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Temporal scaling and inter-individual hemispheric asymmetry of chaos estimation from EEG time series

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Abstract

The aim of the present research was to measure the brain order/chaos inter-hemispheric asymmetry, long memory processing, and predictability of an EEG signal at different timescales during a simple exercise of closed eyes imagination or mental projection. We studied inter-hemispheric asymmetries in frontal, temporal and occipital areas of the brain during 2 minutes of silent and relaxed mental projective task of visualizing themselves performing a physical exercise practice. EEG signal was recorded using the brain-computer device EmotivEpoc® from 8 subjects aged between 20 and 30 years, all fellowships in two weeks of modern dance workshop. The results showed that Hurst (H) exponent used as anestimator of the persistence/anti-persistence dynamics of the EEG process vary inversely with the length of the time window (1, 3, 12, 30 and 120 s) used to calculate H at different timescales.We foundsignificant inter-hemispheric asymmetry in the temporal and occipital regions, with left hemisphere having the higher scores of H. Together with a common general trend we observed inter-individual variability of inter-hemispheric asymmetry between frontal, temporal and occipital lobes, being the temporal the one with the highest scores. We evaluated statistically these differences and significance.

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Keywords; Temporal scaling; EEG time series; inter-individual differences; inter-hemispheric asymmetry; chaos estimation

1. Introduction

Electroencephalography (EEG) corresponds to the recording of brain electrical activity through electrodes located on the scalp [1]. From Berger in 1929 [2] who published the first work of brain electrical activity in humans to date, EEG has been used as a clinical study tool to establish a relationship between behavior and

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brain activity. This cerebral electrical activity is the result of the sum of excitatory and inhibitory post-synaptic potentials of the pyramidal cells of the cerebral cortex, this difference being the EEG record [3].

The intensity and frequency of brain waves can be classified into Delta waves ranging from 1 to 4 Hz, Theta waves from 4 to 8 Hz, Alpha waves from 8 to 12 Hz, Beta waves from 13 to 30 Hz and Gamma waves greater than 30 Hz [4]. In general, different brain activities tend to be associated with different frequency bands, ranging from sleep, in the lower bands, to complex cognitive activities in the high-frequency bands [5]. However, is not enough to understand the brain's action, since it is possible to observe many different phenomena in the same band intensities, being necessary the introduction of notions of nonlinear dynamics, complex systems, chaos theory and fractals, as new approaches to study these phenomena [6].

Chaotic systems are those that possess an aperiodic dynamic behavior and that have extreme sensitivity to the initial conditions, i.e. systems where it is not possible to predict their future behavior based on their present conditions [7]. The Hurst exponent (H) is a measure to analyze the behavior of a system over time that ranges from 0 to 1. When $0 \leqslant H < 0.5$ the behavior of the system is anti-persistent, an increase of events of the past means a decrease of future events and vice versa. If $H = 0.5$ the series is totally random and corresponds to a Brownian motion. If $0.5 < H < 1$, the behavior of the system is persistent, an increase in past events implies an increase in future events or vice versa [8].

A relationship between the H exponent and the EEG frequency bands has been observed, with delta waves having the highest H and the alpha waves being the lowest, together with the increase in H as brain processing works on more complex problems [9]. Cerebral asymmetries have also been observed in EEG records during the resolution of problems in the Raven test [6].

The present study investigates the functional dynamics of the brain during the imagination of a sequence of body movements (projective visualization) and the render of H according to the duration of the time window used to estimate H (1, 3,12, 30 and 120s). We expect to expand the understanding of the order/chaos balance that presents EEG activity of different brain regionsas varying in relation to the timescale we decide to observe it. We also study inter-hemispheric asymmetries comparing brain lobes. The difficulty of an imaginative process should convoke the participation of different regions requiring adjustments and coordination in between different cortical regions. Finally, we expect to find evidence of individual differences in the way each system solves problems based on individual previous experiences and learning, despite similar training and expertise of the subjects participants.

2. Methods

2.1. Design and Sample

A quantitative cross-sectional study was conducted. The sample consisted of 8 professional Chilean volunteer students between the ages of 20 and 30. Of the total 5 (62.5%) are females and 3 (37.5%) are males.

