Bioelectrical markers of ADHD: enhancement of direct EEG analysis

Ramón Martín-Brufau[1], Manuel Nombela Gómez[2]

[1] Métodos de Investigación y Diagnóstico en Educación. Universidad de Murcia, Murcia.
[2] Servicio de Apoyo a la Investigación. Universidad de Murcia, Murcia.

España

Correspondencia: Ramón Martín-Brufau Dpto. MIDE. Facultad de Educación. Campus de Espinardo. Murcia. España. E-mail: r.martinbrufau@um.es

Ramón Martín-Brufau, Manuel Nombela Gómez

Abstract

Introduction. So far some methods to help diagnosis of ADHD grounded in EEG decomposition by the FFT method and the discovery of the relationship between different frequency bands, the most clarifying the TBR rate in the prefrontal regions, have been proposed. This procedure requires a complex gadgetry so we evaluate the advantages of a simple model based on the visual inspection of the EEG tracing presented in an ad hoc method.

Method. In order to compare the accuracy of three diagnostic methods of detection of ADHD against normal individuals based on EEG, the ROC curves were calculated. Three methods were compared: a) the Theta/Beta Ratio (TBR) method after decomposition with the Fast Fourier Transformation (FFT), b) the Delta + Theta / Alpha index obtained by visual position decomposition-Verley method and c) the direct analysis of EEG specific montages performed by untrained individuals in EEG interpretation.

Result. Individuals with ADHD were diagnosed correctly using automatic procedures studied (92.9% of discriminatory capacity by TBR method and 91.7% by the Verley visual method). In addition, 55.5% of not trained individuals were able to discriminate the ADHD from normal cases with a diagnostic accuracy similar to the automated methods (discrimination index 86.8%).

Conclusion. ADHD has a specific EEG pattern that can be easily recognized by the proposed EEG montages. These preparations allow to highlight the richness of Theta and Beta frequencies in the selected regions with a low cost and an adequate diagnostic accuracy, even for subjects without prior training in interpreting the EEG tracing. This fact supports the use of the EEG as a complementary measure in the early diagnostic of ADHD.

Key words: ADHD, EEG, Diagnostic, Education.

Resumen

Introducción. Hasta el momento se habían propuesto métodos de diagnóstico del TDAH fundamentados en la descomposición EEG por el método FFT y el hallazgo de la relación entre distintas bandas de frecuencia, siendo la más aclaratoria la tasa TBR en las regiones prefrontales. Este procedimiento exige un aparataje complejo por lo que se evaluaron las ventajas de un método sencillo basado en la inspección visual del trazado EEG presentado de forma *ad hoc*.

Método. Mediante el cálculo de las curvas ROC, se comparó la precisión de tres métodos diagnósticos de TDAH, frente a trazados de individuos normales, basados en EEG: a) el método TBR tras descomposición FFT; b) el índice delta+theta/alpha obtenido por descomposición visual por el método de Verley; c) los análisis directos del EEG con montajes específicos realizado por individuos no entrenados en interpretación EEG.

Resultado. Los individuos con TDAH fueron diagnosticados correctamente mediante los procedimientos automáticos estudiados (capacidad discriminatoria del 92,9% según método TBR y 91,7% según método visual de Verley). Además, un 55,5% de los individuos no entrenados consiguieron distinguir los casos TDAH y los normales con una precisión diagnóstica similar a los métodos automáticos (índice de discriminación del 86,8%).

Conclusión: El TDAH tiene un patrón de EEG propio que puede ser fácilmente reconocible mediante los montajes EEG propuestos. Dichos montajes permiten resaltar las riquezas Theta/Beta de las regiones seleccionadas con un coste bajo y una precisión diagnóstica adecuada, incluso para sujetos sin entrenamiento previo en la interpretación del trazado EEG. Este hecho apoya el uso del EEG en la detección temprana del TDAH.

