

Wavelet Transform as a Helping Tool During EEG Analysis in Children with Epilepsy

Salko Zahirovic¹, Samir Avdakovic², Feriha Hadzagic-Catibusic³, Nedis Dautbasic², Maja Muftić Dedovic², Enra Suljic⁴, Haso Sefo¹, Ibrahim Omerhodzic¹

¹Department of Neurosurgery, Clinical Center University of Sarajevo, Bosnia Herzegovina

²Faculty of Electrical Engineering, University of Sarajevo, Bosnia Herzegovina

³Pediatric Clinic, Clinical Center University of Sarajevo, Bosnia Herzegovina

⁴Department of Neurology, Clinical Center University of Sarajevo, Bosnia Herzegovina

Corresponding author: Salko Zahirovic, MD, MSc. Ul. Bolnicka 25, Sarajevo 71000 Bosnia and Herzegovina. Phone +387 33 298 529. Fax +387 33 297 820. E-mail: salkozahirovic@gmail.com. ORCID ID: <http://www.orcid.org/0000-0002-5325-6961>.

doi: [10.5455/aim.2021.29.104-107](https://doi.org/10.5455/aim.2021.29.104-107)

ACTA INFORM MED. 2021 JUN 29(2): 104-107

Received: May 22, 2021

Accepted: Jun 27, 2021

© 2021 Salko Zahirovic, Samir Avdakovic, Feriha Hadzagic-Catibusic, Nedis Dautbasic, Maja Muftić Dedovic, Enra Suljic, Haso Sefo, Ibrahim Omerhodzic

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

ABSTRACT

Background: Epilepsy is a brain disorder characterised by unpredictable and excessive nerve cell activity that causes epileptic seizures. Epileptic seizures are more common in children and adolescents than in elderly population. Electroencephalography (EEG) is a diagram of electrical activity of the brain and it is used as a method of choice for diagnosing epilepsy. Despite the accurate EEG tracing of electrical activity in the brain, the disadvantage of this type of analysing is the doctor's skill to read the EEG correctly.

Objective: The aim of this study was to represent further research presented in our previous works with wavelet based EEG analysis after measuring a multiresolution as relation between time and frequency resolution. **Methods:** Signal database set consist of 51 patients: a) healthy patient; b) 50 patients with a diagnosis of epilepsy. Additional characteristics of the analysed data: a) 19 signals-channels of EEG, b) Duration – 20 s or 2688 samples and. Nowadays, we can find dozens of EEG signal analysis papers using mathematical approach and with a focus on identification of epilepsy. **Results:** This paper represents some results relating to the analysis of EEG in children using Wavelet Transform (WT). The signals was collected and analysed at the Department of neuropediatrics, Pediatric Clinic at the University Clinical Center, University of Sarajevo.

Conclusion: Using this approach it is possible to clearly differentiate patients with a diagnosis of epilepsy from healthy ones.

Keywords: electroencephalography, EEG, wavelet transform, analysis, epilepsy, children.

1. BACKGROUND

Epilepsy is a brain disorder characterised by unpredictable and excessive nerve cell activity that causes epileptic seizures (1, 2). Epilepsy is a disease of the brain defined by any of the following conditions:

- At least two unprovoked (or reflex) seizures occurring > 24 h apart
- One unprovoked (or reflex) seizure and a probability of further seizures similar to the general recurrence risk (at least 60%) after two unprovoked seizures, occurring over the next 10 years and
- Diagnosis of an epilepsy syndrome (3)

Electroencephalography is a diagram of electrical activity of the brain and it is used as a method for diag-

nosing epilepsy. Despite the accurate EEG tracing of electrical activity in the brain, the disadvantage of this type of analysing is the doctors skill to read the EEG correctly. Reasons for that may lie in the insufficient experience and practice, as well as the subjectivity which is hard to eliminate during the analysis of EEG tests (4). Diagnostic accuracy of a single routine EEG is relatively poor, with a reported sensitivity of 30% to 50% (5). Epileptic seizures are more common in children and adolescents than in elderly population (6).

2. OBJECTIVE

The aim of this study was to represent further research presented in our previous works with wavelet based EEG analysis after measuring a multiresolution as relation between time

and frequency resolution.

