampled at 128/256 Hz. The device (headset type) is flexible and wireless with electrodes placed according to the international 10-20 positioning system, which is the international arrangement for electroencephalographic analysis.

One of the great advantages of EEG is the high temporal resolution, which reaches an accuracy of milliseconds, when compared to techniques such as fMRI. Figure 2 shows the location of each of the 16 sensors and the anatomical correspondence of the brain area. The odd-terminated channels are located in the left hemisphere and the even-terminated channels located in the right hemisphere, which are: antero-frontal (AF3, AF4), frontal (F3, F4, F7, F8), fronto-central (FC5, FC6), temporal (T7, T8), parietal (P7, P8) and occipital (O1, O2). The mastoid sensor (M1) acts as a reference point to which the voltage of all other sensors is compared. The other mastoid (M2) is a feed-forward reference that reduces external electrical interference.

To begin collecting the electroencephalographic signals, the researcher previously hydrated the electrodes with saline solution, as recommended by the manufacturer. Then the headset was placed on the participant's head, positioning the antero-frontal electrodes (AF3 and AF4) at a distance of three fingers above the volunteer's eyebrow, allowing the adjustment of the other electrodes in their respective areas.

With the EmotivPro 3.3.0.433 software, we verified the connection of all the electrodes, which should appear in the interface with a green color, showing the connection. If any electrode did not show the green color, the researcher made adjustments: removing strands of hair under the electrode or rehydrating it. The collection only started after all the electrodes were connected, indicating the green color. The participant was instructed to avoid moving his head, arms, legs, and hands.

After confirming the connection of the electrodes, data collection begins with the "EEG device baseline protocol," which lasts 40 seconds (with a 5-sec timer to start, another 15 seconds with eyes open, another 5 seconds with timer, and another 15 seconds with eyes closed). After finishing the "baseline protocol", the "1 key" was pressed (by the researcher) to record the beginning of the task.

The acquisition of brain signals is finished when the participant completes the last sentence, ending the 4 min defined in the task. The researcher closes the session and exports the raw data in CSV (Comma-separated values) format, which separates values with commas.

We used four electrodes positioned on the frontal lobe, two electrodes on the left hemisphere (F7, F3) and two electrodes on the right hemisphere (F4, F8) and investigated five frequency ranges: Theta (4-8 Hertz), Alpha (8-12 Hertz), Low Beta (12-16 Hertz), High Beta (16-25 Hertz) and Gamma (25-45 Hertz).

Data processing

Data processing (fig.3) was performed using MATLAB version 9.12 (R2022a) because it is an interactive software for working with calculus, matrices, signal processing, and graph construction.

We started the data preprocessing by developing a script to import the electroencephalographic signals. We imported the CSV files of all the participants. After importing, the beginning of the task was verified (with the record of the numeral 1), so that we could separate and discard the electrophysiological records before the "start" of the task. Raw data loaded and stored in vectors.

We converted the signal to microvolts(uV) and then took the DC level of the signal (offset). The asymmetric response to the fault is called DC Offset and is a natural electrical system phenomenon. Next, we plot graphs of the channels in time and frequency. We followed with the generation of the frequency spectrum, applying the algorithm that calculates the Discrete Fourier Transform (DFT) and its inverse (inverse Fourier Theorem), in short we applied the Fast Fourier Transform (FFT) so that the raw EEG signal could be identified as distinct waves with different frequencies.

With the Signal Processing Toolbox™ we used the Designfilt function for filter testing. We tested FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) filters on the data, analyzing the best option for removing noise and artifacts (e.g. muscle artifacts, motion artifacts, sweating). We also tested the following filters:

a) Low-pass filter: A low-pass filter, allows low frequencies to pass through without difficulty and attenuates the amplitude of frequencies higher than the cutoff frequency.

b) Band-pass filter: A band-pass filter, allows frequencies in a certain range to pass through and rejects frequencies outside this range.

c) High-pass filter: A high-pass or high-pass filter, allows high frequencies to pass through easily, and attenuates the amplitude of frequencies below the cutoff frequency.

We subsequently created "windows" by fragmenting the signal every 5 sec (figure 4). The window creation time was determined by the length of time a sentence is on the video monitor as a stimulus to the participant. We used the calculation of the RMS value of the signal in each window (the effective value, also known as the RMS value from the acronym Root Mean Square). For post-processing we developed scripts called "Brain Activation" and "Band-Power", detailed in the results section.

