J. Biomedical Science and Engineering, 2010, 3, 1175-1181 **JBiSE**
doi:10.4236/jbise.2010.312153 Published Online December 2010 (http://www.SciRP.org/journal/jbise/).

Chaotic features analysis of EEG signals during hallucination tasks of waterloo-stanford standard

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Received 9 October 2010; revised 15 October 2010; accepted 20 October, 2010

ABSTRACT

The present study looks carefully at EEG (Electroencephalograph) signals of people after the hypnosis inductions. Subjects were in three different categories of hypnotizability based on Waterloo-Stanford criteria; low, medium and high. Signals recorded during hallucination tasks of Waterloo-Stanford standard were applied to study the underlying dynamics of tasks and investigate the influence of hypnosis depth and concentration on recorded signals. To fulfill this objective, chaotic methods were employed; Higuchi dimension and correlation dimension. The results of the study indicate channels whose chaotic features are significantly different among people with various levels of hypnotizability. Moreover, a great consistency exists among channels involved in each task with brain's dominant hemisphere and brain lobes' functions. Another considerable result of the study was that the medium hypnotizable subjects were mostly affected by inductions and instructions of the hypnotizer (more than low or high hypnotizable subjects). The present study demonstrates a remarkable innovation in the analysis of hypnotic EEG; investigating the EEG signals of the hypnotized as doing hallucination tasks of Waterloo-Stanford standard orders.

Keywords: Hypnosis; Hypnotizability; Waterloo-Stanford Standard; Fractal Dimension

1. INTRODUCTION

To define hypnosis, it could be referred to a mental state produced through induction. Some people think of that as a kind of hypnoidal anesthesia while the various neurological researches reveal that hypnosis is a state of consciousness in which the individual enjoys the high degree of concentration [1] and as being isolated from peripheral environment, s/he is extremely suggestible.

For the time being, hypnosis is applied in various fields such as medicine, psychology, dentistry and …. To make use of hypnosis as a therapeutic means, the patient should be appropriately receptive to hypnosis to get the required depth-point. It is the point at which the patient would take and accept the therapeutic instructions and could behave or act based on received inductions so that the therapy could be efficiently carried out. International standards are applied to assess/estimate the depth of hypnosis. According to the international standards, the individual goes under hypnosis, then the hypnotizer orders her/him to do a special task. How the patient follows the order helps the hypnotizer to estimate the depth. This method may cause a hypnosis-depth decrease, so it is more beneficial to apply methods which estimate the hypnosis depth ordering the patient and this is what a great deal of researches aim at.

In recent years due to advances in the field of biomedical science, a large number of researches on hypnosis and its impact upon different biosignals have been carried out. While under the influence of hypnosis, the body experiences physiological shifts such as the change in the rhythm of the heart, hypotension, resistance of peripheral vessels, electrical resistance of the skin, basic metabolism, body temperature, rate and depth of breathing et al. Hypnotic inductions can also change the tone of muscles and release of endocrine glands so it has led scholars to do various researches on hypnosis, applying EEG (Electroencephalograph), fMRI, PET, skin-resistance measurement, heart rate et al. since EEG signal recording, in comparison with other methods, is more readily accessible and easier to use, a lot of experts have applied it to hypnosis investigations.

A wide variety of studies focused on the spectrum of the hypnotic EEG signals [1-17] while some recent researches were performed not applying the spectrum. Faber et al. studied the EEG signals during hand rising in both not hypnotized and hypnotized states [18]. Nasrabadi studied EEG signals in different mental status (baseline, tasks, hypnosis) in people with different hypnotizability [19]. Lee *et al*. applied fractal analysis to investigate EEG signals in both states of hypnotized and not hypnotized [20]. Solhjoo et al extracted fractal dimensions of normal and hypnotic EEG signal to classify different mental tasks [21]. Baghdadi studied features extracted from hypnotic EEG using improved empirical mode decomposition (EMD) algorithm [22,23]. Ray investigated the difference between EEG signals' fractal dimensions of lowly and highly hypnotizable subjects [2]. Behbahani analyzed the nature of hypnosis in right, left, back and frontal hemisphere in three groups of hypnotizable subjects by means of fuzzy similarity index method [24,25].

