Auxiliary Neurofeedback System for Diagnostic of Attention Deficit Hyperactivity Disorder

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Abstract

This paper describes a neurofeedback system for auxiliary diagnostic of Attention Deficit/Hyperactivity Disorder (ADHD). The design stresses ease of use and modification so that different interfaces can be added, and different signal processing procedures can be implemented as required. An isolated data acquisition system based on the MC68HC908GP32 microcontroller transfers the acquired EEG signals to a PC. The interface and signal processing procedures were implemented using the Labview (National Instruments) virtual instrumentation software. The software calculates the power density spectrum (PDS) of the signals using the Welch PDS estimation method and Kaiser-Bessel windowing functions, to determine the ratio β-EEG/θ-EEG. Two different screen layouts are available for carrying out the tests. A clinical study was conducted on 4 unmedicated young adults suspected of suffering from ADHD. The test consisted of 6 10-minute sessions, divided in two stages of 5 minutes, over a period of 12 days. The results obtained showed an increased β/θ ratio as sessions progressed.

1. Introduction

Neurofeedback, also known as electroencephalogram (EEG) biofeedback is a somatic treatment for Attention Deficit/Hyperactivity Disorder (ADHD). The technique attempts to treat ADHD by increasing the ratio of high-frequency β-EEG activity to low-frequency θ-EEG activity (Rel (β/θ)). Therefore, it is assumed that the ratio β/θ increases as the number of neurofeedback sessions increases so that the patient can then acquire the ability to increase the ratio β/θ at will [2]. Although there is evidence of the use of neurofeedback since the late 1970´s [6] [8], it is in the late 1980´s [7] when the method started to gain worldwide acceptance. Neurofeedback has been used to treat ADHD as well as multiple disorders [3] [12]. One of the most common signal processing methods used for analyzing EEG signals for neurofeedback applications consists of calculating the DFT power spectrum density [15]. Other processing techniques and algorithms [10] [14] include wavelet transforms [16] and Self-Organizing Maps [4].

Despite the wide acceptance of neurofeedback for the treatment of ADHD, there are researchers that favor the use of other courses of treatment [5]. In addition, the vast majority of reported work focuses on ADHD diagnostic and treatment for children. However, the increasing number of adults affected by ADHD is recognized [1]. Some of the factors that may be associated with ADHD in modern life conditions are familial issues and *stress-related* diseases. Thus, there is the need for auxiliary equipment for *non-pharmacuetical* studies that facilitates the diagnostic and identification of appropriate course of treatment for environmental and *work-related* neurological disorders [9].

The equipment described in this work was developed in response to a request from the *Centro Integral de Atención Neuropsicopedagógica de Michoacán* (Spanish for *Neuro-psychopedagogical Attention Center of Michoacán*) to develop a neurofeedback system to aid the diagnostic of ADHD. The neurofeedback system was required to comply with a number of specifications. First, the equipment must include an auto-calibration function and meet electrical safety requirements. The software has to provide temporal and frequency domain information of the recorded EEG data for the analyst to review. An intuitive interface must be provided for both the patient and analyst. In addition, the software has to be easily modified to include different graphical interfaces and signal processing analysis procedures.

2. Data Acquisition hardware

Fig. 1 shows the block diagram of the data acquisition system. A *three-electrode* EEG measurement strategy is used. The measured signals are *pre-amplified*, filtered and transferred to the digitizing section of the circuit through isolation amplifiers.

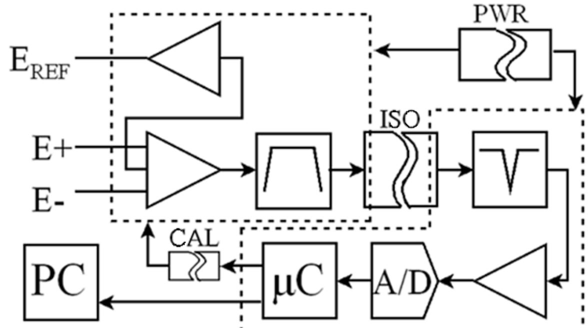

Fig. 1 Block diagram of the data acquisition circuit.

A 60Hz notch filter is used to reduce the mains noise. Later the measured signals are digitized using a 12-bit analog to digital converter. An MC68HC908GP32 microcontroller is used for controlling the measurement process and producing synchronization and calibration signals. An isolated power supply provides energy to both sides of the circuit. Data is serially transmitted to a PC.

3. Safety considerations

Before the equipment is tested on patients, measurements were taken under different *single-fault* and normal operating conditions. The equipment was considered safe if, at least, minimal NFPA 99 leakage current specifications are met:

***A.*-** Patient to Ground (isolated): ≤10μA (GND intact)
***B.*-** Patient to Ground (isolated): ≤50μA (GND open)
***C.*-** Between Leads (isolated): ≤10μA (GND intact)
***D.*-** Between Leads (isolated): ≤50μA (GND open)
***E.*-** Between Leads (non-isolated): ≤50μA (GND intact or open).

