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Approach to functional knowledge of the brain. ASETI Method.

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ABSTRACT: *Numerous disorders of the central nervous system exhaust the diagnostic and therapeutic possibilities available to specialists. The impossibility of predicting the behavior of neuronal systems through electroencephalographic recordings made in humans reflects the existence of non-linear mechanisms involved. Due to the non-linearity and chaoticity in the electroencephalograms, an analysis method was established for better understanding. The electrical signal from the brain was recorded with TrackWalker. The ASETI method was applied to each electroencephalographic recording. The studies analyzed belong to different people who do or do not suffer from some type of disease. An analysis was carried out by region considering the size, shape and value of the attractor, evidencing a great variety of shapes and sizes in different. This diversity reflects that their variability can be used as an indicator of health. From the analysis based on color scale and physiological position, it was obtained that the decrease in the attractor is due to interference fields resulting from possible organic effects. This reduction is given by the inability of the dynamical system to access certain states of the phase space and the increase has an opposite cause. Is possible to use it as a diagnostic method in the future.*
KEYWORDS *– attractor, electroencephalograms, variability*

I. Introduction

There are numerous affections of the central nerve system (SNC) where the diagnostic and therapeutic possibilities with which the specialists constitute a challenge find the solution for the pathological case are exhausted. These affections are the result of inadequate behaviors of the parties that constitute the body.

Several researchers have tested that complex dynamic evolution entails chaotic regimes [1]. In recent years, experimental observations ensure that chaotic systems are common in nature. Existence was found in neurophysiology of chaos, through the discovery of Freeman from the chaotic behavior of the EEG registered in the bulb olfactory in rabbits [2,3].

The impossibility of predicting the behavior of neuronal systems for the result of electroencephalographic records carried out in humans, is reflection of the existence of non-linear mechanisms involved in the behavior of said systems [4]. In theoretical modeling of neuronal systems there is an emphasis on stable or periodic behaviors. A chaotic behavior at the neuronal level could be responsible for schizophrenia, insomnia, epilepsy and other types of disorders [5].

As man is a dynamic and non-linear system many of its complex health situations allow a better understanding with models that consider these characteristics. The brain is usually studied by electroencephalograms (EEG) to which the decomposition of Fourier components is applied and a mapping of the different components is built. However, this approach does not provide a total description of the problems that occur, as the linear components are taken and the chaotic elements of the EEG are not considered. The search for indicators that help to interpret in a better way the information registered in the EEG is one of the research trails. This is a useful tool in the development of this field of medicine because it provides the possibility that this type of analysis has a clinical character, which helps in the detection of many diseases.

The hypothesis of this work is the possibility of using nonlinear dynamic tools to achieve a better interpretation of the EEG. The objectives are the search for new methods and indicators that serve to measure the chaoticity and randomness of a system, as well as the pathological state of a person, and the application of the theory of dynamic systems to the study of EEGs as a record of the functioning of the brain.

With the implementation of a method based on time series, the different brain activity values can be identifiable qualitatively that helps better interpretation of electroencephalograms, so it is necessary to develop the non-linear method based on time series attributors to each electroencephalographic record according to selected pathologies.

An analysis method of the electroencephalographic records was implemented taking into consideration the nonlinear components of the same, in order to provide another interpretation in a less biased way and that has an indicator as a reference for future comparisons between previous studies in the same patient with certain disease and between different types of future pathological entities.

The fundamental scientific contributions that are made in this work are: a new method of analysis and interpretation of the EEG as a complement to the usual protocol in which it is used, as a support staff to the health personnel for a more accurate interpretation in the diagnosis and monitoring of diseases. In addition, the introduction of a quantitative parameter that collects the areas to which the chaotic system, in this case, the brain, had access or not according to the pathology that is studied.

II. Dynamical systems. Chaos. Phase space and trajectory of dynamical systems. Attractor

Dynamic systems are useful to understand how the processes of nature evolve. They have modernly given to important discoveries, such as the existence of chaos [6]. To achieve defining what a dynamic system is due to first internalize in basic concepts such as: linear system [7], nonlinear [8] and complex system [9-11].

1.1. DYNAMICAL SYSTEM

It is a complex system that presents a change or evolution of its state over time [12,13]. Their behavior is characterized by determining the limits of the system, its elements and relationships, elaborating models that seek to represent the structure of the system. By defining the boundaries of the system, the components that contribute to generating the modes of behavior are selected and then the space where the study will be carried out is determined.