Results

From the total of 11 patients evaluated, regarding the determination of the areas of greater brain activation and wave frequencies by EEG, problems occurred in the performance of two patients (Ap10 and Ap11). These two participants went through step 1 of pre-test (fig.1) and verbalized that they understood the task, we moved on to step 2, for connection and data collection. After connecting the electrodes, we started the "Baseline Protocol", with eyes open and then with eyes closed.

However, we noticed that both participants seemed not to have understood the baseline protocol. During the performance of the task these patients frequently shifted their focus of attention to look at their hands, to objects in the room, and verbalized a few words. These two participants had a diagnosis of global aphasia, with deficits in expression and also in comprehension; due to this typology and the degree of distraction, it was not possible to include the data collected in our sample. The absence of comprehension is common in global aphasics. Therefore, for this study we considered only aphasics with preserved comprehension as shown in Table 1.

After importing the raw data we did pre and post processing of the data (fig.3). In the pre-processing we did filtering, as explained in the materials and methods section, and used the strategy of creating "windows" that is normally used by health professionals for visual inspection and selection of windows without artifacts.

With the use of the windows we were able to have the first view (view of each individual of the sample) of how the electrical activation occurred in each of the four electrodes (F7, F3, F4 and F8), verify the frequencies (Delta, Theta, Alpha and Beta), and disregard the windows with artifacts (represented in fig. 4(b) with a red line).

In post-processing we calculated the average value of each wave and normalized the power per electrode, this allowed us to have a comparative view of the frequencies, patient by patient, as shown in figure 5.

We hid the Delta wave because it is recorded more frequently in infants and children, and also because it is related to involuntary body movements such as breathing, heartbeat, and digestion. Focusing our analysis on the language task.

In figure 6 we have examples of aphasic patients and their electrical activation (difference) between hemispheres. For ease of understanding, we considered the left hemisphere to be the negative values (bars down) and right hemisphere to be the positive values (bars up).

We found that there was a significant difference in electrical activation in the brain hemispheres. In 5 patients we found higher electrical activation in the right hemisphere, at all frequencies (Theta, Alpha, BetaL, BetaH, Gamma), as examples in figure 6(a,b). Two patients (AP08 and AP09) showed higher electrical activity at the frequencies Theta, Alpha and BetaL, also in the right hemisphere. One participant (Ap07) had greater activation at the Theta and Alpha frequencies in the right hemisphere (Fig.6d). And a single patient (Ap05) had greater activation, in all frequencies, in the left hemisphere (Fig.6c).

These data show us that 89% of the participants showed increased electrical activation in the non-language dominant hemisphere. These results may be reflecting language migration, counter-lateral processing.

Figure 7 shows the difference in electrical activation between brain hemispheres, considering the average of aphasic patients. Only the gamma frequency had the highest activation in the left hemisphere, with approximately 4%. This wave frequency is associated with the processing of auditory, tactile, and visual stimuli. The other frequencies (Theta, Alpha, BetaL and BetaH) had greater activation in the right hemisphere.

In two male patients (Ap07 and Ap08) we found less electrical activation in the right hemisphere, which may be showing us a lower migration of language to the right side, example in figure 6(d).

Thus the "complete sentences" task was effective in activating language areas, using an EEG, in both hemispheres. These results converge with Lam's (2016) study, which used magnetoencephalography (MEG), with the sentence completion task, and emphasizes that the task "recruits areas distributed in both hemispheres and extends beyond classical language regions."

Our study brings an important contribution to aphasia rehabilitation programs, regarding the use of EEG to identify the areas of greatest brain activation in task execution, during rehabilitation. These results may be highlighting that acquired lesions can cause language to reallocate in the opposite hemisphere.

Discussion

The objective of this study is to investigate the electrical activation of the brain and the wave frequencies during the execution of a sentence completion task, with the expectation of helping health professionals, especially speech and hearing therapists, in the rehabilitation of aphasic subjects and the improvement of language deficits.

In our analysis we did not include data from participants with global aphasia; we only considered aphasics with preserved comprehension because of the definition of the method adopted here. Hemiparesis on the right side was observed in all aphasics and confirmed in an analysis of hospital discharge records. With this we infer that the brain lesion, caused by the stroke, is located on the left side, and that the language dominance is in the left hemisphere. However, based on the data collected and analyzed, we found increased electrical activity in the non-language dominant hemisphere during the execution of the task. This result may be revealing the migration of language to the contra-lateral hemisphere.

Our results are in agreement with Morais (2020) who emphasizes that the brain may suffer "translocation of primary functions, especially when the lesion is located in the dominant hemisphere" (Morais, 2020). Although the left hemisphere is considered the "higher language processor," characterized as verbal, analytical, and intelligent (Harrington, 1989). Therefore, for this study, the translocation (movement or change of something from one location to another) of language may indeed have occurred to the right hemisphere, since the language of these aphasics is allocated to the left (dominant) hemisphere.

