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Study of Correlations of Multichannel Human EEG

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Contained in this paper are preliminary results in describing the multichannel human EEG data by measures of correlation. It is investigated if linear cross-correlation measures such as Pearson's r, Spearman's ρ, and Kendall's τ would give the same information of correlation. The EEG data were recorded from 11 healthy adult human subjects, taken in two conditions: resting eyes closed and resting eyes open condition. The computation is implemented using Scilab 5.1. The results show that using Kendall's τ is impractical because it requires longer computing time. The calculation was carried out with this constraint and the result, Pearson's r and Spearman's ρ yields almost the same results, thus Pearson's r is appropriate to represent a linear measure of cross-correlation. On average the multichannel EEG are relatively uncorrelated in eyes open than in eyes closed condition. This result serves as baseline to identify non-linear correlation between multichannel EEG.

1. INTRODUCTION

The human brain is an example of extremely remarkable complex system because it composes millions of neurons that activate erratically [1]. Electroencephalography (EEG) is the recording of electrical activity along the scalp produced by the firing of neurons within the brain [1]. With these electrical signals the abnormalities of our brain activities can be detected. Though the procedures in diagnostic applications are already established in qualitative description, this is also open to researches that seek further methods to describe the information in the EEG [1].

EEG is seemingly unpredictable which is similar to the behavior of chaotic systems. This behavior leads to the application of tools in nonlinear dynamics and time series analysis since they are promising to extract information or dynamics of a complex real world data such as EEG [2].

The motivation of this research is to quantify the description or dynamics of Electroencephalographic (EEG) data by measures of correlations. The 10-channels EEG data is taken from 11 human subjects. Two set of data were recorded; one for resting eyes closed and another for resting eyes open condition for every human subject. The main goal of this study is to calculate the linear correlation measures such as the Pearson's linear correlation coefficient r, the Spearman's rank order correlation ρ and Kendall's τ, a nonparametric measure of correlation, and compare the nature of correlations between the two eyes condition.

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2. MEASURES OF CORRELATION

In the following section the statistical tools to calculate correlation measures are discussed from literature.

2.1. Pearson's r

The cross-correlation coefficient r is a measure of how two variables track each other. Given a series of simultaneously measured values of two variables pertaining to the same system, $X = \{x_1, x_2, ..., x_N\}$ and $Y = \{y_1, y_2, ..., y_N\}$, the cross-correlation coefficient of X and Y is estimated by,

$$r = \frac{1}{N}\sum_{k=1}^{N}\frac{(x_k - \langle x\rangle)(y_k - \langle y\rangle)}{\sigma_x \sigma_y} \tag{1}$$

where N is the length of the data set, $\langle x\rangle$ is the mean of data set X and $\langle y\rangle$ is the mean of data set Y, σ_x and σ_y are their respective standard deviations [3].

2.2. Spearman's ρ

Spearman's ρ is a non-parametric measure of correlation that is, it assesses how well an arbitrary monotonic function could describe the relationship between two variables, without making any other assumptions about the particular nature of the relationship between the variables. In principle, ρ is simply a special case of the Pearson product-moment coefficient in which two sets of data X and Y are converted to rankings $R(x_k)$ and $R(y_k)$ before calculating the coefficient. The calculation of ρ, if there are no tied ranks is given by:

$$\rho = 1 - \frac{6}{N(N^2-1)} \sum_{k=1}^{N} [R(x_k) - R(y_k)]^2 \quad (2)$$

However if a moderate number of ties is present in the data, Equation (2) is recommended for computational simplicity [4].

