Development of Serious Games for Neurorehabilitation of Children with Attention-Deficit/Hyperactivity Disorder through Neurofeedback

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***Abstract*— Attention-deficit/hyperactivity disorder (ADHD) is a neuropsychiatric syndrome that affects approximately 6 % of the child and adolescent population and 5% of the young adult population. Pharmacological treatment is the most used and is performed with the administration of psychostimulants. However, the use of the medication achieves an efficiency of 70 to 80% with the disadvantage of side effects. An alternative to this type of treatment is the use of the neurofeedback (NFB) technique. The NFB training has a repetitive appearance and may be long lasting for treatment to take effect. Nevertheless, it is often necessary to use a tool to increase the engagement. A widely used tool that can be integrated in training is the use of *serious games.* This work presents the development of a serious game as a strategy for neurorehabilitation of children with ADHD using a neurofeedback system. Three metrics were selected to evaluate the participant's progress: score, an attention index and the ability to sustain attention. In general, the metrics improved throughout the sessions during the experimental validation. Most importantly, it was noticed that motivated patients were able to obtain better results, showing the importance of motivation in NFB strategies for rehabilitation.**

Keywords- Neurofeedback; Electroencephalography (EEG); Serious Games; Unity; Attention-deficit/hyperactivity disorder (ADHD);

I. INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is a neuropsychiatric disorder that affects approximately 6 to 7% of the child and adolescent population and 5% of the young adult population [1]. Children with ADHD may also present cognitive domain deficits such as: problems in working memory, deficits in inhibitory functions, delay in information processing and among others [2].

Pharmacological treatment is the most used in both children and adults and is performed with the administration of psychostimulants. However, the use of the medication achieves an efficiency of 70 to 80% and the individual can present side effects like decrease of appetite, dry mouth and irritability [3].

An alternative to this type of treatment is the use of the neurofeedback (NFB) technique. NFB is a biofeedback method that measures real-time brain activity and aims to teach the user to regulate their own brain waves, as well as, changing underlying neural mechanisms of cognition and behavior [4][5]. There are many non-invasive methods to acquire brain's signals: electroencephalography (EEG), magnetoencephalography (MEG), high spatial-resolution functional magnetic resonance imaging (fMRI), and near-infrared spectroscopy (NIRS). The advantage of the EEG method is in its time resolution, low procedures' cost, and the possibility of using mathematical tools to manipulate the signal [6].

This technique is used for several purposes, from improving cognitive activities such as multi-tasking [5], improving concentration and memory skills [7], helping children with fetal alcohol spectrum disorder (FASD), who are often diagnosed with ADHD [8], and even helping the improvement of children with learning difficulties [9]. During NFB training, the goal of the technique is to increase or decrease brain activity within a certain frequency range of the EEG signals.

The NFB training has a repetitive appearance and may be long lasting for treatment to take effect [10]. In this manner, especially for children, it is necessary to use a tool to increase the engagement and to maintain the interest of the same ones throughout the process. A widely used tool that can be integrated in training is the use of *serious games* [8][11]. These, in addition to entertainment, have educational and/or health related purposes [12]. For the training, the user must maintain the desired cognitive state to learn how to regulate their own brainwaves, so the integration with the serious game causes the player to only advance in the game, receiving power-ups or gaining points when it can maintain this state [5][7][11].

There is no consensus regarding the specific game genre, total number of sessions, interval between sessions, or single acquisition protocol to treat neuropsychiatric/ neurological disorders, or cognitive impairments.

In [5], the authors developed a shooting game, in which the player could shoot and hit the enemies only when it reached the desired cognitive state. For this study were selected 3 individuals not affected by any neuropsychiatric disorder, 6 sessions were performed and the better the player's performance, the more difficult the game became. In [7], to improve concentration and memory skills, the authors developed a memory game, in which the player could only guess which number was in the matrix gap when he achieved an attention state. The training was performed with 5 healthy subjects in a controlled

environment. Controlled parameters were lighting, position in the chair and eye movement during the task.