1.2. CHAOS

It is associated with disorder or confusion [14]. In science it describes an important conceptual paradox that has a precise mathematical meaning [15]. A chaotic system is a deterministic system that is difficult to predict that has a dynamic behavior, where the portion of the phase space where a chaotic system evolves has a very complicated geometric and topological structure, and as a consequence, a dynamic of a high degree of complexity. These sets are called strange attractors because of their structure and "strange" appearance.

1.3. ATTRACTOR

It is a singularity or region in the "space of action" or phase, where a phenomenon occurs, towards which the trajectories of a given dynamic converge and find a local condition of minimum energy, called the attractor basin [16,17]. The existence of an attractor can be detected by observing the dissipation of some kind of energy.

III. Electroencephalograms (EEG)

Living matter is the source of electricity. The brain has an associated electric field. In the brain, electrical potentials are generated in a complex way due to the structures that compose it such as neurons, glials and others [18].

Such a situation leads to only being able to capture and indirectly record the results of this complicated activity in a few rhythms or patterns, which are conventionally called electrical brain activities or rhythms. The set of phenomena that are recorded does not originate in the entire brain, or even in the entire brain, but only in the cerebral cortex and not in the whole of it, since some cortical areas, such as the interhemispheric cortex, are not accessible due to their location. Only a shallow, approachable mantle of cerebral cortex allows for adequate exploration. This explains the frequent incongruity between the anatomical and functional state of the brain, and the EEG results, expressed in abnormal-looking tracings, obtained in normal subjects and vice versa: patients with neurological lesions with a normal EEG.

Consequently, normal brain function is not equivalent to a normal EEG and the tracings can in no way be interpreted as an expression of brain functions, either in the state of health or in the presence of clinical ailment. This limitation has slowed down the correlation between mental illness and EEG. A normal tracing is a strong argument against the presence of a brain tumor, CNS infection, trauma, or vascular disease of the accessible cortex.

Neuronal disturbance has bioelectrical forms of expression limited to three patterns: depression, irritation, and excitation. Depression causes an attenuation of electrical potentials, which in extreme cases can lead to their total disappearance. Irritation is expressed by the irruption of paroxysmal potentials. Finally, arousal often causes changes in the frequency of brain waves.

IV. Materials and methods

Due to the non-linearity and chaoticity of EEGs, an analysis method is proposed for their better understanding so that, together with quantitative analysis, it can be used by the physician to obtain more useful information about the EEG. The EEGs collected for this study have the particularity of having 19 channels governed by the international standard 10/20 (fig. 1).

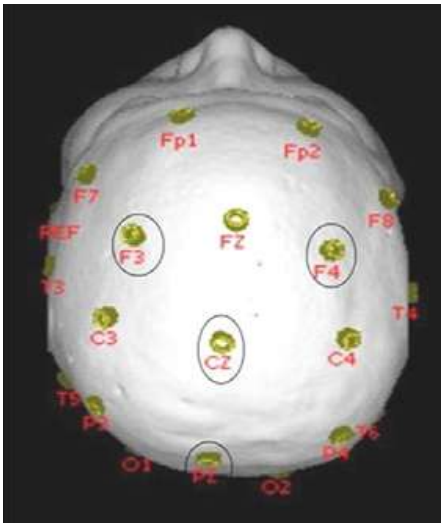

Figure 1. Distribution of electrodes for recording a 19-channel EEG.

1.4. HARDWARE AND SOFTWARE

The EEG recording was made using the MEDICID 5 system and the software that records the EEG, TrackWalker is developed in Cuba, in Neurosciences, which allows the acquisition, processing and analysis of electrophysiological signals. The analysis method used by this software is based on a quantitative method based on the decomposition of EEG into Fourier transforms. This system (TrackWalker) was authorized and widespread in Cuba. Silver disc-shaped surface electrodes were used, placed on all leads of the international system 10-20 (Fp1, Fp2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, O1, O2).

1.5. ASETI METHOD

It is therefore convenient to define a random variable from the data series collected by the EEGs so that the Atb method can be applied to each of the electrodes. It is important to note that EEG is the recorded electrical activity of the brain's behavior, which can be considered as a nonlinear dynamical system. In the EEG the peaks occur chaotically, the occurrence of them can be defined as the random event and the time intervals from peak-to-peak P-P are irregular, chaotic.