2.3. Kendall's τ

The Kendall's τ is a non-parametric statistics used to measure the degree of correspondence between two rankings and assessing the significance of this correspondence. In other words, it measures the strength of association of the cross tabulations. The data sets X and Y consist a bivariate sample of size N, (x_i, y_i) for $i = 1, 2, ..., N$. One pair of observation $((x_i, y_i),\ (x_j, y_j))$ can be counted as concordant if $(y_j - y_i)/(x_j - x_i) > 0$, while it can be counted as discordant if $(y_j - y_i)/(x_j - x_i) < 0$ [4]. Then the measure of correlation proposed by Kendall[4] in case of no ties is

$$\tau = \frac{N_c - N_d}{N(N-1)/2}. \quad (3)$$

where N_c is the total number of concordant pairs and N_d is the total number of discordant pairs out of $N(N-1)/2$ total pairs. In case of ties or $(y_j - y_i)/(x_j - x_i) = 0$ the pair should be counted as $\frac{1}{2}$ concordant and $\frac{1}{2}$ discordant, while if $x_j = x_i$ no comparison can be made, and τ can be computed as [4]

$$\tau = \frac{N_c - N_d}{N_c + N_d}. \quad (4)$$

3. THE EEG RAW DATA

Multichannel EEG signals were recorded from eleven healthy adult human subjects. Monopolar recordings, referenced to linked earlobes Fz, Cz, Pz, Oz, F3, F4, C3, C4, P3, and P4, were obtained using an electrocap as shown in Figure 1. Artifact corrupted records were removed. All EEG impedances were less than 5kΩ. Signals were amplified, Gain = 18000, and amplifier frequency cutoff settings of $0.03Hz$ and $200Hz$ were used. Signals were digitized at $1024Hz$ using a twelve-bit digitizer. Continuous artifact-free multichannel records were obtained in two conditions: resting, eyes closed and resting, eyes open . Figure 2 is the multichannel EEG of human subject 3 in eyes closed and eyes open condition.

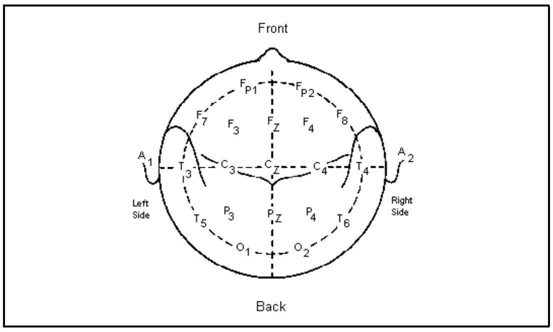

Figure 1. Top view of human scalp showing the "10-20 system" electrode positions for Multichannel EEG.

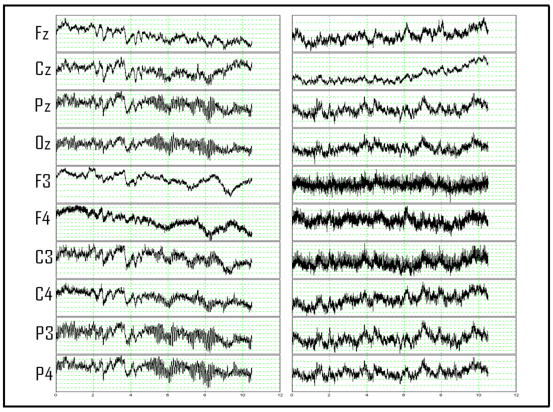

Figure 2. Multichannel EEG of human subject 3, (left) eyes closed and (right) eyes open condition. Horizontal axis is up to 12 seconds.

4. RESULTS AND DISCUSSIONS

The computations are implemented using Scilab 5.1. The calculation for Kendall's τ is impractical for a data set of length $N = 10500$ (the default EEG data length for at least 10sec) because of longer computing time ($\approx$ 26.91 min/channel pair), since it has 55119750 pairs. Because of this constraint, smaller data length $N = 100$ is chosen to compare the calculations of Pearson's r, Spearman's ρ, and Kendall's τ.

Table 1
The summary for pairing of channels.