Palabras Clave: TDAH, EEG, Diagnóstico, Educación

Ramón Martín-Brufau, Manuel Nombela Gómez

Introduction

ADHD is a síndrome caused by a maduration déficit in the basal frontal lobe, according to the available evidence (Sarnthein, Morel, Von Stein, y Jeanmonod, 2005; Saunders y Westmoreland, 1979). It has a prevalence rate of 5-7% in childhood (Willcutt, 2012) and produces behavioral and learning deficits that interfere with the normal development of the individuals who suffer from it. Since the inhibition deficit at inhibiting their own behavior and maintaining attention in an external stimulus, a requirement that is predominant in classroom tasks, forces the student to a great adaptation effort, which is not always successful, as a consecuence, their management in classrooms difficult for teachers. This problem also often occurs at home and hinders the normal process of socialization and adoption of social norms. Thus, both academic and interpersonal demands can be altered; something, teachers and parents tend to agree on. It is known that if they are medicated from a moment near the beginning of the syndrome, the probability of falling into alcohol or drugs and antisocial behaviors decreases by 60-70% (Sweeney, 2009). In the case of adult with ADHD, the lack of attention, their tendency to cognitive fatigability and lack of consistency, interferes with the learning of complex tasks and forces them to be continuously changing their job, which makes their socialization harder, besides academic problems. Their antisocial behavior and their passage to more serious psychiatric forms are frequent, especially in relation to the consumption of drugs. Therefore, a quick and cheap diagnosis would facilitate the treatment from the initial moments of the process.

Another added difficulty to the correct identification of ADHD patients lies in the lack of reliability and validity of the assessment instruments normally used for school guidance and clinical diagnosis. Besides, these are not fully objective nor specific methods for the detection of organic pathology of the central nervous system. These are difficulties taht education proffesionals, parents and society have to face. So far the diagnosis was clinical and the Food and Drug Administration (FDA) and American Association of Neurology recommended that it should be performed by a multidisciplinary team, consisting of Neuropaediatricians, Psychologists and Child Psychiatrists, since it can be caused by multiple causes and overlap with similar symptomatologies originated by other pathologies, which made the process costly both in time and money. In this search, some researchers have proposed to use the electro-encephalogram (EEG) for the diagnosis of ADHD, since it has certain characteristics to make

it a reliable measure of the cerebral activity, given its relation with the cortical functioning and the oscillations of the electric fields caused by the activity of synaptic populations. (Epstein, Bej, y Foldvary-Schaefer, 2006; Moore y Puri, 2012; Snyder, Rugino, Hornig, y Stein, 2015).

Recently, bioelectrical markers extracted from the EEG have been proposed to be capable of identify and distinguish ADHD cases from other disorders of similar or overlapping syntomatology, and do so whith a high discriminative capacity. With the simple analysis of the power spectrum of the frequency bands, measured with FFT on the simultaneous recording electrodes, Magee et al., (Magee, Clarke, Barry, McCarthy, y Selikowitz, 2005), using standard statistical procedures (cluster and regression analysis), obtained a diagnostic sensitivity of 89%, with a specificity of 79.6%. Poil, with a similar procedure, achieved a diagnostic accuracy of 67%, with a reliability of 83% in adults (Poil et al., 2014). Other authors have proposed the Theta / Beta, Theta Beta Ratio (TBR) ratio of frontopolar regions and the frontal midline, which is increased in cases of ADHD but lower than 1 in normal cases, as indicated by Rudo- Hutt (Rudo-Hutt, 2015) and Snyder (Snyder et al., 2015), that is why this calculation is considered as a biomarker for the quick ADHD diagnosis in children with compatible symptomathology. With TBR and coherence data, algorithms are created that reach a level of accuracy of 76% in the discrimination of the normal and ADHD patients EEG, and the 81% if we add age, according to Helgadóttir (Helgadóttir et al., 2015).

Objectives and hypotehsis

However, compared to direct visual analysis of EEG, these procedures, requiere a very sofisticated equipment, that are not always available for the usual neurofisiologic services. According to our experience, certain predetermined presentations of the EEG records, allow a quicker and easier identification, if bipolar montages with no more thatn 5-10 channels per epoch are displayed. The objective of this study is to compare different methods of ADHD discrimination based on the computerized EEG.