2.2. Instruments

For the EEG recording, the EmotivEpoc® brain-interface device was used at 128 Hz sampling frequency for 2 minutes of projective visualization with eyes closed. The EEG registers 14 channels by placing the electrodes according to the 10/20 system (Fig. 1) with reference to the mastoid bone electrodes. EEG data were processed using the EEGLAB and ADJUST program executed on the MATLAB 2008 platform. For the final analysis, we used frontal lobe (AF3 and AF4), temporal (T7 and T8) and occipital (O1 and O2) pairs of electrode recording.

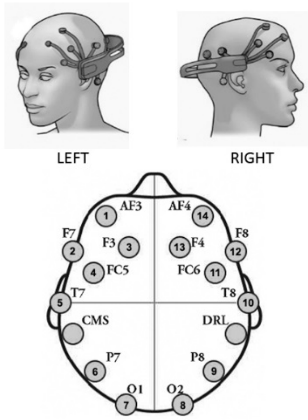

Fig. 1. EmotivEpoc® electrode locations during the study

2.3. Procedure

For 5 minutes each subject of the sample rests relaxed with the EEG on his head in a bright room and without environmental noises. After this, each one had to imagine itself executing a sequence of movements (projective visualization) with closed eyes during 2 minutes. Frequency sampling was 128 Hz, allowing us confident EEG frequency analysis between 1 to 64 Hz. Each subject participated voluntarily and signed an informed consent.

2.4. Data analysis

The Hurst exponent (H) was used as an order/chaos indicator of the sub-surface driving attractor that modulates the EEG record in the frontal, temporal and occipital lobes. We also used t-tests for independent samples and Mann-Whitney U-tests to compare H-means between both hemispheres and ANOVA, Welch and Brown-Forsythe tests to compare H-measures between frontal, temporal and occipital areas.

3. Results

Figure 2 shows the H-estimates made at different time scales of the left and right frontal areas of the eight subjects in the sample. First, the H of each second of the series (with 128 data each) was calculated, obtaining 120 H-values per subject. Subsequently, the mean of these Hs was calculated, obtaining the values H 1 "of Figure 2. The entire sample had a mean of 0.8> H> 0.5 per second, which reveals a persistent behavior of the driving dynamic, Low values of the signal tend to be followed by low values and vice versa.

The H-values of time series of 3 seconds (H 3 "); 12 seconds (H 12"); 30 seconds (H 30 "); and 120 seconds (H 120") were then calculated, resulting in values of 0.7 > H> 0.5 in all subjects at 3 seconds; values 0.6> H> 0.4 throughout the sample at 12 seconds; values 0.4> H> 0.3 in all subjects of the sampletaken at 30 seconds. The above reflects that as the observed time windows are larger the exponents H tends to decrease their value. The 1s and 3stime window present H averages above 0.5 with a self-organized, persistentand long memory behavior. On the other hand, the series of 12, 30, and 120s have H averages less than 0.5 with anti-persistent short-memory behavior (low values tend to be followed by high values and vice versa).