Regarding the two male patients (Ap07 and Ap08), we found less electrical activation in the right hemisphere, which we believe reveals less language migration and perhaps less recovery. There is convergence here with other studies that suggest that there may be "a difference in language impairment and recovery rate after stroke, with women outperforming men" (Halpern, 2000). For Kimura (1983) "there are sex differences in speech organization and praxis in the left hemisphere" and Núñez (2018) states that "women's brains are more globally symmetrical than men's" and emphasizes that several structures have been identified as systematically more symmetrical and that some of these are involved in language production.

Previous research has shown that task batteries are used in the rehabilitation of aphasiacs, but neglect the possibility of "rehabilitation traceability", that is, of doing a follow-up and analysis of data collected during the rehabilitation process, over time. This may be due to the lack of experimentation with accessible techniques in a rehabilitation setting.

The experimental procedure shown in our work adds this capability and indicates that an EEG device is able to adequately capture brain signals, providing a perspective for monitoring the rehabilitation of the aphasic. A device already recognized for providing adequate temporal resolution to track brain activity at the scale of speech production dynamics (Bocquelet et al. ,2016). We believe that if the health care professional applies speech therapy exercises with their aphasic patient, using the experimental procedure of this study, and seeing that a certain frequency is changing, that is a possibility that the patient is better recovering or not.

One of our challenges was to define a strategy that could be implemented outside the hospital environment, that is, that could be used by health professionals in rehabilitation settings.

That said we adopted the reference paradigm proposed by the American Society for Functional Neuroradiology, as a standard language paradigm that strikes a balance between ease of application and clinical utility. It (the language paradigm) was developed as a strategy for "sharing, comparing and generalizing results". The literature shows us that institutions conduct their research with different methods and techniques, and this is a complicating factor for studying the brain (Black et al., 2017). These factors were essential for our study developed at CEPRED as we needed to structure a procedure that was user-friendly, portable, and non-invasive.

A notable limitation in this study was the small number of volunteers, which was attributed to the complexity of the patients' condition, most of whom had depression, sadness, and limitations in moving around. Therefore, our results may not be applicable to all aphasic patients, and do not exclude the possibility of using other techniques. However, the preliminary results obtained may guide the construction of new therapeutic strategies and may help in the monitoring of aphasic patients, aiming to increase neural activation in the language areas of post-stroke patients with expressive aphasia, to improve the language deficit.

Conclusions

We used EEG, which allows the recording of electrical currents emitted by the brain through electrodes applied on the scalp, to analyze how brain activation and wave frequencies occur in aphasic patients with preserved comprehension. Preliminary results indicate that the portable EEG device was able to adequately capture brain signals with the perspective of rehabilitation monitoring, which may support health professionals, especially speech-language pathologists, in rehabilitation centers.

In our sample, 89% of the participants showed increased electrical activation in the non-language dominant hemisphere. This may be revealing a migration of language, counter-lateral processing. This is a very interesting result because the idea is "those who migrate the function to the other side, recover more language". Another interesting result was that the male patients showed less electrical activation in the right hemisphere, which may be revealing less language migration and perhaps less recovery.

These results may be the "starting point" to use in the rehabilitation of aphasic individuals. In a future study we will extend the analysis to the other lobes of the brain in order to obtain a complete picture of oscillations. We hope to improve our experiment by creating a method that can try to predict the improvement of aphasics.

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Figure 1

Design of the experiment procedure.