Method

Participants

This work studied two different samples of subjects. The first sample is constituted by 50 EEG subjects records from between 6 and 15 years, they were matched by sex; 30 had

typical ADHD symptomathology and 20 were normal subjects without ADHD symptomathology that were recorded between years 2005 and 2010, in the Service of Neurophysiology at the General Hospital Santa Mª del Rosell of Cartagena (Spain). That study was approved by ethical commite of the aforementioned hospital. The ADHD subtype was not specified (hiperactive or innatentive) in the sample. First, because this is a retrospective study and many of the cases were not classified following ADHD subtypes. Second, because the study's objective was to fast screen posible ADHD cases, and only then filiate the subtypes, because, as far as we know, EEG has not yet been used for that differentiation.

A second sample was colleted in order to compare a third diagnostic method, which will be further described. For this method, subjects without previous experience in the interpretation of EEG and the clinical diagnosis of ADHD were collected. A total of 21 first grade students of Speech therapy voluntarily performed the diagnostic test based on EEG records. Demographic data of the second sample can be found in Table 1.

Table 1. *Descriptive characteristics of the naive testers sample*

	Mean (range) / frequency (%)
N	21
Age	34,3 years (25-71)
Gender	
Men	14 (66,7%)
Women	7 (33,3%)
Profession	
Non qualified	5 (23,8%)
Engineering	3 (14,7%)
Education/ Teaching	2 (9,5%)
Economy/Business	7 (33.0%)
Management/office worker	4 (19.0%)

Measures

EEG recodings have a duration of 20 seconds, a 1-32 Hz bandpass, and the frequencies used for FFT decomposition were between 1-40 Hz, with a slope less than 40 Hz and with a sampling frequency of 250 Hz. None of these cases had expressive sings of epileptogenic potentiality. These recordings were obtained at rest, with eyes closed and were free of artifacts. They were analyzed by the authors using two methods of frequency decomposition and by a set of subjects with no EEG reading experience through direct visual recognition with an ad hoc montage.

Procedure

The three methods are detailed below:

A) *Fast Fourier Transformation series decomposition* of each of the classical EEG frequency bands (delta, theta, alpha and beta) in each of the cases analyzed and calculating the rate between theta and beta (TBR) rhythms.

b) *Visual decomposition of the frequency richness* of the recordings using the visual method proposed by *Verley* (Verley, 1967) And the calculation of the Delta + Theta / Alpha quotient in the prefrontal derivations of the same.

c) In order to evaluate the expressive capacity of the bipolar EEG tracings, proposed by the authors, we asked a sample of subjects with no prior experience in the EEG interpretation to visualize, 10 seconds of tracing 10 individuals with ADHD symptomatology and 10 traces of normal subjects in the computer. The recordings were randomly presented using a montage consitent of an eight-channel bipolar assembly showing the scalp anterior and posterior regions of the study subject (images 1 and 2 show two recording samples of an individual with ADHD and a normal one). These naive subjects were asked if they had previous EEG reading experience. Five subjects were discarded because the answers were incomplete and this prevented calculating the accuracy rate. None of them had experience in EEG as evidenced by their respective occupations and their answers.

The answers were automatically registered through a computerized application of a web form where the images of the recordings were presented and asked to select whether it was a normal case or ADHD. The subjects previously visualized two examples of normal recordings and two examples of recordings with ADHD, in images similar to those shown in Figures 1 and 2. Subsequently, the presentation began after accepting their express consent. In addition, only during the first five slides, subjects were given the correct choice after their selection in order to provide feedback on their response. When the subjects finished identifying the recordings, they were informed, through the application, of the completion of the test. In addition, a scale of 1 to 10 was included at the end of the test to indicate the subjective difficulty of the task.

Statistical analysis

In order to compare the means between the percentages of the different frequency bands obtained with the first two procedures (automatic and visual, Verley) and the TBR and Delta + Theta / Alfa indices for EEG for ADHD and normal subjects non parametric tests were employed. The Kruskal-Wallis test for independent samples, considering $p < .05$ as significant was calculated. For the calculation of the diagnostic accuracy, the ROC curves were obtained for sensitivity and specificity of each of the methods. The response types were extracted and the Sensitivity / Susceptibility $S = VP / (VP + FN)$ and Specificity $E = NP / (FP + NP)$ (Pepe, 2003). The discriminant capacity, following the ROC curve analysis of each procedure, was calculated using the formula: Sensitivity - (1-Specificity) (see Pepe for a review, 2003). SPSS v.21 was used for these analyzes. See Table 2.