It is possible to define that the time difference in each P-P interval constitutes the chaotic variable for the reconstruction of the attractor and to calculate the value of the total area swept (Atb) by it. Being able to reconstruct the attractor is justified by Takens' theorem. The search for an Attractor applied to the Time Series obtained from EEG recordings will be called the ASETI method. The method will be applied to each electrode, that is, to each channel, so in this case there will be 19 channels, that is, 19 attractors. It is significant to note that the 19 electrodes collect information at the same time, so that the calculation in unison of 19 attractors at the indicated points of the head will provide a numerical criterion of the behavior of each area and thus be able to define patterns of health and pathology. Once the EEG is recorded, the values of the points that define the signal are extracted, which are separated at a fixed interval from each other. The method consists of looking for the maximum values that are the "peaks" of the signal by means of a comparison criterion with the neighboring values (Fig. 2),

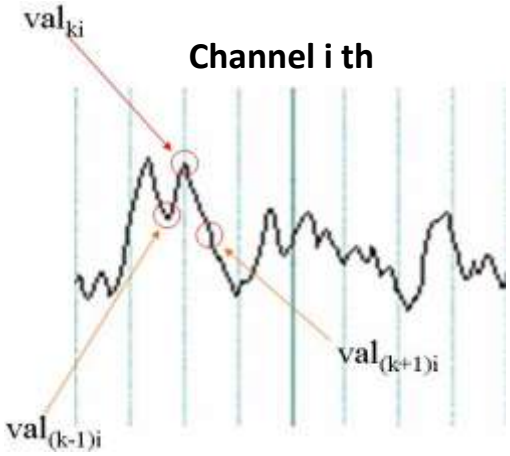

Figure 2. EEG segment illustrating how to determine maximum values.

in other words, the criterion is as follows:

$$val_{ki} > val_{(k+1)i}, \qquad val_{ki} > val_{(k-1)i} \tag{1}$$

If the above is true, then valki is a maximum and corresponds to a peak (P) of the signal. This is true for any channel, where k corresponds to the k-th position of the peak and i corresponds to the channel being analyzed. Next, the temporal separation between two P-P maximums is found. Subtract the positions corresponding to two contiguous maxima and multiply them by the time interval (t) for which each value recorded in the EEG appears, corresponding to t (Fig. 3).

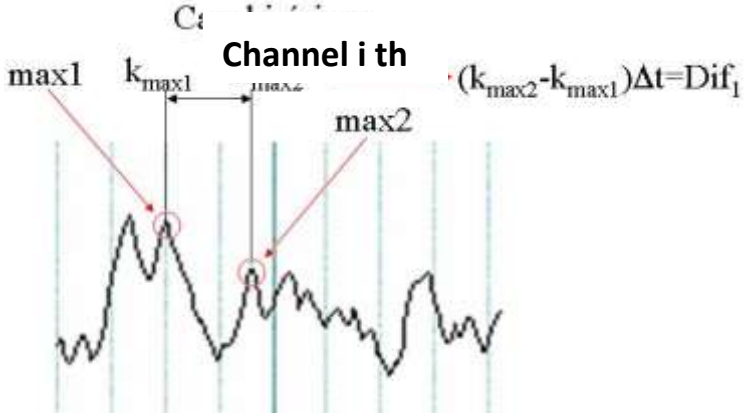

Figure 3. Search for peak-to-peak (P-P) differences.

it's means:

$$(k_{\max_2} - k_{\max_1})\Delta t = Dif_1 \tag{2}$$

With all the differences between existing maximums per channel will be denoted by Dif_{ni}, i.e., n differences that change according to the value of the channels i, the first difference is associated with the variable $X_{(n-2)}$, the next difference with $X_{(n-1)}$ and the next one with $X_{(n)}$. $X_{(n-2)}$ is made to correspond to X, $X_{(n-1)}$ to Y, and $X_{(n)}$ to Z. With the variables X, Y, Z, we proceed to the construction of points with these variables as coordinates which are denoted by P_1, P_2, ..., P_{n-2}, where the number of points formed will correspond to the number of differences minus two. The midpoint Pm is also calculated, whose coordinates X_m, Y_m, Z_m correspond to the mean values of X, Y, Z.

The formed points, as well as their corresponding midpoint, are placed in the coordinate space xyz where the triangles are constructed, the vertices of which are P_1, P_2 and P_m for the case of the first triangle, P_2, P_3 and P_m for the second triangle and so on. The number of triangles will be equal to the number of points minus one, or in other words, the number of differences minus three.