In researches carried out so far, different methods have been used to examine EEG signals of the hypnotized subjects; However, most those researches applied the EEG signals during induction and investigating the EEG signals of the hypnotized as doing mental tasks (standard orders of Waterloo-Stanford) has not still been realized. Therefore in the pursuit of this purpose, the current study has been proposed. This study examined the recorded EEG signals of three groups of people whose hypnotizability levels ranged in low, medium and high hypnosis receptivity. The signal recording was done as they were doing the mental tasks (standard orders of Waterloo-Stanford) so, the impacts of hypnosis depth and concentration rate on recorded signals of these three groups of people -with different hypnotizability levels- could be properly examined and variation of dynamics throughout different mental tasks would be investigated.

The researches performed in the last 25 years indicates the existence of chaotic dynamics in both microscopic (neuron performance) and macroscopic levels (brain activities during sleep) [26,27], so obtaining the accurate and better results, through the application of chaotic methods to EEG investigation in the hypnotized could be expected. By the means of extracting and comparing the chaotic features, the difference between the recorded EEG throughout the same activities but different hypnotizability depth-levels (low, medium and high) could be examined. Therefore in this research, the existing difference of the dominant dynamics in these three groups with different hypnotizability and also the kind of differences have been studied. Should any distinction of the extracted chaotic features between these three hypnotized groups observed, those differences could serve as the criteria for hypnosis-depth determination to exert appropriate inductions, EEG examination during hypnosis provides the data for studying hypnosis stages and the transfer from one stage to another.

2. MATERIALS

For the required data in the study, Nasrabadi data base [19] used. The data were obtained according to 20-10 standard consisting of 19 electrodes. The subjects of the study included 33 male participants with age range of 32 ± 6. The sampling was taken at 256 Hz. The subjects all featured in left-hemisphere dominancy. Being right-handed (writing with right hand) was the criterion to recognize the subjects as left-hemisphere dominants. The signal recording time was the same for all (16 pm-20 pm). Signal recording were taken twice and in 2 different situations: once in a state of being relaxed with their eyes closed-baseline signal- and for the second time, the recording was taken at the state of being hypnotized. To examine the shifts in the level of hypnosis, EEG signals are required to be recorded under the state of hypnosis. To do so, following the whole stages of Waterloo-Stanford standard, a 45-minute audio file was provided, the same audio file was utilized for hypnosis induction in all the subjects and there was no change in speech tone. So, all the subjects were placed under the equal circumstances. The first 15 minutes of audio file was assigned to the hypnosis induction. It starts including an individual- conscious and in normal state, then in order to determine the hypnotizability score, the participant is asked to do 12 different tasks as the following respectively:

1) Hand lowering (ideomotors),
2) Moving hands together (ideomotors),
3) Experience of mosquito (hallucination),
4) Taste experience (hallucination),
5) Arm rigidity (challenge),
6) Dream (memory),
7) Arm immobilization (challenge),
8) Age regression (memory),
9) Music hallucination (hallucination),
10) Negative visual (hallucination),
11) Posthypnotic automatic writing (memory) and
12) Amnesia (memory).

When tasks-performance ends, the scores of hypnotizability and the depth of hypnosis are determined based on each individual performance [28,29]. The EEG signals of all electrodes have been recorded throughout induction and all tasks. In present research EEG signals of hallucination were chosen to investigate.

3. METHOD

Parameters that represent chaotic behavior may be divided to two categories. The first category indicates dynamic behavior. Maximum Lyapunov Exponent (MLE) is of this category. These parameters state how the system behaves oh the nearby trajectories. The second category emphasizes the geometric property of basin of attraction. Fractal dimension is of this category [21]. In present study two fractal dimensions were used: Higuchi fractal dimension and correlation dimension.

3.1. Higuchi Algorithm

k new time series are constructed from the signal under study:

$$x_m^k = \left\{ x(m), x(m+k), x(m+2k), \cdots, x\left(m + \left[\frac{N-m}{k} \right] k \right) \right\}$$

for $m = 1, 2, \cdots, k$

(1).

Where m and k indicate the initial time value, and the discrete time interval between points, respectively. For each of the k time series x_m^k, the length of $L_m(k)$ is computed:

$$L_m(k) = \frac{\sum_{i=1} \left| x(m+ik) - x(m+(i-1)k) \right| (N-1)}{\left[\frac{N-m}{k} \right] k} \quad (2).$$

Where N is the total length of the signal $x(1), x(2), \ldots, x(N)$. An average length is computed as the mean of the k lengths $L_m(k)$ (for $m = 1,2,\ldots,k$). This procedure is repeated for each k ranging from 1 to $k_{\max}$, obtaining an average length for each k. Then the slope of the best fitted line to the curve of $\ln(L(k))$ versus $\ln(1/k)$ is the estimate of Higuchi fractal dimension [30].