Table 2. *Possible responses when trying to discriminate an ADHD from Normal cases*

Answer	TDAH	Normal
It is ADHD (Affirmative)	Hit (VP)	False Hit (FP)
It is not ADHD (Negative)	Miss (FN)	Correct Rejection (VN)

Results

Subjects with ADHD presented a higher Theta / Beta ratio than the normal cases (Table 3). Differences in theta richness in the fronto-prefrontal regions of ADHD cases and normal cases were found. Cohen's d was also calculated with a magnitude of $d = 2.00$. This indicates a size of the high effect on the theta band in cases of ADHD. When comparing the TBR index, the effect size was of also of high magnitude (Cohen's $d = 1.69$) for TBR in ADHD (according to Cohen's interpretation criteria (1969) a Cohen's d value greater than 0.8 is High magnitude). See Table 3.

Table 3. *Mean differences calculated by K-W test between FFT decomposition and the Theta/Beta ratio (TBR) for ADHD and Normal cases*

	TDAH X (s.d.)	Normal X (s.d.)	K-W	p
Delta	16,81 (3,25)	10,48 (1,76)	12,063	.001***
Theta	34,31 (5,98)	25,13 (2,45)	8,836	.003**
Alpha	23,51 (2,8)	27,98 (5,26)	2,727	.099
Beta	29,39 (3,59)	40,82 (5,73)	10,925	.001***
Theta/Beta	1,16 (0,26)	0,61 (0,38)	10,363	.001***

Note: ***p<.01; ***p<.001*

Using the TBR as a diagnostic indicator and using the cutoff value = 1, two groups were obtained: a) <1 for normal and b) > 1 for ADHD. The discrimination coefficient proved to be very effective, separating the cases of ADHD from the Normal ones with a success rate of 92.9% (Discrimination coefficient = .929; p <.003).
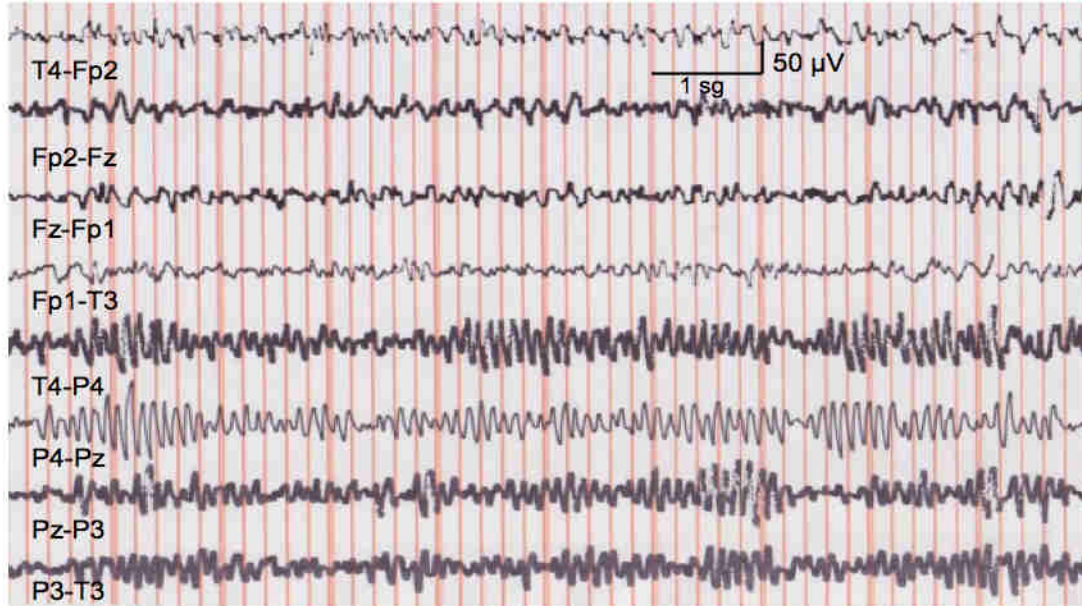