Points P_1, P_2, ..., P_{n-2} will form a complicated figure as a result of the chaoticity of the input data. This figure corresponds to an attractor, which, as already explained, is the reflection of the chaotic behavior of the system being studied. That attractor travels through an area called the total swept area, Atb. The total area swept by the attractor is defined as the sum of all the areas corresponding to the triangles formed, in phase space, from two consecutive points of the trajectory along with the center point.

The larger the area, the more possible physical states the system will reach, thus confirming greater variability and chaoticity. It can then be inferred that the attractor of a healthy person will sweep a totally different area than that of a sick person, but this must be limited because the sick in this complex system can assume states that healthy people do not have. This is also part of the total swept area that is calculated by the Atb, so it will be necessary to limit the accessible states to a maximum. In the same way, the smaller the attractor, the fewer the accessible states and therefore the smaller the area calculated by the Atb, for healthy people there must be a minimum value of the Atb.

The EEGs analyzed belong to different people who suffer or not from some type of disease, a total of 16 people. Such people are in certain groups according to their state of health. These groups are:

- Normal (4 subjects between 21 and 24 years old, InSTEC)
- Persistent vegetative state (1 9-year-old patient).
- Headache (1 15-year-old patient).
- Alcohol dependence (4 patients, between 32 and 50 years old).
- Epilepsy (2 patients, between 53 and 63 years old).
- Behavioral disorders (3 patients of the Havana Psychiatric Hospital, between 27 and 55 years old).

- Supraorbital CSF (cerebrospinal fluid) cyst with no symptoms (1 40-year-old patient).

In particular, in the case of the child in a persistent vegetative state, two EEGs are analyzed, because the EEG without stimuli is compared with the EEG obtained when the mother speaks in the ear. This brings the number of EEGs to be processed to 17.

Table 1. Codes used and groups to which they belong

Code	Group of people
Nor. DG87 RG86 YM85	Normal
NS	Child (vegetative state)
NM	Child (vegetative state) + mom
739	Headache
TOX015 T0X016 TOX25 TOX32	Epilepsy
432 1554	Alcohol dependence
1087 1214 OT380	Behavioral disorders
RH84	Supraorbital CSF

V. Results and discussion

Analysis by regions according to the size and shape of the attractor, as well as the value of the Atb. As already explained, the method used in this work is applied to each channel for each EEG. The number of channels contained in an EEG of those used is 19 and the number of EEGs to be analyzed is 17, so the number of attractor graphs obtained and the calculated Atb values is 323. 6 attractors are shown to see how diverse their shapes and sizes are.

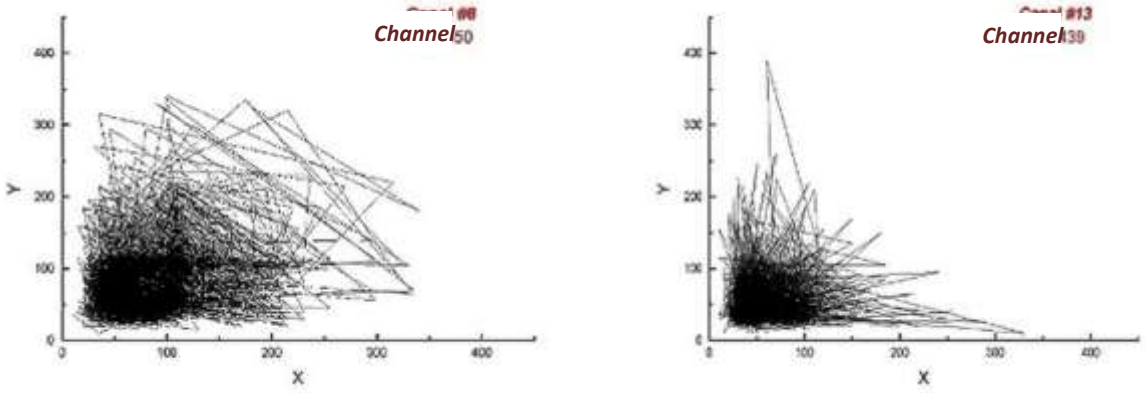

Figure 4. a. Patient Attractor (1214) channel eight. b. Patient Attractor (1214) Channel Thirteen