The circuitry enclosure was placed on an isolated surface (rubber over wood) 3 meters away from any earthed surface. Leakage current measurement equipment was located 40 cm away from unscreened power cables. Measurements were carried out on all possible combinations using a 6 ½ digit meter.

For *ground-intact* tests, the largest leakage current measured was 8.02 μA, between the reference electrode terminal and the mains ground. For *ground-open* tests the largest leakage current registered was 30.15 μA between the reference electrode terminal and the mains ground. Both measurements are within the safety specification values (10μA and 50μA respectively) and thus, pending corroboration from a certified laboratory, the equipment was considered safe.

4. Power Density Spectrum Calculation

The power spectrum calculation method used in this work is based on the Welch method [11]. EEG data is sampled at 256 samples per second (SPS) until a set of N (1024) points has been acquired. The discrete Fourier Transform of the recorded data is calculated as described elsewhere [13]. Data sets of 256 measurements are 50% overlapped in the register and windowed using the Kaiser-Bessel windowing function w(n) (1):

$$\boldsymbol{w(n)} = \frac{\boldsymbol{I_O \beta_W} \sqrt{\mathbf{1} - \left(\frac{\boldsymbol{2n}}{\boldsymbol{N-1}}\right)^{\mathbf{2}}}}{\boldsymbol{I_O \beta_W}} \qquad (1)$$

where Io is the modified zero-order Bessel function, N is the number of points in the data set, and β_W corresponds to the attenuation factor at the boundaries of the data set. The modified periodograms are then calculated by (2):

$$\mathrm{P(k)} = \frac{1}{\mathrm{MU}} \left[\sum_{n=0}^{\mathrm{M-1}} \mathrm{x(n)\,w(n)}\, e^{\left(-\frac{2j\pi nk}{N}\right)} \right]^2 \qquad (2)$$

where M is the number of points in each L data set and U is the normalizing factor (3):

$$\boldsymbol{U} = \frac{\mathbf{1}}{\boldsymbol{M}} \sum_{n=0}^{M-1} \boldsymbol{w^2(n)} \qquad (3)$$

The power density spectrum is calculated by (4):

$$\boldsymbol{E}\left[\boldsymbol{P^{WE}(k)}\right] = \frac{\mathbf{1}}{\boldsymbol{L}} \sum_{J=0}^{L-1} \boldsymbol{P_J(k)} \qquad (4)$$

Each time a data set is acquired, the oldest data set is replaced and calculation of the PDS is repeated. The program updates every 3 seconds approximately.

5. Software Interface

The interface and signal analysis procedure were implemented in Labview. The program outputs sounds through the sound card if required, and displays visual events related to β-EEG/θ-EEG activity. In addition, the interface provides temporal and frequency information for the therapist to review. Two graphical interfaces are available (Fig. 2).

The dolphin scenario (Fig. 2A) begins with a dolphin at the bottom of the screen. Fishes move from right to left at the top of the screen. If the measured β-EEG/θ-EEG ratio exceeds a predetermined threshold level the program responds by moving the dolphin towards the region where the fishes are. If the attention level is maintained, so that the dolphin intercepts a fish, the program generates an animation displaying the *fish-catching* event.

The car race interface (Fig. 2B) provides a measure of the attention level by means of a circular speed gauge. Initially, both cars are located at the bottom of the screen. If the ratio β-EEG/θ-EEG is maintained the *patient-controlled* car (left car) moves forward. Both scenarios are accompanied by sound effects if desired.

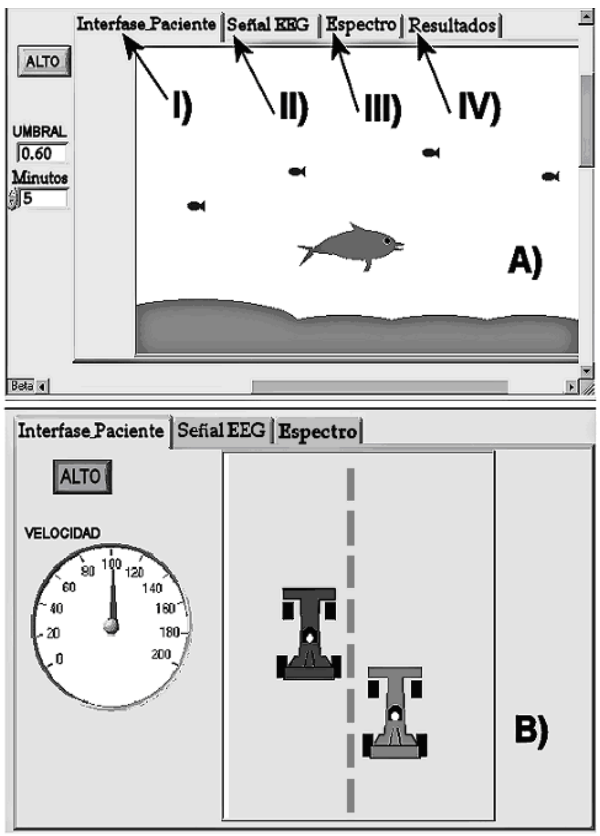

Fig. 2 Graphical interface of the neurofeedback system. A) A dolphin catching fishes and B) racing cars. Selection tags: AI) Patient interface, AII) EEG signal plot, AIII) spectrum plot and AIV) test results.