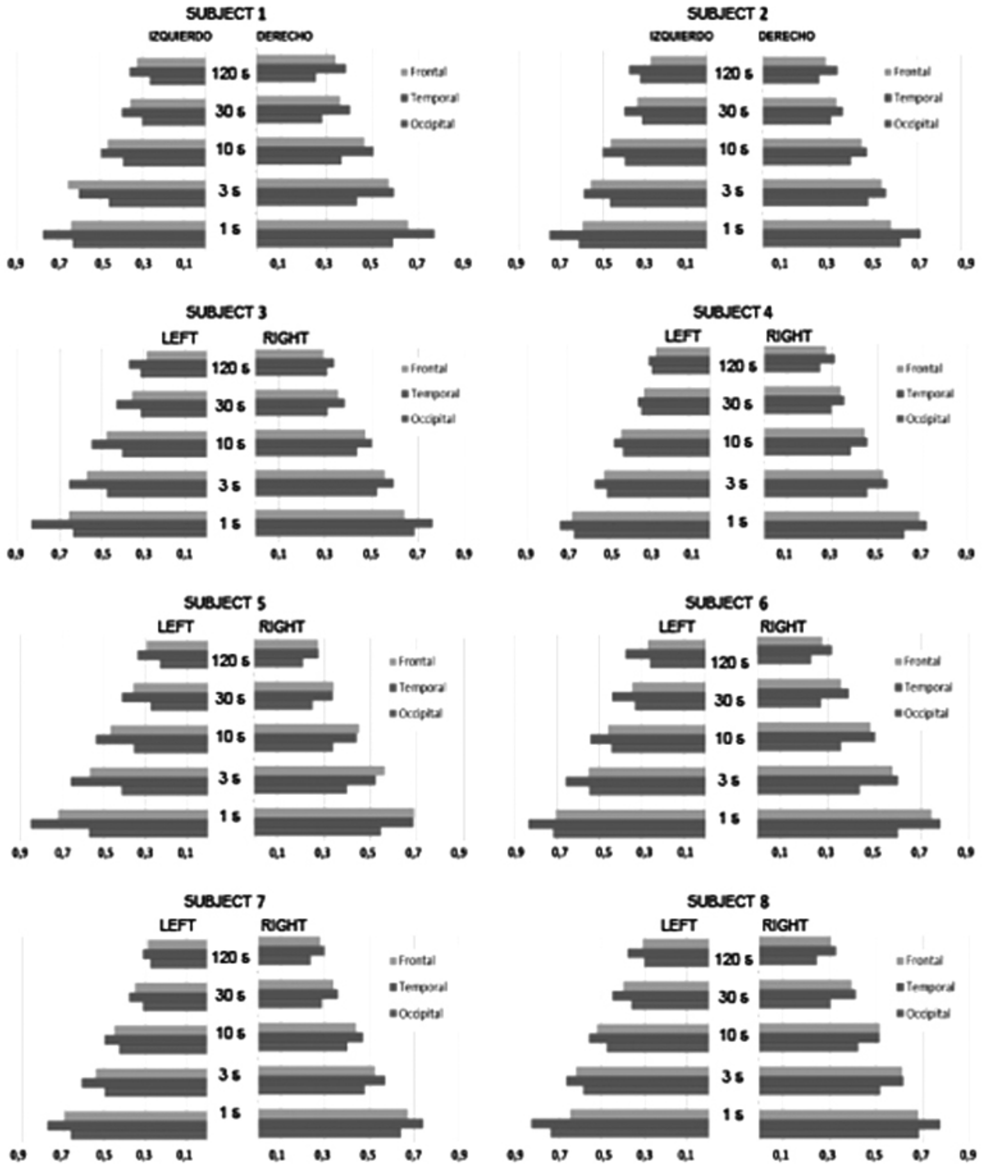

Fig. 2. Exponents H of the frontal, temporal and occipital area of the right and left hemispheres of the total sample estimated in different time series.

Figure 2 shows the H of each time window comparing the frontal area of both hemispheres (in green). The t-tests for independent samples comparing the H 1s time window show significant differences in subjects 5 ($t = 2.223$, f.d. = 238, $p = 0.027$) and 6 ($t = -3.059$, f.d. = 238, $p = 0.002$), While there are no differences in the other six subjects in the sample. The t-tests comparing the H 3s time window and the Mann-Whitney Utestscomparingthe H 12s time window do not show significant differences between the two frontal lobes in any of the evaluated subjects. Finally, the Mann-Whitney U tests comparing the H 30s time window show significant differences in subjects 4 (MW = 0.500, p = 0.029) and 6 (MW = 0.000, p = 0.021). There are no differences in the other six subjects in the sample.

Figure 2 shows the H estimates made at different time scales of the left and right temporal lobes(in brown) of the eight subjects in the sample. In the average of the 1s timewindow, the whole sample has an average of 0.9> H> 0.6 which reveals a strong persistent behavior of the system, thesame situation that occurs for the time window of 3s where 0.7> H> 0.5. For the time window of 12s,the mean values of H are less than 0.5 in some subjects, while others have values slightly higher than 0.5. Even values H = 0.5 are observed in a pair of subjects in the sample, indicating a random walk-like or uncorrelated behavior. For the time series of the 30s and 120s, the whole sample has H <0.5 indicating an anti-persistent behavior.

