Computational strategy for aphasia support

Estratégia computacional de apoio à afasia

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ABSTRACT

Aphasia, a language disorder resulting from brain lesions, impacts communication abilities, and is commonly diagnosed through formal tests assessing speech fluency, comprehension, naming, and repetition abilities. These tests aid in devising treatment plans and evaluating recovery potential. Technological advances have enabled the development of devices and techniques for recording brain activity. Despite their potential, the high cost, device robustness, and complexity often limit their application in rehabilitation centers outside hospitals. In this study, we propose a computational strategy that uses electroencephalography devices to support aphasia rehabilitation therapies. The research was conducted with aphasic participants undergoing rehabilitation at the Center for Prevention and Rehabilitation of People with Disabilities within the Unified Health System in Bahia-Brazil. Preliminary results obtained from the silent word generation task, as outlined in the adult language paradigm by the American Society for Functional Neuroradiology, suggest that increased electrical activation in the right hemisphere may indicate language migration to the non-dominant hemisphere, potentially leading to improved recovery.

Keywords: aphasia; electroencephalography; biomedical signal monitoring; language rehabilitation, computational strategy
RESUMO

A afasia, uma perturbação da linguagem resultante de lesões cerebrais, afeta as capacidades de comunicação e é normalmente diagnosticada através de testes formais que avaliam a fluência do discurso, a compreensão, a nomeação e as capacidades de repetição. Estes testes ajudam a conceber planos de tratamento e a avaliar o potencial de recuperação. Os avanços tecnológicos permitiram o desenvolvimento de dispositivos e técnicas de registo da atividade cerebral. Apesar do seu potencial, o custo elevado, a robustez dos dispositivos e a sua complexidade limitam frequentemente a sua aplicação em centros de reabilitação fora dos hospitais. Neste estudo, propomos uma estratégia computacional que utiliza aparelho de eletroencefalografia para apoiar terapias de reabilitação da afasia. A pesquisa foi realizada com participantes afásicos em reabilitação no Centro de Prevenção e Reabilitação de Pessoas com Deficiência do Sistema Único de Saúde na Bahia-Brasil. Os resultados preliminares obtidos com a tarefa de geração de palavras silenciosas, conforme descrito no paradigma de linguagem para adultos pela Sociedade Americana de Neurorradiologia Funcional, sugerem que o aumento da ativação elétrica no hemisfério direito pode indicar migração da linguagem para o hemisfério não dominante, potencialmente levando a uma melhor recuperação.

Palavras-chave: afasia; eletroencefalografia; monitorização de sinais biomédicos; reabilitação da linguagem, estratégia computacional

INTRODUÇÃO

Aphasia is a language disorder acquired after brain injury that affects the ability to communicate. The aphasic individual's speech impairment causes suffering, feelings of helplessness, and leads to isolation. Stroke is the most common cause of aphasia, in Europe, for example, there are one million new cases of stroke per year (MATTIOLI, 2019) and in general one third of people committed by stroke have aphasia (BRADY, 20216).

The evaluation and classification of aphasias is given by the performance of the patient where it is usually evaluated: the fluency of speech, comprehension, naming ability and repetition ability (MINEIRO, 2008) as shown in Table 1.
Table 1 – Types of Aphasia

<table>
<thead>
<tr>
<th>Aphasia</th>
<th>Fluency</th>
<th>Comprehension</th>
<th>Nomination</th>
<th>Repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broca</td>
<td>Non Fluent</td>
<td>Normal</td>
<td>Disturbed</td>
<td>Disturbed</td>
</tr>
<tr>
<td>Wernicke</td>
<td>Fluent</td>
<td>Disturbed</td>
<td>Disturbed</td>
<td>Disturbed</td>
</tr>
<tr>
<td>Conduction</td>
<td>Fluent</td>
<td>Normal</td>
<td>+/- Disturbed</td>
<td>Disturbed</td>
</tr>
<tr>
<td>Anomic</td>
<td>Fluent</td>
<td>Normal</td>
<td>Disturbed</td>
<td>Normal</td>
</tr>
<tr>
<td>Transcortial Motor</td>
<td>Non Fluent</td>
<td>Normal</td>
<td>Disturbed</td>
<td>Normal</td>
</tr>
<tr>
<td>Transcortial Sensorial</td>
<td>Non Fluent</td>
<td>Disturbed</td>
<td>Disturbed</td>
<td>Normal</td>
</tr>
<tr>
<td>Global</td>
<td>Non Fluent</td>
<td>Disturbed</td>
<td>Disturbed</td>
<td>Disturbed</td>
</tr>
</tbody>
</table>