The study was performed in [8] lasted for 12 weeks with 16 children with FASD and, unlikely the previous referenced articles, there was no inhibition in the game when the desired mental state was not reached. In this study, the textures gradually obscured the graphics of the game chosen by the user, making it less enjoyable to be played. If the obfuscation was exaggerated, it would be impossible to progress. In this way, when the user performed the main task, the game experience improves with no modification on the game mechanics, allowing full visualization.

This work presents the development of a serious game as a strategy for neurorehabilitation of children with ADHD using a neurofeedback system. Aiming at improving the quality of life through technological solutions, children with ADHD may benefit of an alternative and complementary therapy, to regulate their brain waves and reduce symptoms that hinder or may disrupt them in the course of their life.

This paper is organized as follows. Section II presents the EEG and the equipment used in the project, the algorithm developed for the classification of cognitive states, the serious game and the protocol used for neurofeedback training. Section III presents the results and the discussion from this research, and Section IV, the conclusion and future work.

II. MATERIALS AND METHODS

A. *Materials*

The Quick-20 (Cognionics, United States) dry EEG wireless headset was used for capturing the EEG activity and is presented as a space helmet to the children participating in this study. For data acquisition, online processing of EEG signals, and game development, a desktop computer (i7-7700 processor, a GeForce GTX 1080 6GB, HDD 1 TB, SSD 120 GB, 16 GB RAM) was used. Data acquisition was performed with a proprietary software by Cognionics. Matlab was used for data pre-processing and online processing of EEG signal. A library called Lab Stream Layer is used for exchanging data between the Cognionics proprietary software and Matlab for online processing.

Unity was chosen as the game development platform, considering its low cost, ease to learn and with potential for 2D and 3D games. In addition, Unity allows the communication with other signal processing software, which is suitable to the application proposed in this work.

B. *Neurofeedback Technique*

The neurofeedback technique used in this research is presented in Fig. 1.

The EEG data was collected at 500 Hz and 7 electrodes were chosen to be used in the NFB-based game: F3, F4, C3, Cz, C4, P3 and P4, shown in Fig. 2. A1 was used as reference.

As described in the following paragraphs, data pre-processing is performed, characteristics are extracted from this new signal, and, after passing through a classifier, the mental state is defined. In this study, two mental states were used: *attention* and *nonattention*.

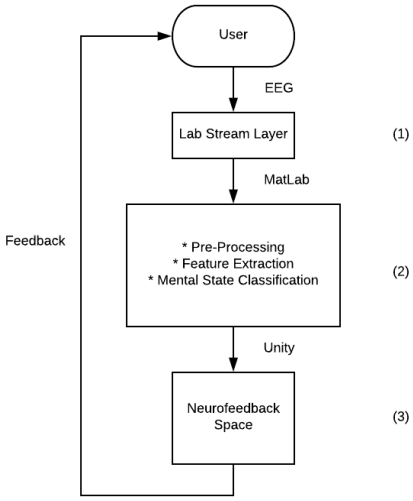

Figure 1. The developed neurofeedback system's flowchart. (1) Library used to exchanging data between the Cognionics proprietary software and Matlab. (2) stage of signal processing consisting of filtering, feature extraction and mental state classification. (3) Serious Game.

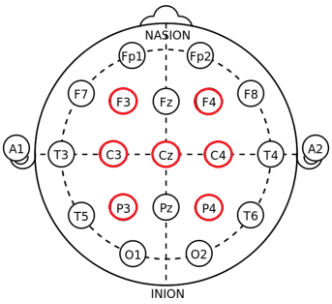

Figure 2. 10-20 System with the 7 chosen electrodes.

In the data pre-processing, the EEG signals were band-pass filtered (0.5-35Hz) with the Butterworth filter aiming to have a frequency response as flat as possible in the passband.

After filtering the signals, Welch's method was used to estimate the power spectral density (PSD) for each of the desired frequency bands. For each electrode, 5 features were calculated: PSD for θ (4-7 Hz), α (8-10 Hz), low β (15-19 Hz) and the ratios α/ low β [13] and θ/ low β [5].

Fisher Linear Discriminant Analysis (LDA) was used to reduce the thirty-five features (five per electrode) to seven features (one per electrode) to be used in the Support Vector Machine (SVM) classifier.