3. MATERIALS AND METHODS

Wavelet Transform (WT) represents one of the most effective mathematical tools for time-frequency analysis of nonstationary signals. It has significant applications in all branches of science. The wavelet transform (WT) introduces a useful representation of a function in the time-frequency domain (7-10). Basically, a wavelet is a function $\psi=L2(R)$ with a zero average:

$$\int_{-\infty}^{\infty} \psi(t)dt = 0 \quad (I)$$

Continuous Wavelet transform (CWT) is applied (using Morlet wavelet function) for analysis of EEG signals. Global Wavelet Spectrum (GWS) is used for discrimination between healthy and epileptic patients.

A multiresolution is relation between time and frequency resolution. Signal database set consist of fifty one (51) patients:

- 1 – healthy patient
- 50 patients with a diagnosis of epilepsy

Additional characteristics of the analysed data:

- 19 signals-channels of EEG
- Duration - 20 s or 2688 samples and
- Sampling rate $F_s = 134.4$ Hz which is enough for identification of all components of EEG signals. The coefficients distribution of a WT is presented in the time-frequency domain, shown on Figure 1. (11).

Wavelet transform is oftenly refered to as mathematical microscope because of its multiresolutional analysis which provides very complex analysis of nonstationary signals such as EEG signals.

First it is sampled very well in time, then very high frequencies are obtained, then frequency band is doubled to get the better frequency resolution and so on. Basically we have wavelets (short wavelike functions that can be scaled and translated) and similarities between wavelets and signals at different scales are measured using them.

Also in Table 1 are presented five frequency bands and corresponding EEG signal components. Components of EEG signals are gamma, beta, alpha, theta and delta. Of par-

Frequency band (Hz)	Components of EEG signals
33.60-67.20	Gamma
16.80-33.60	Beta
8.40-16.80	Alpha
4.20-8.40	Theta
0.00-4.20	Delta

Table 1. Frequency bands and corresponding EEG signal components

ticular importance are alpha (8.40-16.80), theta (4.20-8.40) and delta (0.00-4.20). This is presented in (12-15).

4. RESULTS

Before processing, the signals of a healthy patient and a patient with epilepsy are very similar and it is very difficult to discriminate them. After Wavelet transform is applied things are changed and using Global Wavelet Spectrum which represents time-frequency wavelet analysis, we can clearly distinguish those signals.

Figure 1. represents GWS of one healthy patient and the

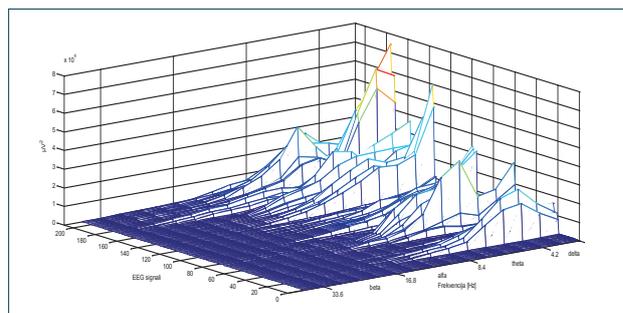


Figure 1. GWS of one healthy patient and the first group of ten epileptic patients

first group of ten epileptic patients:

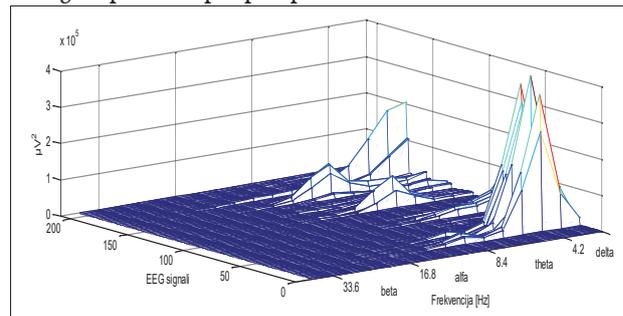


Figure 2. GWS of one healthy patient and the second group of ten epileptic patients