Source: Mineiro (2008)

Speech-language pathologists assess language deficits using formal cognitive tests (e.g., Boston Diagnostic Aphasia Examination, Western Aphasia Battery, Boston Naming Test, Token Test, Action Naming Test) to aid in treatment planning and to evaluate the potential for recovery.

However, in light of the variability in existing practices for assessing language function, the American Society for Functional Neuroradiology (ASFNR) organized a clinical practice committee to develop a set of standardized language paradigms used in fMRI. The result of this work identified the most frequently used paradigms, shown in Fig. 1 (BLACK, 2017).

Figure 1 – Language Assessment Tasks

![Image of Figure 1](image)

Source: Black (2017)

As evidenced in Fig. 1, the most frequently employed tasks were Silent Word Generation (SWG) and Sentence Completion (SC) which stood out from the other tasks.
In the literature, SWG and SC were identified as the most reliable and useful tasks. These two tasks have become "the core of the standard language task battery" (BLACK, 2017). For Pagliarin (2013), "language assessment instruments, whether formal or functional, in addition to allowing a more accurate, objective and quantitative diagnosis, can serve as a treatment strategy."

With the development of new technologies, brain-computer interfaces, designed to record brain activity, capture information from the Central Nervous System (CNS) and send it to the outside of the body, being able to activate other devices or applications (ZAPATA, 2018). To record the brain activity different techniques are being implemented such as fMRI, fNIRS, EcoG, MEG and EEG, however some of these methods have high cost and have little mobility for being very robust.

Although Real-Time functional Magnetic Resonance Imaging (RT-fMRI) is used as a neurofeedback strategy to improve activation in the language areas of stroke and aphasia patients, this strategy requires many hours of training and the system is not portable, making the cost very high. It is possible to activate the specific study regions using lower cost and portable methods, such as EEG-based system, which may be feasible for rehabilitation (SREEDHARAN, 2020).

Given the scarce financial and human resources, and considering that this work was developed in a Center for Prevention and Rehabilitation of Persons with Disabilities (CEPRED) of the Unified Health System (SUS), a reference in the state of Bahia-Brazil, we sought to answer the following question: How can EEG contribute to the rehabilitation of aphasics, using the conventional therapeutic process?

Therefore, the objective of this study is to develop a computational strategy with an Electroencephalography (EEG) device, as a support to the conventional therapeutic process, to contribute to the rehabilitation of aphasia.

As a premise for application in rehabilitation centers, the strategy has three pillars: daily accessibility (cost and mobility of the equipment), usability (ease of use of the equipment-therapy) and whether the technology is invasive or not for the patient.

**METHODS AND MATERIALS**

The study is exploratory, which means that there has been little research on the use of EEG device supporting the rehabilitation of aphasia and this concept must be explored and comprehended (CRESWELL, 2017).
This research was approved by the Research Ethics Committee (REC), according to Resolution 510 of the National Health Council (CNS). Approval of the REC of the Integrated Manufacturing and Technology Campus (CIMATEC) - Senai/Bahia with Certificate of Ethics Appreciation Presentation (CEAP) of n. 29622120.2.0000.9287, under opinion n. 4.759.328 and REC of the Health Secretariat of the State of Bahia (SESAB) with CEAP: 29622120.2.3001.0052, under opinion n.4 492.254, which approves the study and binds CEPRED as a co-participating center.