The general approach of the LDA is that it is possible to find the component that maximize the data variance through a linear combination, and the components that maximize the separation between multiple classes.

Reducing to one characteristic per electrode, and not reducing 35 to a specific number regardless this preference, was a strategy adopted because in previous tests, using PCA, not all electrodes appeared in the selected features to calculate the principal components.

That means that, for that acquisition, all the information (the five features) from one electrode was excluded. Also, in different sessions, the excluded electrode was not necessarily the same for the same participant. Thus, to have all electrodes' information, even if not the most relevant in that session, and to have a uniformity in the data, the LDA was applied in each electrode. Thereby, reducing 35 features to 7.

Subsequently, the SVM classified the data and a label with the mental state information is sent to the serious game, elements of the game are changed depending on the sent label. This will be presented in Section *Serious Game: Neurofeedback Space*. The user receives this mental state feedback from the game and can learn how to achieve the desired mental state trough the neurofeedback training.

C. Experimental Protocol

In each session, two types of data were collected before the neurofeedback training to respect the brain's individuality. This is a very important step, because EEG signal and user's motivation to play the game can be altered with mood changes. For that purpose, and to maintain a uniformity, a protocol was created for the data acquisition.

Three male participants diagnosed with ADHD participated in the neurofeedback protocol (Nº of the consubstantiated opinion of the Committee of Ethics in Research – 2.021.705 / CAAE-19403713.6.0000.5060). They were at the age group of 7-12 years old and each session was accompanied by a clinical staff that repeated the protocol's instructions.

First, a starry space image (Fig. 3) was displayed in the monitor and the children were instructed to remain as calm as possible and not to fixate the eye gaze in any object for 15 seconds. This data was labeled as *nonattention*.

Figure 3. Starry space image used to collect nonattetion data.

Secondly, a spaceship and a text written "Pay attention to the spaceship, the game is about to begin" were added in the previous image, observed in Fig. 4, and the children were instructed to maintain focus in one or in a part of an object for 15 seconds. This data was labeled as *attention*. The spaceship was the same as the spaceship that was displayed in the game, so the patient could get familiar with the game environment.

Figure 4. Spaceship image used to collect attetion data.

With the data collected and processed, the classifier was trained to separate these two data types. After that, the children were able to play the game and the data were processed online: every second the signal was processed and the SVM would classify this signal as *attention* or *nonattention*. Such classification is based in data obtained in offline mode.

Initially, the acquisition protocol lasted 2 minutes (1 minute for the attention label and 1 minute for the nonattention label) and it was based on the literature, even without a protocol duration consensus. For example, in [7], to achieve the threshold desired for the online mode, the authors took 10 trials and each trial was separated in 3 phases: preparation, concentration and rest. The authors took 17 seconds per trial, therefore 2 minutes and 50 seconds. However, when working with children with ADHD data acquisition can be challenging.

In the first test, because of the hyperactivity level, the patients couldn't hold attention for long, thence, the protocol was shorted to 15 seconds for each data type. To adjust to this sample reduction, a 50% overlap window was used.

Establishing the number of sessions per week was also challenging as the children's relatives and the children themselves, throughout the neurofeedback training, became ill, had appointments and schoolwork. In this manner, the agreement with the patients' relatives was 2 sessions per week for at least 6 weeks.

D. Serious Game: Neurofeedback Space

1) Game Levels and Panels Description: A serious game called "Neurofeedback Space" was developed to provide an experience of comfort and immersion for children. The space theme was chosen, as already mentioned, because the EEG cap can be compared to a space helmet used by the pilots. Also, two Non-Player Characters (NPC's) were designed to be the spaceship's crew.

The game was divided in three parts. The first one is the menu panel, as shown in Fig. 5. Before playing, the astronaut, as the participant is called, must write his name, date of birth, which session he is currently engaged and the current date. This Login was designed to be a logbook and to increase interaction with the game. This panel can be observed in Fig. 6.