In the same figure also the H of each time series are shown comparing the temporal lobes of both hemispheres. The t-tests for independent samples comparing H 1stime window show significant differences in subjects 2 (t = 3.207; f.d. = 238, p = 0.002), 3 (t = 5.675, f.d. = 238, p = 0.000), 5 = 13.483, f.d. = 238, p = 0.000), 6 (t = 4.384, f.d. = 238, p = 0.000), 7 (t = 2.461, f.d. = 238, p = 0.015) and 8 (t = 238, p = 0.000), all of them being the left temporal zone who obtained the highest score. The t-tests comparing the H 3stime window show significant differences in subjects 3 (t = 3.944, f.d. = 78, p = 0.000), 5 (t = 9.189, f.d. = 78, p = 0.000), (T = 4.331, f.d. = 78, p = 0.000), 7 (t = 2.431, f.d. = 78, p = 0.017) and 8 (t = 2.862, f.d. = 78, p = 0.05) They higher the score of the left temporal zone. The Mann-Whitney U tests comparing the H 12 "of the third series show significant differences between the two temporal areas in subjects 3 (MW = 18,000, p = 0.002), 5 (KW = 8,000, p = 0,000), 6 KW = 28,000, p = 0.011), 7 (KW = 36,000, p = 0.038) and 8 (KW = 21,500, p = 0.003), being greater in the left temporal zone. Finally, the Mann-Whitney U tests comparing the H 30s time windows show significant differences only in subject 5 (KW = 0.000; p = 0.020).

Finally, the H estimates made at different time scales of the left and right occipital areas of the eight subjects of the sample are observed. In the mean of the first time window (H every 1s) the whole sample has an average of 0.8> H> 0.5 which reveals a persistent behavior of the system. For the 3s time window, there are 0.6> H> 0.4 showing a diversification of slightly persistent or slightly anti-persistent brown noise-like activity. For the time window of 12s mean values of H <0.5 same situations occurring in the time window of the 30s and 120s.

The same figure 2 shows the H of each time series comparing both hemispheres. The t-tests for independent samples comparing the H 1s time window between the two occipital lobes show significant differences in subjects 1 (t = -3,457, f.d. = 238, p = 0.001), 3 (t = -3.237; f.d. = 238, p = 0.001), 4 (t = 3.932, f.d. = 238, p = 0.000), 6 (t = 7.757, f.d. = 238, p = 0.000) and 8 (t = 3.856, f.d. = 0.000), with the left occipital lobesrendering the highest score. The t-tests comparing the H 3stime window show significant differences in subjects 1 (t = 2.055, f.d. = 78, p = 0.043), 3 (t = -2.991, f.d. = 78, p = 0.004) , 4 (t = 3.748, f.d. = 78, p = 0.000), 6 (t = 6.537, f.d. = 78, p = 0.000) and 8 (t = 3.917, f.d. = 78, p = 0.000), the highest score of the left occipital lobe. The Mann-Whitney U tests for the H 12stime window show significant differences between the two temporal lobes in subjects 3 (MW = 32,000, p = 0.021), 4 (KW = 25,000, p = 0.007), 6 KW = 3,000, p = 0.000) and 8 (KW = 25,000, p = 0.007). Finally, Mann-Whitney U-tests comparing the 30s time window show significant differences in subjects 4 (KW = 0.500, p = 0.029) and 6 (KW = 0.000, p = 0.021). In both cases the left area has higher scores.

The ANOVA tests by Welch and Brown-Forsythe to compare the H-means of the frontal, temporal and occipital area show that with the time window of 1s there are significant differences in the eight subjects of the sample, observing that the higher scores were achieved in the occipital areas. In the time window of 3s, there are significant differences between the three areas, with the temporal region having the highest scores in all subjects (except subject 1), in addition to being the occipital region with the lowest H values. In the time window of 12s,there are significant differences between the three areas, the temporal area being the highest score and the occipital area the lowest value. Finally, in the 30s time window, the temporal region has the highest scores and the frontal and occipital regions have the lowest values.