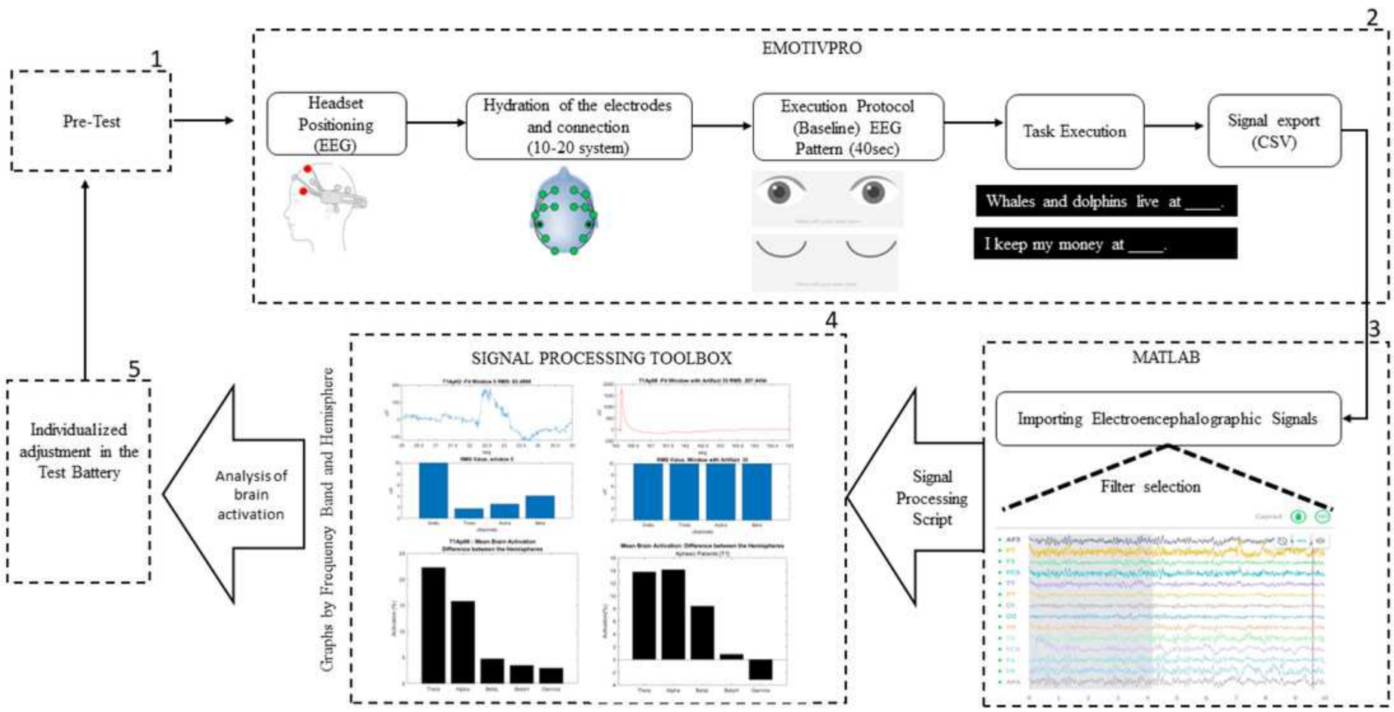
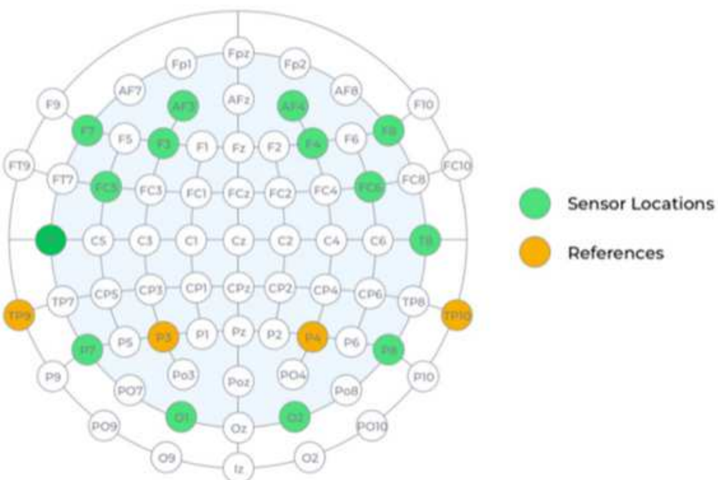


Figure 2

Location of electrodes on the 10-20 system and anatomical correspondence of brain areas (source: Epoc+ specifications).



Electrodes	Corresponding brain area
AF3/AF4	Left/right prefrontal cortex
F3/F4	Left/right frontal cortex
F7/F8	Left/right frontal cortex
FC5/FC6	Left/right primary motor area
T7/T8	Left/right temporal cortex
P7/P8	Left/right parietal cortex
O1/O2	Left/right occipital cortex

Figure 3

Data Processing Schematic.