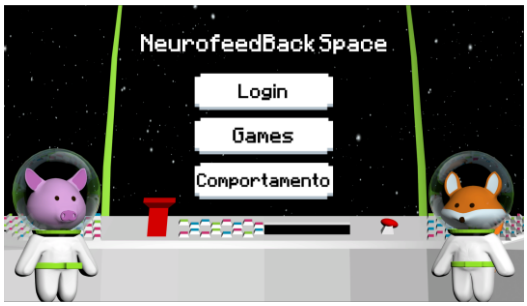

Figure 5. Screen capture of "Menu Panel".

Figure 6. Screen capture of "Login Panel".

After filling out the form, the data is saved in an SQLite database. In the game, three levels were designed aiming to provide different difficulties and experiences. In each session two levels were played. The games order was chosen by the PhD student in psychology after asking a few questions about the participant's mood and well-being. If the user was not feeling well or secure enough, the games 1 and 2 were selected, otherwise, the games 2 and 3.

The first Level can be seen in the Fig. 7 (a) and it is the easiest game to play of them all. The level was composed by 6 elements.

The first one was the spaceship, and it was designed to look the same from the menu panel, but with an "outside" view. The second one was the star pickups. The spaceship should collect them throughout the game. The third one was the speed feedback bar, and it is located at the bottom-left of the image. During the game, the spaceship accelerated or braked due to the participant's attention or lack of it, this will be explained in the next subsection.

The third element was the timer, located at the bottom-right and every game had a 5 minutes duration. The fourth element was the score text, situated at the top-right of the image and it showed the number of pickups collected. The fifth element was the Background, and it was very important to the game environment, because two space images were used as parallax, and they moved at two different speed rates, which gave a sense of depth in the game.

The last element is the "menu button", used when the game was finished, or if the user wanted at any time, for some discomfort, to give up the game.

(a) (b)

Figure 7. Screen captures from the environment of the (a) first and (b) second levels of the game.

The second level had the same elements as the first, but a gas tank, the red object in Fig. 7 (b), was added to make the game more challenging and also prepare the player for the game 3. The gasoline tank level decreases throughout the game and if the tank empties, the spaceship continues to move, but the player can't collect stars until he picks up another gas tank element. An orange bar, at the bottom of the image, show to the player how much gasoline the spaceship has in its tank.

The third level had the same elements as the second one, but it was designed to be more challenger than its antecessor. If the gasoline tank (orange bar) was empty, the player would lose 1 point per second until he picked up another gas element. This "punishment" can cause stress if the player is not secure enough to play it. That's why the third game was only played with the participant's verbal consensus.

The last panel presents the behavioral observations that will be discussed further in this article. After finishing the game, another game was chosen, like previously explained, and the desired elements, such as score and which game was played, were updated in the database.

2) Neurofeedback Space Operation: The game's goal was to teach the patients to self-regulate their brain so they could understand how to focus and pay attention not only to the game but also to their daily activities. Therefore, the game "punishes" the players when they aren't paying attention and reinforce when they are.

In *Neurofeedback Space*, the element chosen to be the feedback to the user was the spaceship's velocity. If the label "attention", that was sent as "1" to Unity, was identified, the spaceship would have its velocity increased in 10%. Otherwise, "-1" was sent to Unity, the velocity would decrease in 10% per second. Therefore, the player has always a visual feedback, and when the spaceship is getting slower, he can find another focus point that work better for him, so that the velocity increases again.

To evaluate the participant's progress, three items were selected. The first one was the score. So, how many stars the player can collect in 5 minutes. The second one was in how many samples, from 300 samples, the label "attention" had been identified. The last one was how long could the player sustain the label *attention.* That means, the greatest "1" label sequence received in the game.

At the end of each game, before the behavioral observations, children were questioned regarding what did they make to do the spaceship go faster. That was a strategy to encourage self-perception. If the participants can identify what they are doing to have more focus, it can

help them in real life in daily situations. They were also encouraged to do that in school when they felt that they weren't paying attention to the subject or teachers.