4. Discussion

This research focuses on studying the variation of Hurst exponent (H) as chaos content estimator applied to an EEG time series. H estimator has been commonly applied to time series with a relatively small sequence of samples. When we apply H estimator to an EEG time series, data sample can be very large, so calculating it using a set of different sample number to study the time series at different timescales could be informative in comparing for example H values calculated over the whole data sample or over a sequence of shorter data sample depicting the chaos content variation over time. To do that we used a set of EEG data sample coming from 8 individuals executing a mental task who consisted in to imagine a set of movements as part of a future performing dance.

The results of the analysis showed that as the length of the time windows increases (from 1s to 120s), the Hurts exponents decrease, going from time windows whose H values tend to be followed by values of the same trend (series of 1s and 3s), to series with H values that are followed by values of opposite tendencies (the 30s, and 120s), giving two different time scales ofsub-surface brain processing attractors. The first oneworking in the short-term processing scale, in time windows between 1 to 3 seconds, and where it is possible to make fine adjustments of the activity that is going through thought [9] and a second timescale window that works in the long-term modulation, in times windowshigher than 10 seconds.This is characterized by more relaxed processes that could be important for an imaginative projective and long duration sequential processing [6].

On the other hand, EEG activity comparison analysis between cerebral hemispheres reveal that there are almost no differences in the right and left cortex region during the imaginative activity. The frontal lobes are brain structures related to the planning, regulation, and control of cognitive processes [10]. In both hemispheres, the H values are similar and greater than 0.5 in any of the time series analyzed, which represents a tendency to continue with the previous values allowing a long-term memory of the systemic processes. The left prefrontal cortex is more related to logical decisions under determined conditions and known decision spaces; contrary with what occurs in the right frontal hemisphere, which activates when facingnew conditions and relationships in unknown areas[11]. This is consistent with the requested projective visualization of a sequence of body movements since this activity is familiar for all the subjects that are sharing a 2 weeks workshop in the field of corporal expression. This may explain the tendency to order the left frontal lobe in the sample, but at the same time representing a novel creation challenge, which strongly involves the right frontal lobe.

On the other hand, the temporal zone shows important differences between both hemispheres. The temporal lobes are structures related to the recognition of faces, with hearing (there is the Wernicke area) and within it are structures that allow memory to be generated [12]. The region of the temporal plane is larger in the left hemisphere, which is related to the degree of right dominance [13], and it has also been observed that the area of auditory association is also greater in the temporal left region [14]. These characteristics may explain the difference in the H of both temporal areas in the majority of the subjects of the sample in all the timescales. The projective visualization of a sequence of organized movements requires agreat development of the coordination of both sides of the body situations that work more strongly in the cerebral left temporal zone, hence the highest H values recorded in this area.

The occipital area also shows important differences between both hemispheres. The occipital lobes are structures related to vision, spatial recognition, colors and perception of movement [12]. The fact that visual information has a greater component of the clever side of the body [13], a situation that may still occur during the imagination process, could explain the heterogeneous activity of both occipital areas in the majority of the subjects in the sample, the left region (which receives information from the right eye) is the one with the highest H.

Finally, when comparing the H exponents found in the frontal, temporal and occipital areas of the sample, higher scores can be observed in the temporal region since, as explained earlier, this area is related to auditory work (music evoking during projective visualization) and with the memory of the same elements to be developed during the organized sequence which gives a logic about the greater activity of this region.

5. Conclusions

The study of the brain as a nonlinear system gives new information on how we process information and solve problems, in this occasion, in an imaginary motor context through the projective visualization of a sequence of organized sequential movements. Understanding the dynamics of the brain at a temporal level (seconds, minutes or hours) or regions involved (frontal, parietal, temporal and occipital) could allow a better management of our brain faculties when facing a problem. The regions of the cerebral cortex that allow us to hear, see, and read a word are very similar to regions that are activated when you think a word, just as imagining a movement is related to execution of it, so it would be expected that the subjects with greater values of self-organization (H estimator) in the EEG activity during the visualization of an activity should bethe same ones that achieved a greater expertise in its execution. Future research will allow us to delve deeper into these and other brain phenomena that have an impact on better learning and better motor performance [15].

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