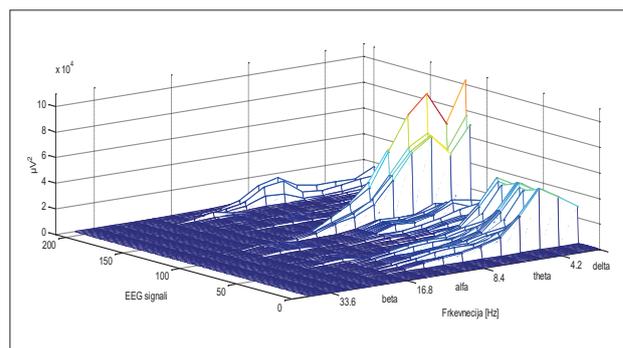


Figure 3. GWS of one healthy patient and the third group of ten epileptic patients

- first 19 GWS are related to a healthy patient,
- second to eleventh 19 GWS are related to the epileptic patients,

It can be seen that alpha, theta and delta components of EEG signal have much higher values for patient with epilepsy. On the z-axis are presented powers of EEG signals which are much higher for persons with epilepsy. The same situation can be seen on the Figures 2-5.

Figure 2. represents GWS of one healthy patient and the second group of ten epileptic patients:

- first 19 GWS are related to a healthy patient,
- second to eleventh 19 GWS are related to the epileptic patients,

Figure 3. represents GWS of one healthy patient and the third group of ten epileptic patients:

- first 19 GWS are related to a healthy patient,
- second to eleventh 19 GWS are related to the epileptic patients,

Figure 4. represents GWS of one healthy patient and the fourth group of ten epileptic patients:

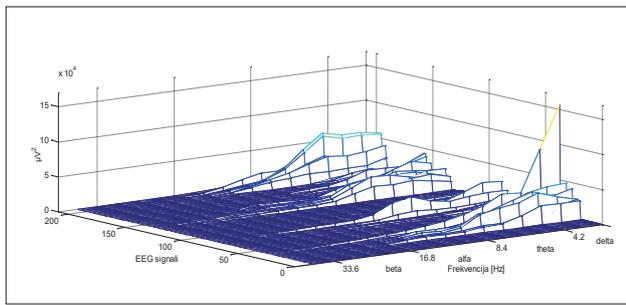


Figure 4. GWS of one healthy patient and the fourth group of ten epileptic patients

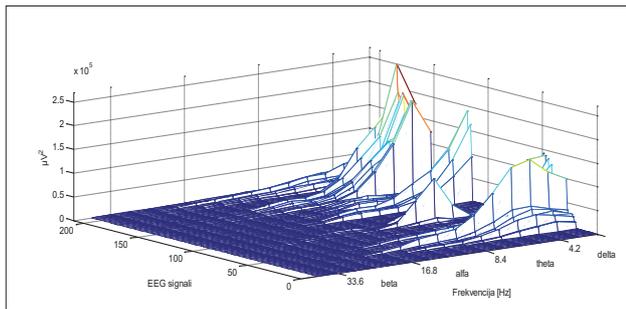


Figure 5. GWS of one healthy patient and the fifth group of ten epileptic patients

- first 19 GWS are related to a healthy patient,
- second to eleventh 19 GWS are related to the epileptic patients,

Figure 5 represents GWS of one healthy patient and the fifth group of ten epileptic patients:

- first 19 GWS are related to a healthy patient,
- second to eleventh 19 GWS are related to the epileptic patients.

5. DISCUSSION

Insight into the currently available literature, as well as available medical databases, we did not come across studies that would be in a comprehensive and systematic way to examine the possibility of wavelet EEG analysis and describe its clinical significance. None of the studies concerned the prospective analysis of the electroencephalographic record in the pediatric population with the help of a wavelet, those performed on the pediatric population mainly relate to the case studies (13, 16–20). In our study, which analyzed the EEG records of 50 patients diagnosed with epilepsy, we obtained absolute confirmation of signal energy deviations in all patients with a previously diagnosed epilepsy, which is clearly and visually seen in the graphs shown. In two patients out of fifty examined, we can see that the energy values do not deviate significantly as in other patients, i.e. that their signals have approximately the same energy values as healthy patients, which supports the high sensitivity of wavelet methods.