3) Behavioral Observations: The last panel, observed in Fig. 8, was dedicated to evaluate the patient's experience. Four questions, at the end of every game, were asked: "Were you feeling agitated or relaxed during the game?", "Were you feeling concentrated or distracted?", "How was your motivation today?" and "How much difficult was the game?". The last two were answered in a 5-point likert scale. Being the scale, in the third question: 1- not motivated, 2- less motivated, 3- neutral, 4- motivated and 5- very motivated. And in the last question: 1- very easy, 2- easy, 3- neutral, 4- difficult, and 5- very difficult.

Figure 8. Interface with a questionnaire to evaluate the patient's experience after the game.

The last one is the observation field where notation by the staff following the session. The observations are important to avoid data inconsistence. Because children can report that they were relaxed, but along the session they were agitated.

III. Results and Discussion

A. Subject Participation

The first participant did 6 NFB sessions, but the first one wasn't considered valid. He is hyperactive and, at the first session, he was very excited to play the game and moved abruptly during the session, shook his head, and did not follow instructions. The levels 1 and 2 were played per session.

The second participant also did 6 NFB sessions and had his first session disregarded due to technical problems with the EEG. In the second game of the second session, he preferred to play the third level, claiming ease in playing level 1. Although, in all other sessions, the levels 1 and 2 were alternated per session.

The third participant did 9 NFB training sessions. For comparison purposes, the first six sessions will be evaluated with the other participants and an extra result will be analyzed separately. In the fourth session, the subject was emotional, feeling stressed and asked to leave the session. Therefore, the session was interrupted and disregarded. After this event, the willingness to participate in the training oscillated, and the participant almost gave up in some sessions. The level 1 was played in the first three sessions and after that the levels 1 and 2 were alternated.

B. Score

The Fig. 9 shows the participants' score in each session and a tendency line was plotted to each data.

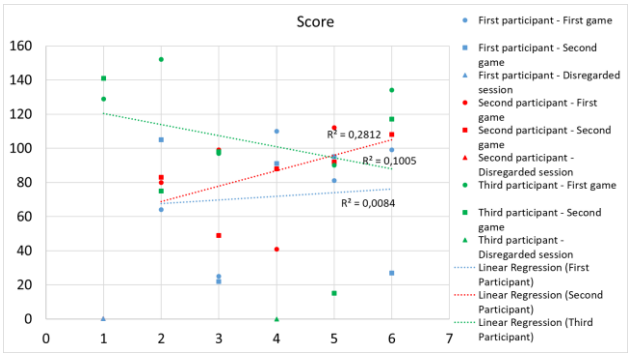

Figure 9. Graphic of the participants' score in each session and their tendency lines.

It is possible to notice an ascending line in the first participant data, which indicates an improvement, even if subtle, throughout the sessions. The maximus score reached was 110 in game 1 in the fourth session, and the worst was 22 in game 2, second game played in the third session.

The second participant, as well as the first, got an ascending line in the score during the sessions. Also, it showed a greater tendency line's slope, suggesting a greater improvement. His best score was 117 points in the sixth session game 1, and his worst result was 41 points in the fourth session level 1.

The last subject, up to the third session, got good scores and was excited and motivated to continue the study, however, from the 4th session, his score oscillated with his willingness to participate and ended with a downward tendency line. His best score was 152 and his worst 15 points.

C. Attention

The measure of attention corresponds to the percentage of data that the classifier labeled as attention. This result, from all participants, is in Fig. 10.

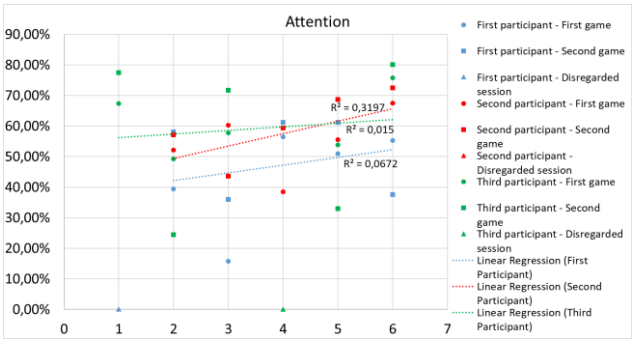

Figure 10. Graphic of the percentage of the data that the classifier labeled as attention for each participant.