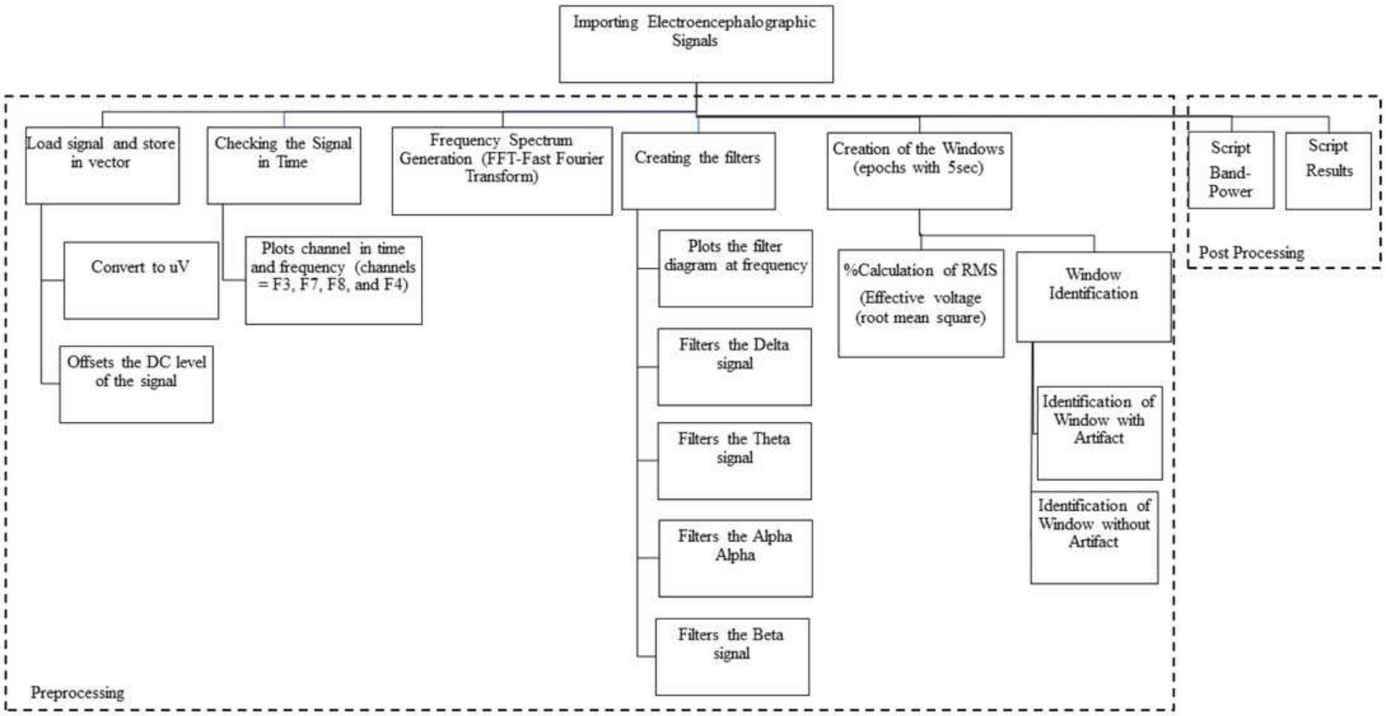


Figure 4

Examples of EEG recording windows (electrode F3) and the frequencies.

(a) Aphasic participant 1, Window 1. (b) Aphasic participant 8, Window 33 with artifact.

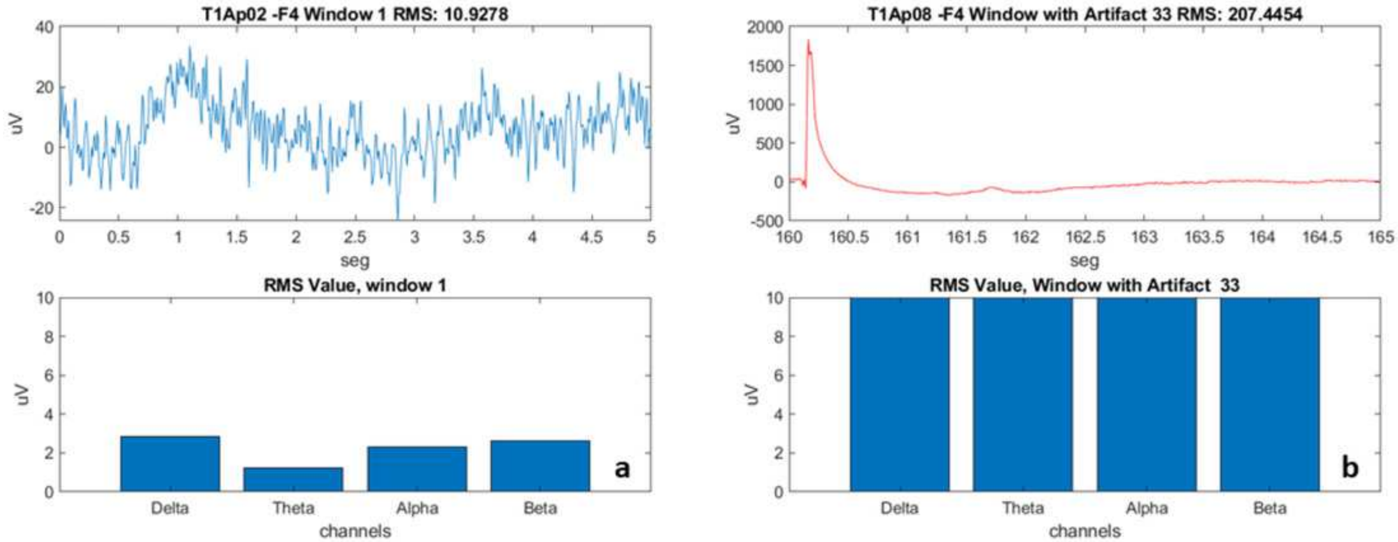


Figure 5

Examples of Brain Activation by electrode (normalized data).