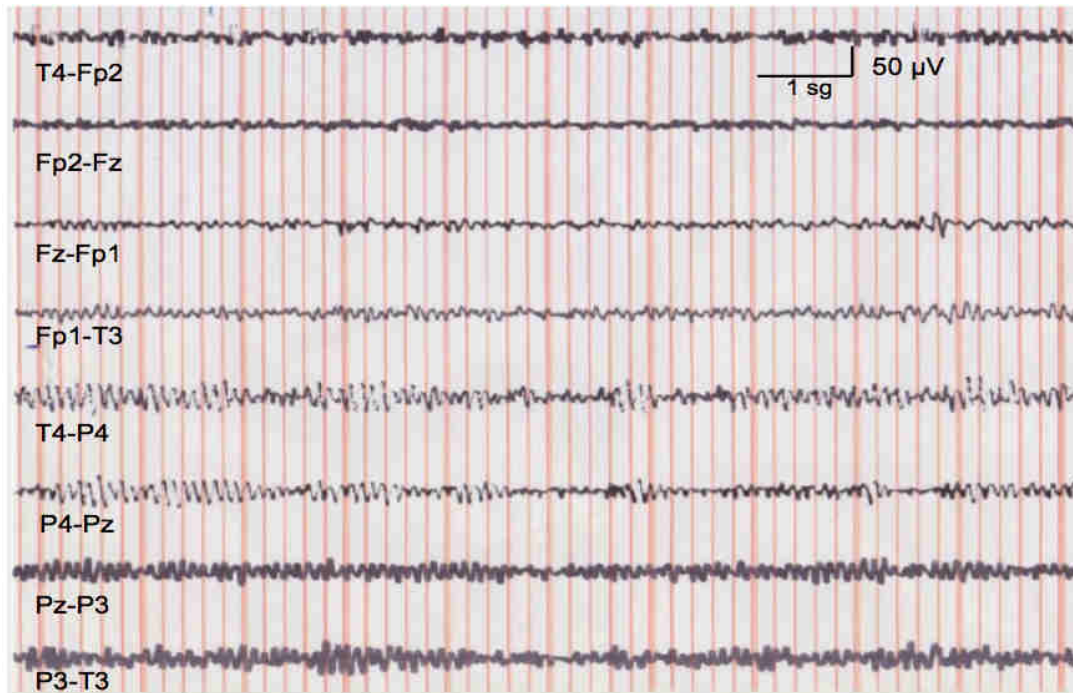Figure 1. *EEG recording of a 9 year old ADHD patient*

Figure 2. *EEG recording of a 7 years old normal subject*

We calculated the percentages of richness of the different frequency bands in the fronto-polar derivations analyzed by the visual procedure, according to Verley's temporal technique (Table 4). The Beta rhythm appears so scarce because it is very difficult to identify the times in which it is dominant, since it generally appears overimposed to other slower activities that are dominant with the naked eye. As in the FFT discrimination procedure based on FFT, Verley's visual analysis showed that the richness of slow waves (delta + theta) in the fronto-central regions was much higher in the cases of ADHD (*Cohen's d* = 2.05). The ROC curve calculation of the Alpha and Delta + Theta rhythm richness through the quotient for the identification of ADHD vs. Normal, yielded a significantly discriminatory capacity of 91.7% (*Discrimination coefficient* = 0.917, *p* < .016).