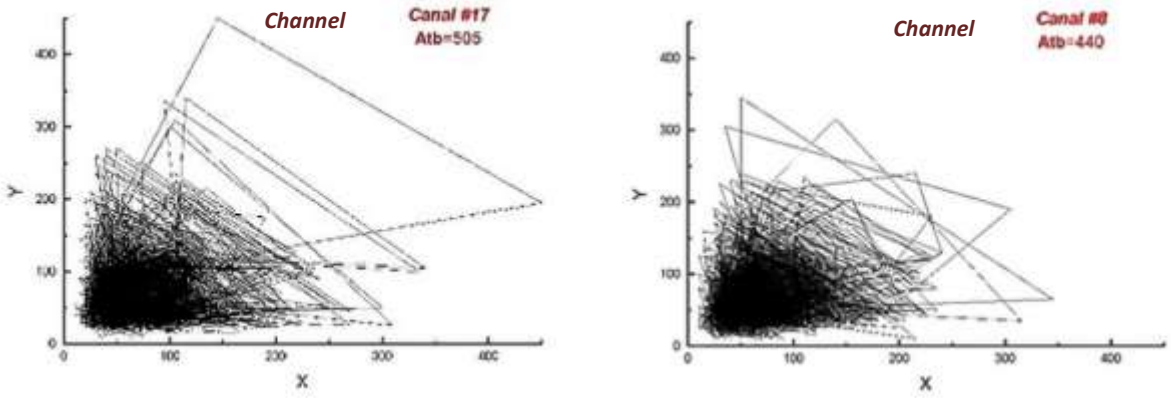

Figure 5. a. Patient Attractor (1214) channel seventeen. b. Patient Attractor (1554) channel eight.

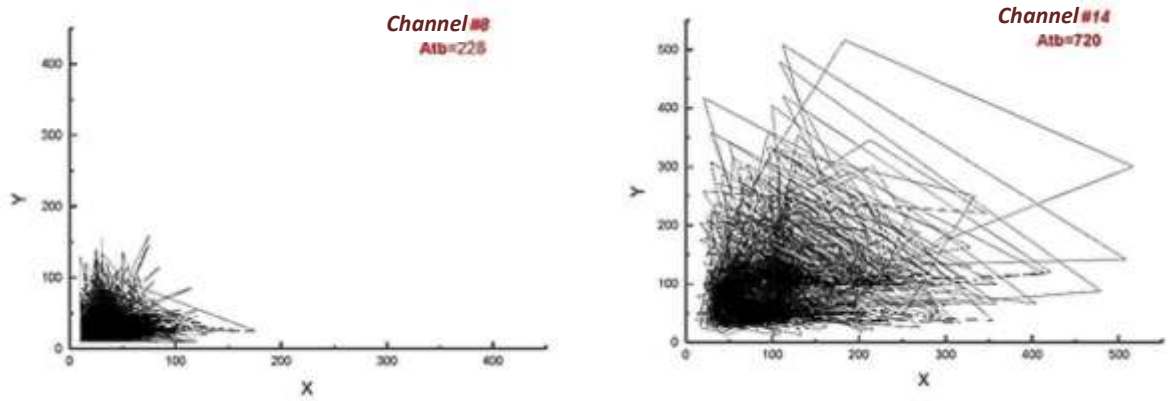

Figure 6. a. Patient attractor (NS) channel eight. b. Patient attractor (RG86) channel fourteen.

Attractors of the same person are observed, evidencing their different characteristics. (Fig. 4a, Fig. 4b, Fig. 5a). Channel 8 was analyzed for different people who showed different attractors and Atb values (Fig. 4a, Fig. 5b) and despite this, there is a great contrast with the size, shape and value of Atb when compared to the child (Fig. 6a) who is decreased as a result of the pathological state. Observe the shape of the attractors that limit their path in the form of "spikes" (Fig. 4b, Fig. 6a), a situation that may be linked to some pathological decrease. In the healthy case, one of the high Atb values is shown (Fig. 6b), further investigations should check whether it is a case of special abilities (possibility).

From the attractors obtained, it can be concluded that there is a great variety of shapes and sizes in different people and even in the same person. The diversity of shapes and sizes reached by these figures corresponds to the assertion that their variability can be used as an indicator of health.

In order to carry out a more detailed analysis without showing the totality of the calculated attractors, a typical case was selected from each identified group; so that they will be shown by zones and comparatively seven different EEGs. Its attractors and Atb values are displayed.