(a) Aphasic patient. (b) Aphasic patient 2. (c) Aphasic patient 5. (d) Aphasic patient 7.

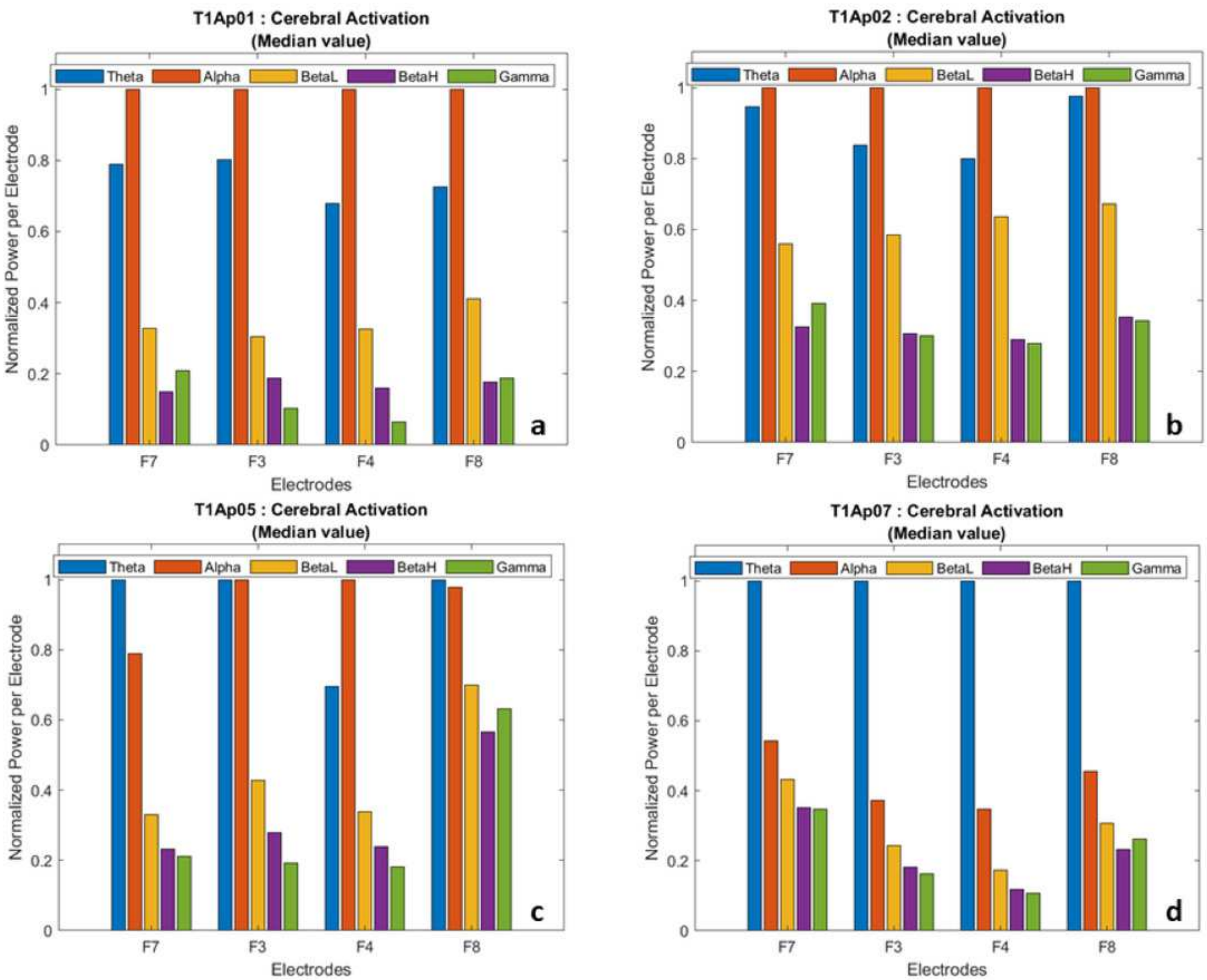


Figure 6

Examples of the difference in electrical activation between hemispheres.