Tabla 4. *Mean differences between Verley direct visual method and the Delta+Theta/Alfa for ADHD and Normal cases*

	TDAH X (s.d.)	Normal X (s.d.)	U M-W	p
Delta+Theta	56,8 (16,88)	26,58 (14,31)	2,402	.015*
Alpha	7 (4)	63,33 (15,12)	-2,934	.002**
Beta	14,2 (13,06)	10,08 (3,8)	0,242	ns
Delta+Theta/Alpha	8,11 (0,21)	0,42 (3,31)	-2,882	.002**

Note: *p*<.05; **p*<.01

Regarding the discriminative capacity of the global visual test for the naive subjects without previous experience, we found different results depending on the perceived difficulty. A 55.5% of the naive subjects who showed a low level of difficulty in discriminating between the cases / controls were 86.6% (*Discrimination coefficient* = 0.868, *p* < .01). While the rest reached a discrimination index of 0.726 that was not significant (*p* > .05). The comparisons of the discrimination indices for the three methods are shown in Figure 4. It can be noticed that the sensitivity or susceptibility of detection of a case of ADHD is greater in the direct global visual test of the tracing than the automated calculation method of Theta / Beta. Frequency band analysis procedures (both FFT and visual) proved to have a more specific discrimination profile, while the overall visual diagnosis of subjects with no experience was more sensitive to ADHD cases. In summary, we found that direct visual procedures are capable of detecting ADHD cases with typical clinical practice, even by a group of subjects without previous training.

Discussion and conclusion

In classrooms, teachers and counselors often find children from whom they suspect they might have psychoeducational alterations beyond normal difficulties. Differentiating those cases that could improve with an educational intervention alone from those who need complementary treatment (psychological, medical, etc ...) is overdemanding for the educator, more oriented to teaching. In addition, in the case of ADHD, the diagnostic difficulties, so evident in the literature, require a more precise screening compared to other more manageable alterations in the educational environment. Our results offer a fast, EEG-based screening method that promotes referral to multidisciplinary teams and can shorten the time from the detection of the psycho-educational problem to the begining of treatment.

As Moore and Puri point out in their book "Texbook of Clinical Neuropsychiatry and Behavioral Neurosciences" (Moore & Puri, 2012), The interpretation of an EEG is far from intuitive. While some knowledge of Neuroanatomy makes it easy to understand an MRI or CT scan, understanding the EEG, as well as the EKG, requires a certain degree of preparation, since, as Epstein points out, EEg recordings requiere both correct registration and appropiate presentation (C. Epstein et al., 2006). Taking these facts into account, plus the verification that depending on the region in which they appeared specific visual preparation of the recordings facilitated the recognition of rythm abnormalities, we had to admit the utility of the proposed bipolar montages, with few derivations by derivation, allowing global visual recognition in the EEG recordings in cases of probable ADHD syndrome. This can be made easily and cheaply, since it does not need more apparatus than the simple electroencephalograph. This idea is supported by Snyder who, in a work published in "Brain and Behavior", suggested that the EEG could be of help in the diagnosis of ADHD (Snyder et al., 2015).

The fact that an important number of people without previous knowledge of electroencephalography and even medical knowledge were able to identify ADHD cases, with only a discreet information on what the task requested and through the Internet, shows that the presentations are clear enough and the cases of ADHD differ from the normal ones. It also makes clear that the mere knowledge of the bioelectrical manifestation of the syndrome is enough to suspect its presence in a subject, given that it has a concrete structure that is manifested by the excess of theta activity and by a deficit of rapid rhythms specially in fronto-polar regions. Snyder et al. (Snyder et al., 2015) found an average increase of 32% of the frontal

theta rhythm in subjects with ADHD compared to the activity of normal subjects, and in line with our data, these authors found a high magnitude difference (Cohen d = 1.53). A similar increase in theta rhythms in a previous review study analyzing a total of 1498 cases of ADHD compared to normal, was also found (Cohen's d between 1.14-1.48) (Snyder Y Hall, 2006a). In our study, we found differences of similar magnitude (Cohen's d = 2.00) for the TBR method and for the visual decomposition method of the EEG recording using the Delta + Theta / Alpha index (Cohen's d = 2.05). Notice that all the results point in the same direction.