3.2. Correlation Dimension

It begins by writing the correlation sum as the following form:

$$C^{(d)}(R) = \frac{1}{N(N-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \Theta \left[R - \left| \vec{x}_i - \vec{x}_j \right| \right] \quad (3).$$

Where d is the number of embedding dimension and x values are vectors in that embedding dimension. Then the correlation sum tells us the relative number of pair of points that are located within the distance of R of each other in this space. $D_c(d)$ is defined to be the number that satisfies $C^{(d)}(R) = kR^{-D_c(d)}$. For $d > d_{sat}$ (a saturation value), D_c becomes independent of the embedding dimension d and this is the estimate of correlation dimension (**Figure 1**) [31-33]. A d dimensional vector is the collection of d components

$$\vec{x}_i = \left(x_i, x_{i+t_L}, x_{i+2t_L}, \cdots, x_{i+(d-1)t_L} \right) \quad (4).$$

Where t_L is called the time lag and represents the time interval between the successively sampled values that we use to construct the vector $\vec{x}_i$. To choose the time lag t_L there are two dominant methods. The first is to choose the lag at which the first zero-crossing of the autocorrelation function for the data occurs. Another method is to select the first local minimum of the average mutual information function. In present study the later procedure was applied [34].

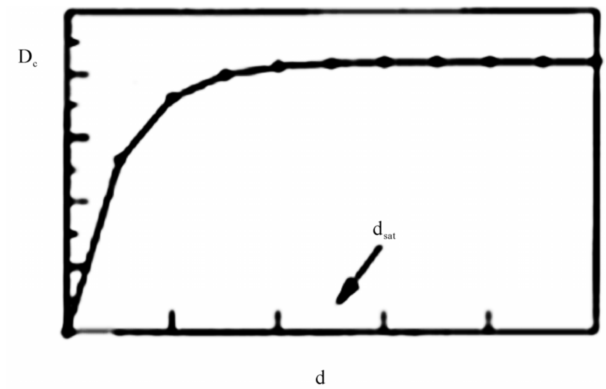

Figure 1. D_c as a function of embedding dimension.

4. RESULTS

First, the DC parts of each signal were removed and Higuchi and correlation dimension of both baseline and hypnotic signals calculated. In the next stage, with the purpose of normalizing the fractal dimensions of hypnotic signals, those of baseline signals were employed. Applying ANOVA statistic analysis, the following stage went on in order to find out if there is a significant difference of their features- either normalized or not normalized- among three hypnotizable groups (low: 1, medium: 2 and high: 3) while going through the same tasks. Analysis results of hallucination tasks including channels whose fractal dimension enable us to differentiate three hypnotizable groups with p-values less than 0.05 and mean values of fractal dimensions for distinguished groups are presented in the following tables.

As can be seen from **Tables 1** and **2** of task3 (experience of mosquito), **Tables 3** and **4** of task4 (taste experience), **Tables 5** to **8** of task9 (music hallucination) and **Tables 9** to **12** of task10 (negative visual), in hallucination tasks, channels of left hemisphere (except task3)and frontal lobe were more efficient and this is consistent with function of frontal lobe concerned with the reception and processing of sensory information from the body [35].

5. CONCLUSIONS

Employing the chaotic methods, the current study was going to find out the impact, if any, of hypnosis depth on EEG signals recorded while the individuals were doing mental tasks under the hypnosis. The results of the study indicates just a few number of channels, not all, can be of an aid in discriminating between people with various levels of hypnotizability and the similarity among those

Table 1. Task3-Higuchi dimension-Normalized.

channels	Distinguished groups(mean)	
F_3	1[a](0.963)	3(1.060)

a. Low: 1, medium: 2, high: 3.