According to a study published by Barkmeier et al., in 2012, three experts for reading EEG findings (two from the same institution, and a third employed at another institution) were asked to interpret the EEG findings of 10 patients, thus marking all interictal spikes spotted on all channels. A total of 78,743 spikes were marked by all three experts, of which only 23.7% of these spikes were marked by at least

two experts, and only 3.1% by all three experts. The researchers then used algorithmic EEG analysis in MATLAB where they detected many more interictal spikes than indicated by the experts, 50,315 (the highest number of spikes per EEG-reading expert was 39,802). Since the EEG analysis in MATLAB revealed many more spikes than the doctors originally discovered, the researchers asked themselves whether these were false-positive spikes or whether the experts overlooked these spikes. The same doctors were then asked to analyze whether these spikes, which the algorithm read as interictal spikes, were real or false. The analysis showed that most of these spikes are true interictal spikes that were missed during the EEG analysis by the doctor, and not false positives (5). In the 2015 study, Ibrić, Avdaković and co-workers using the Hilbert-Huang transformation for two groups of EEG signals: one representing EEG signals of healthy subjects, and the other of patients with seizure-free epileptic syndrome, obtained results indicating that EEG signals of patients with epileptic syndrome contain components with significant values of amplitude in the frequency range up to 10 Hz, which physically represents the range of delta and theta waves. Data taken for the study were used from an online available EEG database, from the Center for Epilepsy, University of Bonn (13). Andrzejak RG and associates, in the study from 2001, compared the dynamic properties of the electrical activity of the brain from different imaging regions and in different physiological and pathological conditions of the brain. Using nonlinear prediction error and estimating the effective correlation dimension in combination with the iterative amplitude method of customized replacement data, they analyzed sequences of electroencephalographic time series: surface EEG images of healthy volunteers with closed and open eyes, and intracranial EEG free recordings with patients without seizures in the generated seizure zone as well as outside it, as well as intracranial EEG recordings during epileptic seizures. The highest indications of nonlinear deterministic dynamics were found for epileptic activity (20). In a paper published in 2003, Adeli H and co-workers analyzed the EEG record of a patient diagnosed with epilepsy using wavelet transformation. Using this mathematical microscope, a number of observations have been made, such as the potential suggestion of a physiological process occurring in the brain during an epileptic seizure, and the possibility of automatic detection of epileptogenic discharges that could be used to predict epileptogenic seizures (21).

In our country, the first EEG analysis in adults using the Global Wavelet spectrum was done by Avdaković S, Omerhodžić I. and associates, who presented their work at the sixth European Conference of the International Federation of Medical and Biological Engineering and whose work was published in 2015 (12). The first EEG analysis in children, case studies, using the Global Wavelet spectrum, which preceded this study, were performed by Zahirović S and associates (1). As additional evidence to our methodology, statistical features for GWS signal magnitude, of one healthy and one patient with epilepsy, were included in this study. The special frequency bands are alpha, theta and delta and the features for these components are mean and modality. The mean value is the most common value while the modality represents the av-

erage value extracted from the signals of a healthy patient and a patient with epilepsy. The results show that the mean and modality in a healthy patient have much lower.

6. CONCLUSION

WT as a mathematical tool has been in use for analysis of the EEG signal for a long time. In this work WT proved to be a successful technique in terms of EEG analysis in children (between 1-18 years). Visual EEG analysis often does not provide quality conclusions.

By using the wavelet method, the risk of subjectivity of the doctor which is always possible in the process of interpretation of the EEG test, would be prevented, as well as the possibility of interpretation of the regular EEG records as epileptiform ones.

The GWS presentation of the EEG signal enables excellent observation of activities within the specific components (delta and theta), and clear distinction between healthy and epileptic childrens.

- **Author's contribution:** All authors were involved in preparation of this article. Final proofreading was made by the first author.
- **Conflict of interest:** None declared.
- **Financial support and sponsorship:** Nil.