The program also provides information for the therapist: temporal information, frequency data and a record of the session results (Fig. 3).

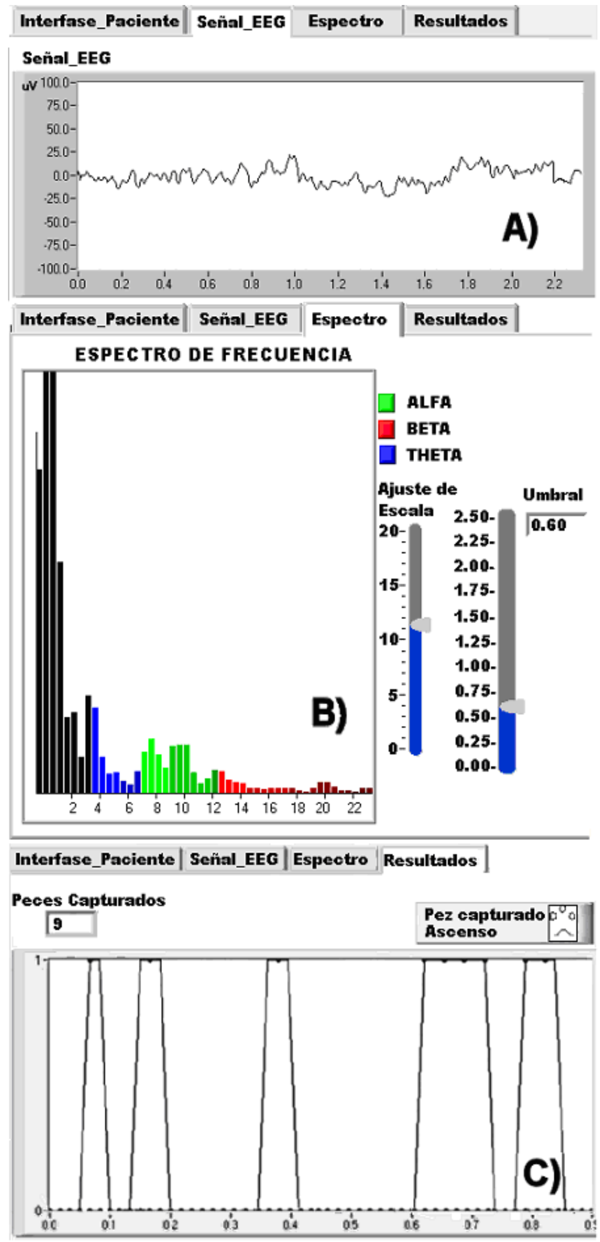

Fig. 3 Screen capture of results obtained using the dolphin interface. A) temporal information over a 3 second period, B) spectrum density and C) session results.

6. Clinical Study

A clinical study was conducted at the *Neuro-psychopedagogical Attention Center of Michoacán*. Four unmedicated adults (3 Male, 1 Female), suspected of suffering from ADHD were referred to use the equipment. The average age of the test group was 25 years-old. The threshold level was determined at the beginning of the first session for each patient. Each session consisted of two 5-minute stages with a 3-minute resting interval in between. The sessions were conducted over a 12-day period. Table 1 shows a summary of the results obtained from using the dolphin interface.

Table 1. Summary of the results for 4 patients (3 Male, 1 Female)

SESSION	1		2		3		4		5		6		TL
Period	1°	2°	1°	2°	1°	2°	1°	2°	1°	2°	1°	2°	
M1	4	15	5	13	3	12	12	14	9	7	12	19	0.60
M2	1	9	5	12	11	15	14	12	3	10	16	4	0.61
M3	1	11	7	22	15	7	14	21	5	14	11	4	0.53
F1	3	7	4	2	4	11	9	13	16	11	13	15	0.55

In all cases, the results indicate that, as patients learn to operate the interface, the number of fishes caught is increased as sessions progressed. The result is consistent with healthy patients. Patients were referred to social services and further evaluation instead of receiving prescription medication.

7. Conclusions

Throughout this work, the design and construction of a neurofeedback system, auxiliary equipment for the treatment of Attention Deficit\Hyperactivity Disorder was described. The design stresses ease of use for both the patient and analyst. The equipment can be easily modified so that different visual interfaces can be included. In addition, other signal processing methods can be included without altering the overall design.

The equipment was tested on four young adults suspected of suffering ADHD. The results were consistent with healthy patients. Thus the patients were referred to social services and further evaluation without prescribing medication. This could have important implications in the quality of life of suspected patients, whereby the equipment can contribute to taking the appropriate course of treatment.

6. References

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