Analysis based on color scale. Analysis by physiological position. The scale was defined for the cases that were studied, which were 16 people and 17 EEGs. It is possible that this scale will be modified as the number of cases analyzed increases. It is important to note that no normal case has an Atb value of less than 250, however, patients with known pathologies do have a large number of values in their corresponding Atb below the number already mentioned. Based on the above, the scale is defined to consist of four colors that correspond to four ranges of Atb values.

Table 2. Color Scale

Value Atb	Color Scale
Atb ≤ 250	
250 <Atb ≤ 320	
320 <Atb < 550	
Atb ≥ 550	

For Atb values less than 250, there are points of possible interference fields (IC) that cause the bioelectrical signals to be incorrect, so it is assigned a red color. For Atb values between 251 and 320, an observation zone (O) is defined in which, as its name indicates, surveillance must be carried out to obtain how the area evolves over time, this type of point was assigned the color yellow. If the Atb value is between 321 and 550, a normal zone (N) is pathologically defined and assigned a green color. When the Atb exceeds the value of 550 or is equal to 550, an excited zone (E) is defined, which should be studied in more detail in another study. This last interval was given a blue color.

In a circle above each electrode, the color that corresponds to it is placed according to the value of the Atb in that case. At the end, a "map" of the colors of the head where the electrode is located is obtained, with its corresponding color, providing a useful method to differentiate between possible types of diseases and non-pathological people. Shown below is the representation that links the electrode with physiological position and the figures elaborated by this method for the same seven EEGs whose attractors were shown in the zonal analysis.

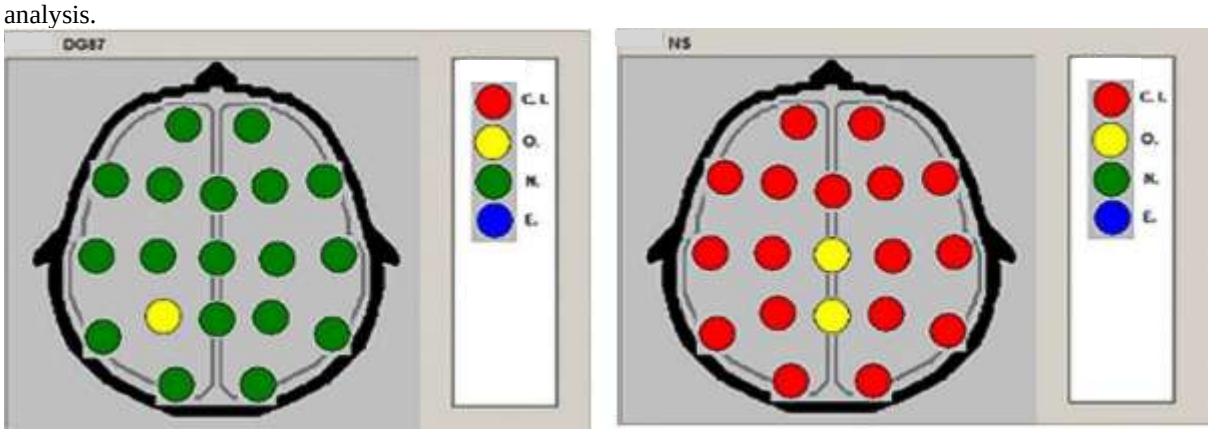

Figure 7. a. Color scheme for DG87. b. Color scheme for NS.