REFERENCES

1. Zahirovic S, Zubcevic S, Avdakovic S, Dautbasic N, Muftic Dedovic M. Analysis of Electroencephalogram Report Using the Wavelet Transform. *J Neurol Surg A Cent Eur Neurosurg.* 2015; 76-A094.
2. Zahirović S, Dautbašić N, Muftić Dedović M, Zubčević S, Avdaković S. Analysis of Electroencephalogram on Children with Epilepsy Using Global Wavelet Spectrum. In: Hadžikadić M, Avdaković S. (eds) *Advanced Technologies, Systems, and Applications. Lecture Notes in Networks and Systems, Volume 3*, Springer, Cham.
3. Fisher SR, Acevedo C, Arzimanoglou A, Bogacz A, Cross JH, Elger CE, et al. Epileptic seizures and epilepsy: definitions proposed by the International League Against Epilepsy (ILAE). *Epilepsia.* 2014; 55(4): 475-482.
4. Patnaika LM, Manyamb OK. Epileptic EEG detection using neural networks and post-classification. *Elsevier* 2008; 91: 100-109.
5. Barkmeier DT, Shah AK, Flanagan D, Atkinson MD, Agarwal R, Fuerst DR, Jafari-Khouzani K, Loeb JA. High inter-reviewer variability of spike detection on intracranial EEG addressed by an automated multi-channel algorithm. *Clin Neurophysiol.* Jun 2012; 123(6): 1088-1095.
6. Newton CR. Epilepsy in poor regions of the world. *The Lancet.* 380 (9848): 1193-1201.
7. Omerhodžić I, Avdaković S, Nuhanović A, Dizdarević K. Energy distribution of EEG signals: EEG signal wavelet-neural network classifier. *International Journal of Biological and Life Sciences.* 2010; 6: 210-216.
8. Daubechies I. *Ten Lectures on Wavelets.* Philadelphia: Society for Industrial and Applied Mathematics, 1992.
9. He H, J. Starzyk A. A Self-Organizing Learning Array System for Power Quality Classification Based on Wavelet Transform. *IEEE Transaction On Power Delivery* 2006; 21(1): 286-295.
10. Mallat S. *A Wavelet Tour of Signal Processing.* San Diego, CA: Academic, 1998.
11. Morales C, Ronquillo-Jarillo G, Campos-Enriquez JO. Multi-scale analysis of well-logging data in petrophysical and stratigraphic correlation, *Geofisica*, 2009.
12. Avdakovic S, Omerhodzic I, Badnjevic A, Boskovic D. Diagnosis of epilepsy from EEG signals using global wavelet power spectrum, 6th European Conference of the International Federation for Medical and Biological Engineering, Springer International Publishing. 481-484.
13. Ibrić S, Avdaković S, Omerhodžić I, Suljanović N, Mujčić A. Diagnosis of Epilepsy from EEG signals using Hilbert Huang Transform, *Folia Med Fac Univ Saraeviensis.* 2015; 50(1): 68-73.
14. Subasi A, Alkan A, Koklukaya E, Kiyimik MK. EEG signal classification using wavelet feature extraction and a mixture of expert model, *Expert Systems with Applications.* 2007; 32(4), 1084-1093.
15. Subasi A, Ercelebi E. Classification of EEG signals using neural network and logistic regression, *Computer methods and programs in biomedicine.* 2005; 87-99.
16. Ricker JH, Martinez RR, eds. *Differential Diagnosis in Adult Neuropsychological Assessment.* Springer Publishing Company. 2003; 109.
17. Sakkalis V, Giannakakis G, Farmaki C, Mousas A, Padiaditis M, Vorgia P, Tsiknakis M. Absence Seizure Epilepsy Detection using linear and nonlinear EEG analysis methods. 35th Annual International Conference of the IEEE EMBS Osaka, Japan, 3-7 July, 2013.
18. Gadhouni K, Lina JM, Gotman J. Discriminating preictal and interictal states in patients with temporal lobe epilepsy using wavelet analysis of intracerebral EEG. *Clinical Neurophysiology.* 2012; 123: 1906-1916.
19. Sharmila A, Aman Raj S, Shashank P, Mahalakshmi P. Epileptic seizure detection using DWT-based approximate entropy, Shannon entropy and support vector machine: a case study. *J Med Eng Technol.* 2017 Dec; 18: 1-8.
20. Andrzejak RG, Lehnertz K, Rieke C, Mormann F, David P, Elger CE. Indications of nonlinear deterministic and finite dimensional structures in time series of brain electrical activity: Dependence on recording region and brain state. *Phys Rev E Stat Nonlin Soft Matter Phys.* 2001; 64(6 Pt 1): 061907.
21. Adeli H, Zhou Z, Dadmehr N. Analysis of EEG records in an epileptic patient using wavelet transform. *Journal of Neuroscience Methods.* 2003; 123(1): 69-87.