(a, b) Greater electrical activation in the right hemisphere, at all frequencies. (c) Greater electrical activation in the left hemisphere, at all frequencies. (d) Greater electrical activation in the right hemisphere at the Theta and Alpha frequencies and with greater electrical activation in the left hemisphere at BetaL, BetaH and Gamma.

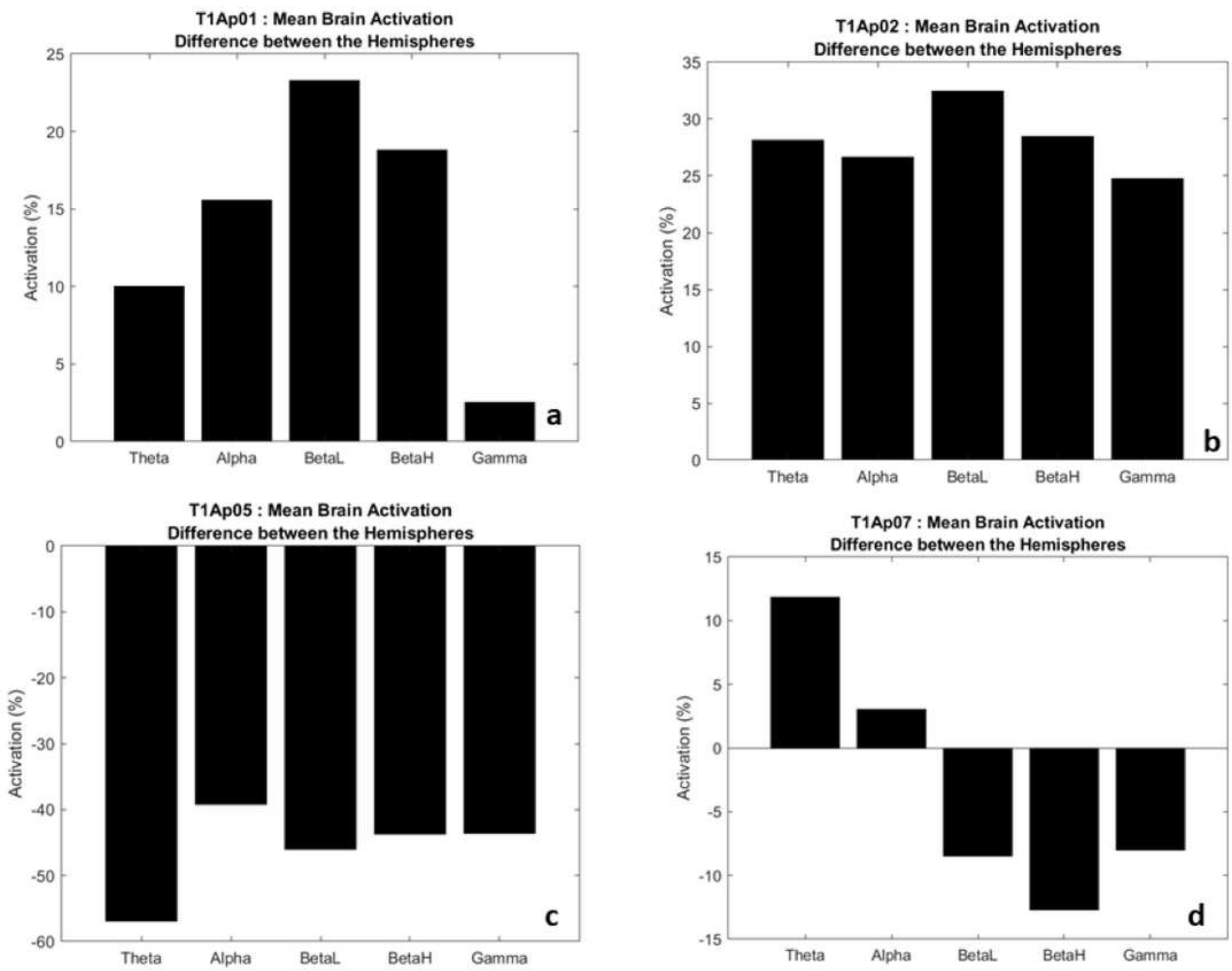


Figure 7

Difference in electrical activation between the cerebral hemispheres (average in aphasic patients).