The attention, for the first participant, was the item with the best improvement. It is possible to observe that the tendency line has a larger slope than in Fig. 10.

The second participant had also an improvement in his results. Throughout the sessions, he achieved an improvement from 52% to 75% approximately.

The last subject had practically no improvement in his attention, as can be seen in Fig. 10. His tendency line has practically no alteration throughout the sessions. This result may have occurred because the subject did not follow instructions and, when he did not get his expected result, he stopped paying attention and wanted to give up.

D. Sustained Attention

It is expected that the participant, along the sessions, learn to hold and focus his attention increasingly due to self-perception. Sustained Attention evaluates the highest consecutive data sequence that the classifier labeled as attention.

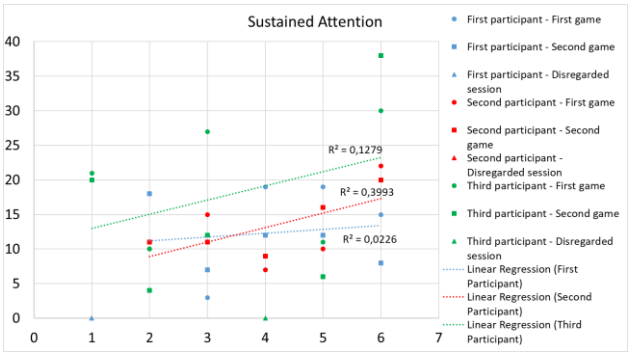

Figure 11. Graphic of the consecutive data sequence that the classifier labeled as attention for each participant.

All the three participants had an improvement in this metric throughout the sessions. The second subject had the best progress, as observed in Fig. 11, and in the last session could sustain his attention for 22 seconds.

The other two subjects had also a positive tendency line, but with a subtle slope. This behavior probably happened due to the hyperactivity of these participants. Since the second participant presents a deficit of attention, but not a hyperactivity. Then, when the hyperactive prevailing subjects tried to hold their attention, they presumably became distracted and lost the attention sequence.

E. Third Participant NFB training

The subject participated in 9 NFB training sessions. At the fourth session, as mentioned previously, the participant asked to leave, and the session was interrupted and canceled. Thenceforth, he oscillated between following and not following instruction. In the second game of the last session, he reported that he no longer wanted to participate in the project, that he wasn't feeling motivated and asked to leave.

Observing the Fig. 12, Fig. 13 and Fig. 14 it is possible to notice a worsening throughout the sessions and a great oscillation in the results. In several sessions, when he realized that he could not focus, the participant closed his eyes purposely, shook his head sharply repositioning the electrodes, and he was visibly annoyed. All the tendency lines of these figures. have a downward slope. With this, it is possible to perceive that the motivation directly interferes in the results. The subject must want to participate and feel motivated in the environment where it is. Otherwise, the likelihood of him not wanting to continue in NFB training increases.

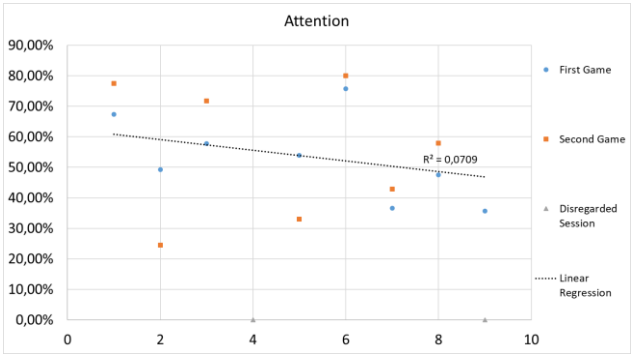

Figure 12. Graphic of the percentage of the data that the classifier labeled as attention for the third participant.