Table 2. Task3-Correlation dimension-Normalized.

channels	Distinguished groups(mean)	
F_4	2(5.2483)	3(3.074)
T_4	1(5.099)	3(2.051)
	2(4.073)	3(2.051)

Table 3. Task4-Higuchi dimension-Normalized.

channels	Distinguished groups(mean)	
F_Z	1(0.957)	2(1.009)
F_3	1(0.958)	3(1.079)
	2(1.019)	3(1.079)
F_7	1(0.961)	3(1.071)
	2(0.998)	3(1.071)
C_3	1(0.981)	3(1.054)
P_3	2(0.995)	3(1.041)

Table 4. Task4-Correlation dimension-Not normalized.

channels	Distinguished groups(mean)	
C_4	2(8.398)	3(6.758)

Table 5. Task9-Higuchi dimension-Not normalized.

channels	Distinguished groups(mean)	
P_3	1(0.736)	2(0.858)

channels of the same task type is considerable (**Figure 2**).

Looking closely at the results, it can be noticed that in all tasks except task3, channels of left hemisphere were more efficient and this fact may be due to subjects being right-handed and left hemisphere dominancy.

A great consistency exists between channels involved with corresponding brain lobes: task3, task4, task9 and task10 of hallucination type; channels of frontal lobe.

A remarkable finding yielded through the statistic in

Table 6. Task9-Higuchi dimension-Normalized.

channels	Distinguished groups(mean)	
F_Z	1(0.914)	2(1.0199)
	1(0.914)	3(1.063)
F_3	1(0.906)	3(1.092)
	2(1.020)	3(1.092)
F_7	1(0.964)	3(1.084)
	2(1.020)	3(1.084)
C_3	1(0.972)	3(1.069)
	2(1.013)	3(1.069)
T_6	1(0.908)	2(1.015)
	1(0.908)	3(1.094)
	2(1.015)	3(1.094)
P_3	1(0.875)	2(0.997)
	1(0.875)	3(1.056)
	2(0.997)	3(1.056)

Table 7. Task9-Correlation dimension-Not normalized.

channels	Distinguished groups(mean)	
C_4	1(5.893)	2(8.543)
T_6	1(2.275)	2(7.661)
	1(2.275)	3(7.160)
P_3	1(4.212)	2(7.628)
	1(4.212)	3(7.590)
O_2	1(3.842)	2(8.967)

Table 8. Task9-Correlation dimension-Normalized.

channels	Distinguished groups(mean)	
T_6	1(1.562)	2(4.549)

Table 9. Task10-Higuchi dimension-Not normalized.

channels	Distinguished groups(mean)	
P_3	1(0.715)	2(0.854)