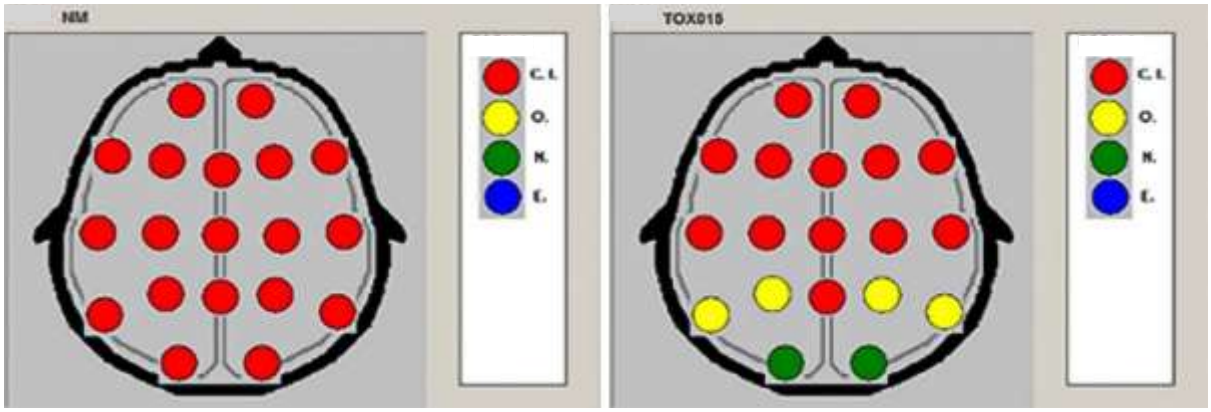

Figure 8. a. Color scheme for NM. b. Color Scheme for TOX015

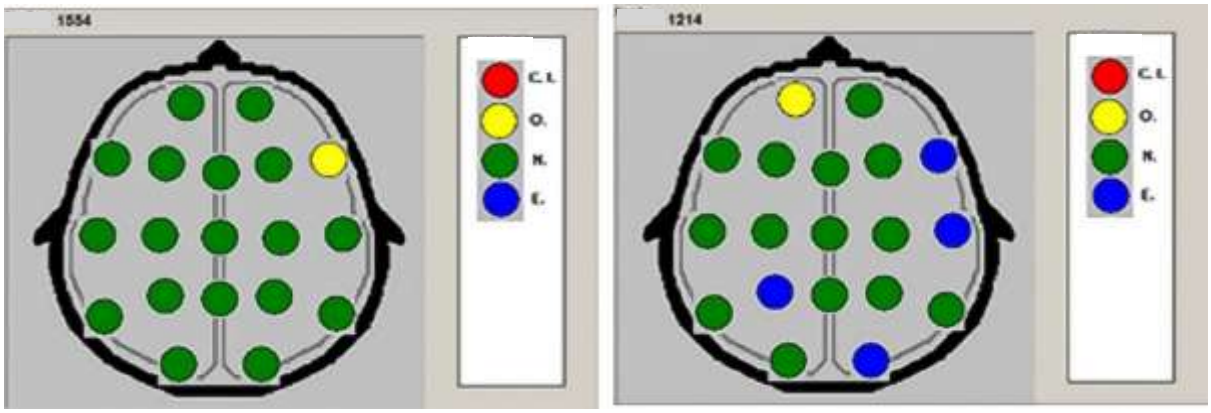

Figure 9. a. Color scheme for 1554. b. Color scheme for 1214.

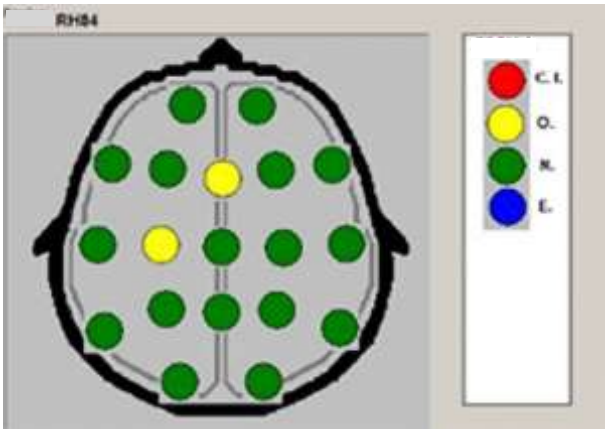

Figure 10. Color scheme for RH84.

From the figures shown, it can be easily concluded that, in reality, the patient in a persistent vegetative state has severe affectation in all the areas where the electrodes were placed on the head, which are red. Both in the stimulated (Fig. 8, NM) and non-stimulated (Fig. 7, NS) state, the persistent vegetative state presents a generalized red affectation except in two positions whose color is yellow. This is consistent with the conclusions made for the case of the zonal analysis discussed above. As there is a total affectation, symmetry cannot be analyzed.

In patients suffering from epilepsy, a point is marked at which their Atb value enters the range of observation (Fig. 8, TOX15), which leads to a more in-depth investigation corresponding to the yellow color, as it could be a possible focus of the disease. There is no total symmetry in this case.

The patient in the alcohol dependence group had severe head involvement (Fig. 9, 1554). There are only two points that are exempt from pathology marked with green, a result that corresponds to the one obtained in the zonal analysis. In this case, however, there is symmetry and at the same time affectation, which implies that it presents an affectation in almost all the corresponding points.

In the case of the patient belonging to the conduct disorder group, only one position to investigate is observed in yellow and four more positions that are excited marked with blue whose meaning is still unknown and will be the subject of study in another study (Fig. 9, 1214). There is a loss of symmetry for this case.