The Strategy

The strategy developed in this study used EEG, which is a method of electrophysiological monitoring that is based on the electrical activity of the brain, sending the signals to a computer (Fig. 2). Fourier analysis was used to process the signals by separating the data into frequency intervals. For the collection and processing of the brain signals we used:

- A laptop: with Intel i7 processor, 11th generation with 8 Gb RAM, with 64-bit operating system (Windows 11).
- EEG: wireless and portable: Emotiv Epoc + with 16 channels (Fig. 2), EEG Brainwear. The electrodes are positioned according to the international 10-20 positioning system, which is the international arrangement for electroencephalographic analysis. Designed for human brain research, commercially available and validated in another research ((BADCOCK, 2013), (YU, 2016), (KOTOWSKI, 2018), (FOUAD, 2021), (MELEK, 2020)).
- Matlab: Version 9.12 (R2022a) where we worked with calculus, matrices, signal processing, and graph construction.
Each participant performed the task generating a data file that was then exported from the EEG platform (EMOTIPRO) in CSV (Comma-separated values) format to be imported into Matlab. Of the 16 electrodes, we used for this study four electrodes positioned in the frontal lobe, two in the left hemisphere (F7, F3) and two electrodes in the right hemisphere (F4, F8).

The EMOTIVPRO Epoc+ signal acquisition system has a frequency response from 0.16 to 43 Hz and captures the electroencephalographic signal at a sampling rate of 2048 Hz, with 16 bits of quantization, generating a 20-bit interpolated signal when subsampled to 128SPS (Samples per Second). The acquisition full scale is ± 4.17mV. The signal provided by the acquisition software is given with an offset and is represented in natural numbers. So, the first step is to remove this offset and convert the signal to microvolts (µV) for correct data processing. We use Signal Processing, a toolbox for analysis and treatment of EEG data signals. We apply digital filters to decompose the signal into frequency bands.

We created an algorithm to fragment the signal into "windows", also separating them into frequency bands, to analyze the stimulus and control intervals. We use the calculation of the RMS value for each band (the effective value, also known as the RMS value from Root Mean Square) and compute the mean and median per window.
The Test Sample

The sample consisted of 11 Aphasic Participants (BP = eight women, three men), with a mean age of 54 ± 7 years. Of these participants, ten had brain lesions in the left hemisphere and one person with lesion in the right hemisphere, all with hemiparesis (difficulty to move half of the body), as described by the participants in Table 2.

Table 2 – Aphasic participants

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

Source: Table of the author

As inclusion criteria in this study, we considered participants of both genders, over 18 years of age, with a diagnosis of post-stroke aphasia and normal or corrected-to-normal vision. And as exclusion criteria, we considered participants with mental disorders, with unstable cardiovascular diseases or other serious diseases that would prevent them from performing the task.

All participants signed a consent form declaring their interest in participating in the study. This document contained information about the privacy of the participants' data, details of the study tasks, and the researchers' contacts for any questions. The only risk identified for the participants was the possibility of fatigue when connecting and validating the electrodes.
Regarding sample size, in general, experimental studies have few participants, due to the condition of patients and the limitations acquired by the stroke. As an example of experiments with participants with speech impairment, we cite study with 8 participants (MANYAKOV, 2011), with 7 participants (MULLER, 2010), with 8 individuals (RILEY, 2017) and 5 participants (KLEIH, 2016).

The Language Task: Silent Word Generation – SWG

We collected electrophysiological signals from aphasics undergoing rehabilitation. We analyzed the brain activation and wave frequencies of each individual during the Silent Word Generation (SWG) task described in the adult language paradigm (BLACK, 2017).

The task of generating silent words has as its stimulus letters that appear on the screen. By visualizing the letter, the patient must silently think of words that begin with that letter, as long as the letter remains on the screen. When a new letter appears, the participant must again think, without speaking or moving their lips, of words that begin with the letter that appeared, and so on until the task is finished.

The 20sec stimulus period (with letters) is followed by a control period (with symbols), also 20sec. The sequence starts with two symbols, presented one at a time, and then two letters, also, one at a time. So, there are two symbols and two letters in this sequence. Totaling 12 letters and 12 symbols, as exemplified in Fig. 3.