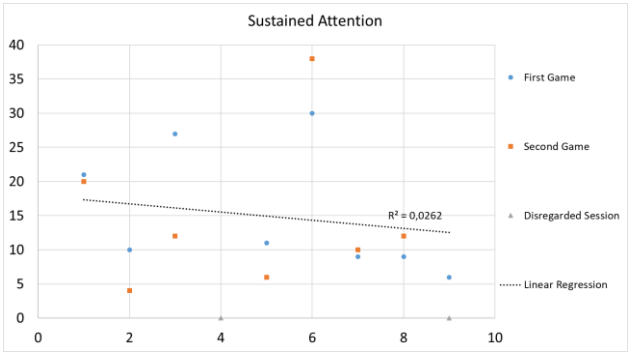

Figure 13. Graphic of the consecutive data sequence that the classifier labeled as attention for the third participant.

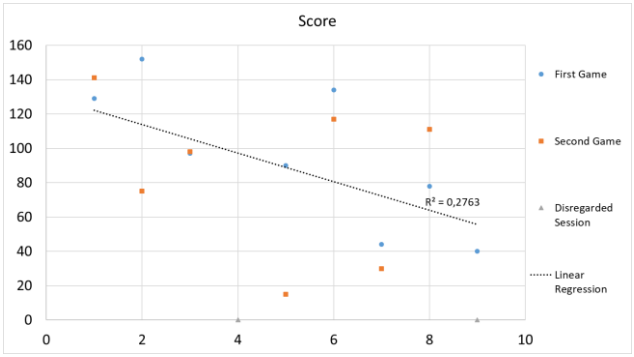

Figure 14. Graphic of the the third participant's score in each session and its tendency lines.

F. Behavior

A behavioral analysis was done in each session to analyze a possible improvement of the participants in following instructions, and in calming down when an agitated state was perceived. Also, to check for engagement and motivation.

The first participant reported in all sessions, except for the last, that the game was very easy, even when he hadn't

the best score, and also that he was very motivated to play every session. After every game, he wanted to share his score with his relatives and also with the BRAEN (Brazilian Research Group on Cognitive Engineering) research group, and if the score wasn't good as the others, he reported that he wasn't upset about it and that in the next session he would be better.

Also, it was possible to realize throughout the sessions that he could control, most of the time, the impulse to touch the computer, and he could follow the instructions given for the data collection and NFB training better.

The best results obtained, when analyzing score, attention and sustained attention, belonged to the second participant. He did not have a hyperactive predominance and was the oldest among the group. Important to note that he was not impulsive and could follow instructions.

The participant had a good development of his self-perception. Throughout the game, he tested the system by withdrawing the focus from the object of the game, and, when he realized that the spaceship slowed down, he returned to focus on a point to increase the spaceship's velocity.

The behavior of the third participant has already been discussed in the previous subsection. He is predominant hyperactive and throughout the sessions lost the motivation to participate in the NFB training. From the fourth session, its performance oscillated, but it had a worsening tendency.

IV. Conclusion

Neurofeedback can be used as an alternative treatment for ADHD and it is also used for improving concentration, memory skills, and cognitive activities such as multi-tasking.

With 6 sessions, it is not possible to conclude by the metrics used if there will be a continuous improvement, since sustained attention and score have had an oscillatory behavior. However, analyzing the tendency line, it is clear that, in general, the metrics improved, even subtly, throughout the sessions.

It was noticed that patients who were more motivated or who were able to follow the instructions were able to have better results. In the case of subject 3, who was hyperactive and not motivated to continue NFB training, the data showed a significant worsening throughout the sessions. The subject 1 was also hyperactive, but he was very motivated to play the game *Neurofeedback Space*, and that helped him to continue and improve his results.

For future work, this study will be continued to gather more data and to have a more concise result. Also, the low beta band and theta band will be used as a metric to also measure an improvement in the brain signal. It is expected that the subject learns to regulate its brainwaves and that this change is visible throughout the sessions.

Additionally, using a webcam, a gaze tracking will be developed to map the points that were most chosen by users to maintain its attention. Also, because a supervised classifier was used to classify the data, there can be a small error when the user is not paying attention to the task (not following instructions), but the computer is labeling this data as *attention*. Therefore, this system will be used in conjunction with the NFB system to make sure that the user is focusing in a certain place/object and thus it can increase the reliability of the data.

The system will also be tested with adults not diagnosed with neuropsychiatric disorders to measure improvement in the performance of their attention.

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