Under normal conditions, the richness of frontal beta activity is usually higher than that of theta activity. As a consecuence, the TBR ratio is usually less than one. However, in the ADHD syndrome it is always greater than one and the higher the ratio the more significant. Therefore, the TBR has to be considered as a true biomarker. The cases of similar clinic, with a TBR ratio above the normal (TBR <0.7) but low in relation to the most significant cases (admission limit for ADHD = 0.98) (normal mean + 1.5 SD normal) (Monastra, Lubar, Y Linden, 2001), usually have a clinical symptomatology comorbid to the typical ADHD, which is best explained by other psychiatric or neurological pathologies (criterion E of the DSM)(Daley, 2004; Mirsky Y Duncan, 2001; Snyder et al., 2015; Zametkin et al., 1990). This means that the cases selected by the bioelectrical method must be recognized by a multidisciplinary clinical team as indicated in the introduction. In addition, there is a group of ADHD clinical syndromes that have normal EEG and only manifest the clinical symptomps. These can only be diagnosed by clinical study. At present, they represent between 16 and 18% of the prevalence of ADHD (Loo Y Makeig, 2012), for this reason EEG research continues in this syndrome in order to find faster and more reliable algorithms than the current ones.

In our case, for children with typical clinical presentation, we obtain a discrimination index using the automatic TBR of 92%, which is similar to other studies reviewed by Loo (Loo Y Makeig, 2012) which range between 63% to 97% and between 61 y el 88 %, according to another meta-analysis review (Snyder Y Hall, 2006b). With the direct visual method (Verley), we obtain a discrimination index of 91.7%, calculatin the ation between slow activity (delta+theta) and alpha activity. This may be suggesting that the (Theta+Delta)/Alpha index as calculated by the authors is a reliable method for the selection of posible ADHD cases and does not requiere any additional instrument apart from the EEG recording device.

The correct treatment is very important to be successful with the integration of these patients in society. However, in the history of patients of this type there are often large dis-

crepancies between the observations of parents and teachers, which is completely understandable. That is why an objective biomarker is currently considered to be very useful. For all these reasons, in all Western societies, an alternative easy, safe and cheap method for diagnosis is being explored to diagnose and treat these patients as early in their life as possible. According to our results, although it is more accurate to have serial decomposition and calculation of the TBR of the prefrontal region, the EEG test can be directly evaluated if the appropriate montages are used, speeding up the detection of ADHD cases.

This study presents some limitations that must be considered when interpreting the results. First, the division into subtypes of ADHD was not taken into account. The reason was that this study focused on frontal lobe defects, which according to the previously mentioned research form the common nucleus that characterizes the disorder under study. In addition, at the moment, work with sufficient reliability is not known to demonstrate that a differentiation in EEG-based subtypes is possible. A second limitation is that the screening has not been correlated with the information extracted from the neuropsychological tests normally used for the diagnosis. However, this was not the intention of the study, but rather the comparison between different EEG-based diagnostic procedures, so that the correlation between bioelectrical activity and cognitive function, evaluated through such tests, should be studied in future work. Also, future work should be directed to apply this type of techniques in the school population in order to identify those individuals at risk of ADHD. We intend, in collaboration with educators, to organize a system for detecting the possible existence of ADHD, which would consist primarily of recognizing a learning and / or behavioral defect with parent and / or teacher observations and, secondly, If this first screening is positive, it would allow the rapid inspection by the center's counselor team and its referral to the neurophysiology service for a more accurate diagnosis, and referral, if appropriate, to a multidisciplinary treatment team for its treatment.

References

C. Epstein, M. Bej, Y N. Foldvary-Schaefer. (2006). Guideline 1: Minimum technical requirements for performing clinical electroencephalography. *Journal of Clinical Neurophysiology:* Official Publication of the American Electroencephalographic Society, 23(2), 86. https://doi.org/10.1097/00004691-200604000-00002

Daley, K. C. (2004). Update on attention-deficit/hyperactivity disorder. Current Opinion in Pediatrics, 16(2), 217–226. https://doi.org/10.1097/00008480-200404000-00020

Helgadóttir, H., Gudmundsson, Ó. Ó., Baldursson, G., Magnússon, P., Blin, N., Brynjólfsdóttir, B., … others. (2015). Electroencephalography as a clinical tool for diagnosing and monitoring attention deficit hyperactivity disorder: a cross-sectional study. BMJ Open, 5(1), e005500. https://doi.org/10.1136/bmjopen-2014-005500

Loo, S. K., Y Makeig, S. (2012). Clinical utility of EEG in attention-deficit/hyperactivity disorder: a research update. Neurotherapeutics, 9(3), 569–587. https://doi.org/10.1007/s13311-012-0131-z