**Figure 3** – Example of the Silent Word Generation (SWG) task: symbols and letters
According to the language paradigm (BLACK, 2017) adopted in this study, the frontal and temporal area have increased activation while performing this task, with the frontal area being most highly activated. The Broca's area is specifically highlighted as being activated.

RESULTS AND DISCUSSION

Although the sample consisted of 11 aphasic participants, two of them with global aphasia did not follow the guidelines of the research protocol. Thus, the study was limited to the analysis of aphasic participants with preserved comprehension. Another limitation in this study was the sample size due to the situation of the aphasic, some had depression, sadness, and problems with locomotion. Thus, we considered nine participants in our analysis.

Fig. 4 shows that three aphasics (a, b, c) had greater electrical activation in the right hemisphere (bars up) than in the left hemisphere (bars down) in all wave frequencies: Theta, Alpha, BetaL, BetaH, Gamma. The y-axis shows the difference in percentage of electrical activation between the two hemispheres of the brain.

In Fig. 4.a the participant had a 25% to 30% greater increase in electrical activation on the right side of the brain, than on the left hemisphere, which is the language dominant hemisphere. Whereas in fig. 4.b the participant has on average 25% greater activation in the right hemisphere. In fig. 4.c the participant also showed increased electrical activation on the right side of the brain, with the Theta and Alpha frequencies with approximately 30% greater activation on the right side, while the other frequencies (BetaL, BetaH, and Gamma) had greater electrical activity on the left hemisphere, although with lower percentages of activation. Greater electrical activation in the right hemisphere (a, b, c), at all frequencies.
Figure 4 – Examples of the difference in electrical activation between hemispheres.

Figure 5 shows three aphasic participants (d, e, f) who had three to four frequencies with greater activation in the right hemisphere of the brain. We also note that the Gamma frequency, in all three participants, was most active in the left hemisphere. This wave frequency is associated with the processing of auditory, tactile, and visual stimuli. Greater electrical activation in the right hemisphere (d, e, f), at least three frequencies.
**Figure 5** – Examples of the difference in electrical activation between hemispheres.

In our sample, 6 of 9 participants (Fig.4 and Fig.5) showed increased electrical activation in the non-language dominant hemisphere, with 3 of 9 participants having the 5 frequencies (Theta, Alpha, BetaL, BetaH, Gamma) with more activation in the right hemisphere; 2 of 9 having 4 frequencies (Theta, Alpha, BetaL, BetaH) more active in the right side; 1 of 9 having 3 frequencies (Theta, Alpha, BetaL) more activated in the right hemisphere. These results may be revealing language migration to the non-language dominant hemisphere, which for these participants is the right hemisphere of the brain.

Figure 6 shows that 3 of the 9 participants (g, h, i) had between 4 and 5 frequencies most activated in the left hemisphere of the brain (bars down) and a single participant (Fig. 6.i) with all the most active wave frequencies in the left hemisphere, the language hemisphere.
CONCLUSION

With the preliminary results presented in this study, which aimed to develop a computational strategy to support aphasia with an EEG device, using the Silent Word Generation (SWG) task, we can conclude: the greater electrical activation in the right hemisphere may be revealing language migration, a contralateral processing. Migrating language function to the other side, may mean increased recoverability from aphasia.

The computational strategy presented in this study can assist the health professionals in defining and adjusting the procedures used. The technological and processing devices used (Laptop, EEG, Matlab) are accessible to the rehabilitation environment, are easy to use (usability), and are not invasive to the participant.

This strategy provides support to the conventional therapeutic process, in real time, where the visualization of graphics can be used as a challenge to the participants to engage more in the rehabilitation process.
In alignment with this study, and with the expansion of our sample, the next steps will include new tests of the adopted paradigm, such as: sentence completion task, rhyming task, and object naming task. Our expectation is to develop a method that can aid rehabilitation and try to predict improvement in aphasia.

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REFERÊNCIAS