For patients with cerebrospinal fluid cysts, there are two yellow points to investigate, which, as can be seen, are close to each other (Fig. 10, RH84). Thus, it is concluded that the regions marked in yellow should be studied, since they correspond to the part where your problem lies. There is a loss of symmetry. Attractors were grouped by region. These regions are divided into:

- Frontal (corresponds to electrodes Fp1, Fp2, F3, F4, F7, F8, FZ), which are identified with series 1, 2, 3, 4, 11, 12 and 17.
- Temporal (corresponds to electrodes T3, T4, T5 and T6), which are identified with series 13, 14, 15 and 16.
- Central (corresponds to electrodes C3, C4 and CZ), which are identified with series 5, 6 and 18.
- Parietal (corresponds to the P3, P4 and PZ electrodes), which are identified with series 7, 8, 19.
- Occipital (corresponds to electrodes O1 and O2), which are identified with series 9 and 10.

The tables below contain a first column representing the channel number to which the tabulated values correspond. The beginnings of columns appear with written codes which are presented in the legend already placed above.

Table 3. Frontal Zone Color Scale

C	Nor.	DG87	RG86	YM85	NS	NM	739	T0X015	T0X016	TOX25	TOX32	432	1554	1087	1214	OT380	RH84
1	325	433	605	456	119	104	237	206	390	269	477	276	379	382	280	402	442
2	279	378	566	429	166	139	205	205	392	240	400	471	343	304	446	409	414
3	381	359	533	518	123	123	337	221	306	289	541	556	383	364	480	359	383
4	376	329	638	523	149	144	321	187	292	325	412	514	363	412	372	397	382
11	347	372	555	339	164	123	400	129	345	329	516	512	327	248	375	338	398
12	320	455	513	477	196	135	390	133	310	321	504	461	310	415	825	371	391
17	465	333	544	599	247	150	359	222	270	321	530	471	360	402	505	377	300

Table 4. Temporal Zone Color Scale

C	Nor.	DG87	RG86	YM85	NS	NM	739	T0X015	T0X016	TOX25	TOX32	432	1554	1087	1214	OT380	RH84
13	426	440	565	469	126	95	287	173	291	371	587	469	340	411	439	515	385
14	375	424	720	523	109	104	466	149	359	357	544	499	412	359	890	437	367
15	352	350	607	348	167	93	451	257	287	426	570	483	490	451	431	485	409
16	386	333	585	591	158	126	388	280	280	462	404	470	367	532	434	417	346

Table 5. Central Zone Color Scale

C	Nor.	DG87	RG86	YM85	NS	NM	739	T0X015	T0X016	TOX25	TOX32	432	1554	1087	1214	OT380	RH84
5	415	473	597	652	209	142	374	226	243	363	572	473	369	413	533	380	309
6	399	487	570	483	195	136	353	199	239	369	545	478	397	398	437	412	386
18	409	323	614	455	258	157	423	231	212	304	502	441	378	412	424	391	434

Table 6. Parietal Zone Color Scale

C	Nor.	DG87	RG86	YM85	NS	NM	739	T0X015	T0X016	TOX25	TOX32	432	1554	1087	1214	OT380	RH84
7	377	286	590	299	231	143	383	264	217	447	497	425	369	391	487	422	416
8	388	460	588	438	228	155	389	269	233	431	581	274	440	434	550	392	449
19	396	408	453	459	282	159	404	240	192	449	565	419	344	369	506	291	395

Table 7. Occipital Zone Color Scale

C	Nor.	DG87	RG86	YM85	NS	NM	739	T0X015	T0X016	TOX25	TOX32	432	1554	1087	1214	OT380	RH84
9	323	400	535	434	180	114	364	339	274	511	531	369	478	429	545	397	389
10	366	396	570	453	127	111	383	359	266	513	558	487	415	282	619	392	424

In the tables it can be seen that there is a diversity of colors depending on the patient and the area, offering information that shows the pathological state of the patient.

VI. Conclusions

New methods and indicators were found to measure the chaoticity and randomness of a system, as well as the pathological state of a person. Proceeding using this type of method is very feasible to quickly identify where there are potential problems because it delimits which physiological region is affected. The ASETI method is useful as a diagnostic tool for analyzing EEGs, it was successfully applied for the first time in this work and constitutes a useful tool in the field of medicine.

VII. Acknowledgements

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