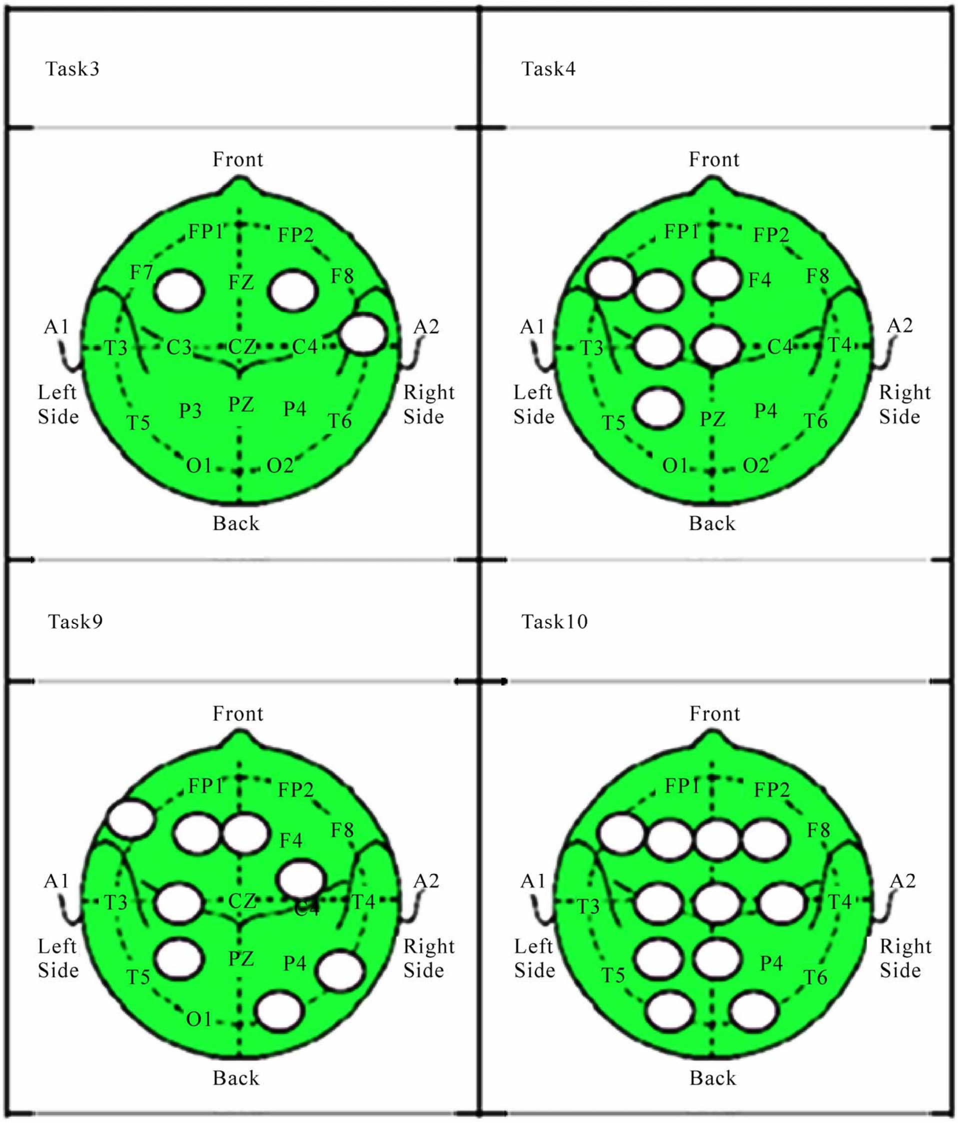

Figure 2. channels of hallucination tasks.

Table 10. Task10-Higuchi dimension-Normalized.

channels	Distinguished groups(mean)	
F_z	1(0.910)	2(1.004)
F_3	1(0.894)	3(1.070)
	2(1.000)	3(1.070)
F_7	1(0.939)	3(1.052)
P_3	1(0.850)	2(0.992)
	1(0.850)	3(1.030)

vestigations was that in extracting various features of all 10 tasks and all 19 channels the features' variance of the medium hypnotizable group was the least and the low hypnotizable group showed the maximum variance in each extracted feature. This fact shows that the medium hypnotizable subjects were mostly affected by inductions and instructions of the hypnotizer (more than low or high hypnotizable subjects) and the low hypnotizable subjects had the least affectability while the high hypnotizable subjects stood in between, less affectability than medium hypnotizables and more affectability than low hypnotizable ones.

For further study these channels could be applied to proposing various kinds of classifiers so as to define more objective hypnosis scoring methods.

Moreover, the results of the study can be applied to study the dynamics of any task by the means of fractal dimensions.

Table 11. Task10-Correlation dimension-Not normalized.

channels	Distinguished groups(mean)	
F_4	1(3.666)	2(8.050)
	1(3.666)	3(7.096)
F_z	1(5.039)	2(8.423)
F_3	1(3.510)	2(7.683)
	1(3.510)	3(7.532)
F_7	1(4.763)	2(7.546)
C_4	1(5.117)	2(8.374)
C_z	1(4.838)	2(8.534)
	1(4.838)	3(8.348)
C_3	1(5.277)	2(8.976)
P_z	1(4.484)	2(8.260)
	2(8.260)	3(6.454)
P_3	1(3.419)	2(8.842)
	1(3.419)	3(8.022)
O_2	1(3.694)	2(8.608)
O_1	1(5.112)	2(9.186)

Table 12. Task10-Correlation dimension-Normalized.

channels	Distinguished groups(mean)	
F_3	1(1.310)	2(4.068)
	1(1.310)	3(3.586)
C_3	1(2.305)	2(5.431)
P_z	2(5.077)	3(3.011)

Hallucination tasks:

1) In task3, correlation dimensions of group 3 are less than others and by contrast higuchi dimension of group 3 is higher than that of group1.

2) In task4, Higuchi dimension of group 3 are greater than others, Higuchi dimension of group1 is less than that of group2 and by contrast correlation dimension of group 2 is higher than that of group3.

3) Task9 indicates group 1 fractal dimensions are less than those of group 2 and 3 and dimensions of group 3 are greater than those of group 2.

4) Task10 shows group 1 fractal dimensions are less than those of group 2 and 3 and higuchi dimension of group 3 is greater than those of group 2 while correlation dimension of group 3 is less than those of group 2.

Considering the above-mentioned analysis, similarities among dynamics of tasks of the same type are considerable. The results of the study can not be compared with any other research because there is no previous study over EEG signals of Waterloo-Stanford tasks.

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