	Channel Pairs		Channel Pairs		Channel Pairs
1	Cz-Fz	16	C3-Fz	31	P3-Pz
2	Pz-Fz	17	C3-Cz	32	P3-Oz
3	Pz-Cz	18	C3-Pz	33	P3-F3
4	Oz-Fz	19	C3-Oz	34	P3-F4
5	Oz-Cz	20	C3-F3	35	P3-C3
6	Oz-Pz	21	C3-F4	36	P3-C4
7	F3-Fz	22	C4-Fz	37	P4-Fz
8	F3-Cz	23	C4-Cz	38	P4-Cz
9	F3-Pz	24	C4-Pz	39	P4-Pz
10	F3-Oz	25	C4-Oz	40	P4-Oz
11	F4-Fz	26	C4-F3	41	P4-F3
12	F4-Cz	27	C4-F4	42	P4-F4
13	F4-Pz	28	C4-C3	43	P4-C3
14	F4-Oz	29	P3-Fz	44	P4-C4
15	F4-F3	30	P3-Cz	45	P4-P3

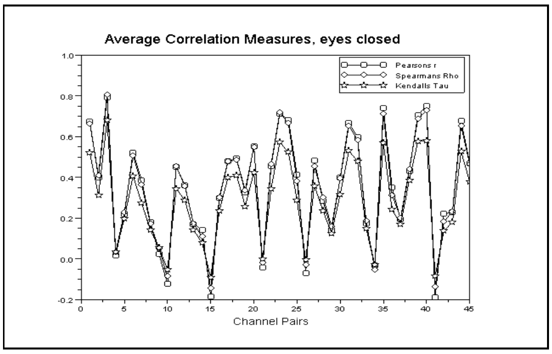

Figure 3. Comparison between the three measures of correlation using length $N = 100$.

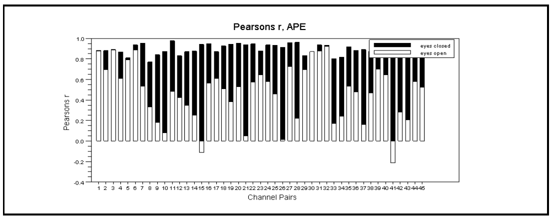

Figure 4. Pearson's r of human subject 1 in eyes closed and eyes open condition.

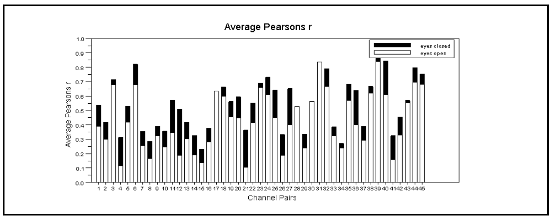

Figure 5. Average Pearson's r over 11 subjects in eyes closed and eyes open condition.

The results are shown in Figure 3. This shows that the three measures rise and fall together. Spearman's ρ yields almost the same result with Pearson's r, while Kendall's τ seems to differ by some scaling factor. In fact the cross-correlation coefficient (r) of Pearson's r and Spearman's ρ is 0.98, Pearson's r and Kendall's τ is 0.97, then Spearman's ρ and Kendall's τ is 0.98 using their average in eyes closed condition. The important thing is that they convey the same information on how a particular channel pair is correlated relative to other channel pairs. Thus for practicality, the Pearson's r was chosen in this study to represent linear measure of correlation because it is easier to implement.

To compare the nature of correlations in the resting eyes closed and resting eyes open condition for 11 human subjects, $N = 10500$ is used in the computation of Pearson's r. The first human subject was already introduced in the review of A.M. Albano [3] and it is reproduced and shown in Figure 4. This result shows that with eyes closed, all channel pairs are highly correlated, while with eyes open, most are relatively uncorrelated. In order to generalize the conclusion, all subjects are taken into account. The average for all human subjects were calculated. The result is shown in Figure 5. The result exhibits the same behavior with the first human subject except for channel pairs 17, 28, 30 and 31.

5. SUMMARY AND CONCLUSION

The three measures of correlation gave the same results qualitatively and quantitatively by their cross-correlation coefficients, Kendall's τ differ from the other two measures by some scaling factor. Using Pearson's r, resting eyes closed and resting eyes open condition of the human brain was distinguish from its EEG signals in 11 human subjects. That is, with eyes open condition most channel pairs of EEG are relatively uncorrelated with respect to eyes closed condition.

This paper serves as baseline to further investigate non-linear correlations between multichannel EEG, this can be carried out by comparing Pearson's r to mutual information I from information theory since I can detect both linear and non-linear correlations between data streams.

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