Magee, C. A., Clarke, A. R., Barry, R. J., McCarthy, R., Y Selikowitz, M. (2005). Examining the diagnostic utility of EEG power measures in children with attention deficit/hyperactivity disorder. Clinical Neurophysiology, 116(5), 1033–1040. https://doi.org/10.1016/j.clinph.2004.12.007

Mirsky, A. F., Y Duncan, C. C. (2001). A nosology of disorders of attention. Annals of the New York Academy of Sciences, 931(1), 17–32. https://doi.org/10.1111/j.1749-6632.2001.tb05771.x

Monastra, V. J., Lubar, J. F., Y Linden, M. (2001). The development of a quantitative electroencephalographic scanning process for attention deficit–hyperactivity disorder: Reliability and validity studies. Neuropsychology, 15(1), 136. https://doi.org/10.1037//0894-4105.15.1.136

Moore, D. P., Y Puri, B. K. (2012). Textbook of Clinical Neuropsychiatry and Behavioral Neuroscience 3E. CRC Press. https://doi.org/10.1201/b13258

Pepe, M. S. (2003). The statistical evaluation of medical tests for classification and prediction. Oxford University Press. https://doi.org/10.1002/sim.2185

Poil, S.-S., Bollmann, S., Ghisleni, C., O'Gorman, R. L., Klaver, P., Ball, J., … Michels, L. (2014). Age dependent electroencephalographic changes in attention-deficit/hyperactivity disorder (ADHD). Clinical Neurophysiology, 125(8), 1626–1638. https://doi.org/10.1016/j.clinph.2013.12.118.

Rudo-Hutt, A. S. (2015). Electroencephalography and externalizing behavior: A meta-analysis. Biological Psychology, 105, 1–19. https://doi.org/10.1016/j.biopsycho.2014.12.005.

Sarnthein, J., Morel, A., Von Stein, A., Y Jeanmonod, D. (2005). Thalamocortical theta coherence in neurological patients at rest and during a working memory task. International Journal of Psychophysiology, 57(2), 87–96. https://doi.org/10.1016/j.ijpsycho.2005.03.015.

Saunders, M. G., Y Westmoreland, B. F. (1979). The EEG in evaluation of disorders affecting the brain diffusely. Current Practice of Clinical Electroencephalography, 370–371.

Snyder, S. M., Y Hall, J. R. (2006a). A meta-analysis of quantitative EEG power associated with attention-deficit hyperactivity disorder. Journal of Clinical Neurophysiology: Official Publication of the American Electroencephalographic Society, 23(5), 440–455.

Snyder, S. M., Y Hall, J. R. (2006b). A meta-analysis of quantitative EEG power associated with attention-deficit hyperactivity disorder. Journal of Clinical Neurophysiology, 23(5), 441–456. https://doi.org/10.1097/01.wnp.0000221363.12503.78.

Snyder, S. M., Rugino, T. A., Hornig, M., Y Stein, M. A. (2015). Integration of an EEG biomarker with a clinician's ADHD evaluation. Brain and Behavior, 5(4). Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/brb3.330/full

Sweeney, M. S. (2009). Brain: The Complete Mind: how it Develops, how it Works, and how to Keep it Sharp. National Geographic Books.

Verley, R. (1967). Les secteurs d'activité électro-corticale. Leur développement post natal. Regional Develop] Ent of the Brain in Early Life, Blackwell, Oxford, 367–394.

Willcutt, E. G. (2012). The prevalence of DSM-IV attention-deficit/hyperactivity disorder: a meta-analytic review. Neurotherapeutics, 9(3), 490–499. https://doi.org/10.1007/s13311-012-0135-8.

Zametkin, A. J., Nordahl, T. E., Gross, M., King, A. C., Semple, W. E., Rumsey, J., … Cohen, R. M. (1990). Cerebral glucose metabolism in adults with hyperactivity of childhood onset. New England Journal of Medicine, 323(20), 1361–1366. https://doi.org/10.1016/0006-3223(92)90515-2.

Intentionally blank page