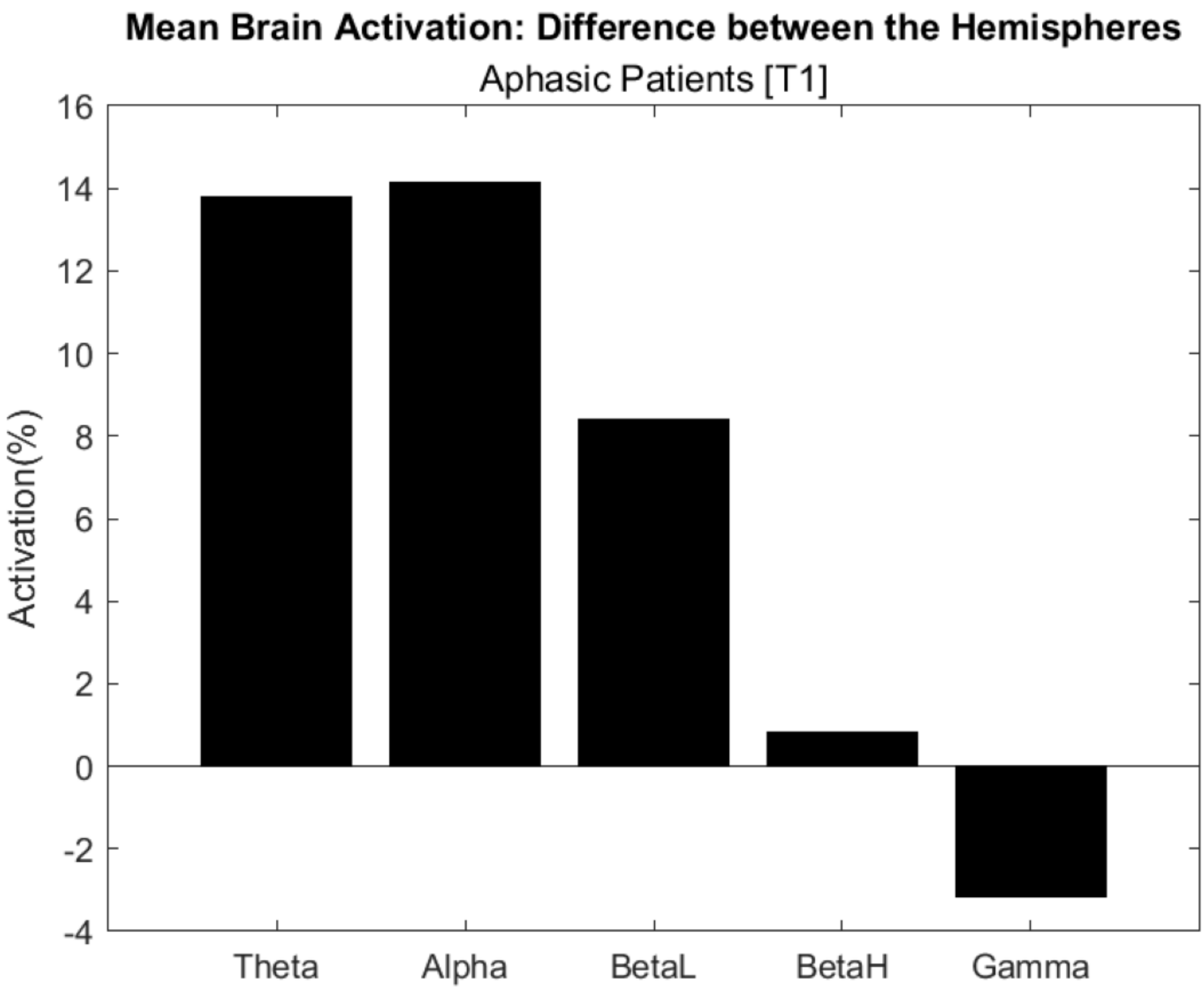


Table 1(on next page)

Description of the patients.

Patient ID	Gender	Age	Hemiparesis	Hemisphere affected	Time of stroke (year/month)	Type of Aphasia
Ap01	F	53	Right	Left	03/03	Broca (Expression)
Ap02	F	51	Right	Left	06/11	Broca (Expression)
Ap03	F	53	Right	Left	02/01	Anomic
Ap04	F	45	Right	Left	01/05	Transcortical motor
Ap05	F	63	Right	Left	04/05	Broca (Expression)
Ap06	F	45	Right	Left	01/03	Transcortical motor
Ap07	M	58	Right	Left	01/07	Broca (Expression)
Ap08	M	63	Right	Left	00/05	Broca (Expression)
Ap09	F	59	Right	Left	10/11	Broca (Expression)
Ap10	F	45	Left	Right	05/03	Global
Ap11	M	60	Right	Left	01/03	Global

1