Connectivity analysis of quantitative Electroencephalogram background activity in Autism disorders with short time Fourier transform and Coherence values

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Abstract

Electroencephalography (EEG) is widely used in clinical settings to investigate neurophysiology. Since EEG signals contain a wealth of information about brain functions, there are many approaches in analyzing EEG signals with spectral techniques. We have used short time Fourier transform (STFT) at 19 channel's of EEG for 10 Autism disorders (6-11 years old) and 7 age matched control subjects. The values were assessed with variance analysis. Results are shown that beta band (14-34Hz) has 82.4% discriminate between two groups. Coherence values at between 112 pairs of 19 channels EEG are shown there are abnormalities connectivity in parietal lobe and temporal lobe and connectivity between these lobes and central lobe.

Keywords: EEG, Autism, STFT, coherence

1. Introduction

Autism spectrum disorders (ASDs) are devastating conditions with an onset in early childhood and core symptoms of varying degree involving communication and social and cognitive development, and usually sparing gross motor development.

In 1943, Kanner [1] first described the case of an autistic individual who developed epilepsy, and since then, multiple case reports or population series have described an association of abnormal EEG findings within autistic individuals [2-5].

Autism spectrum disorders affect 1 in 166 births. Although EEG abnormalities and clinical seizures may play a role in ASDs, the exact frequency of EEG abnormalities in an ASD population that has not had clinical seizures or prior abnormal EEGs is unknown [6].

The electroencephalogram (EEG) is a record of a time series of evoked potentials caused by systematic neural activities in brain. The measurements of the human EEG signals are performed through electrodes placed on the scalp, and they are usually recorded on paper against time. The voltage of the EEG signal corresponds to its amplitude. The typical amplitudes of the scalp EEG lay between 10 and 100 μV, and in adults more commonly 10 and 50 μV [7, 8].

EEG signals involve a great deal of information about the function of the brain. But classification and evaluation of these signals are limited. Since there is no definite criterion evaluated by the experts, visual analysis of EEG signals in time domain may be insufficient. Routine clinical diagnosis needs to analysis of EEG signals. Therefore, some automation and computer techniques have been used for this aim. Since the early days of automatic EEG processing, representations based on a Fourier transform have been most commonly applied. This approach is based on earlier observations that the EEG spectrum contains some characteristic waveforms that fall primarily within five frequency bands-delta (<4Hz), theta (4-8Hz), alpha (8-12Hz), beta (14-34Hz) and gamma (34-44Hz). Such methods have proved beneficial for various EEG characterizations [7, 8].

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Interactions between EEG channels were assessed by coherence values. Electroencephalographic coherence analysis constitutes a noninvasive technique for studying cortico -cortical associations and can be interpreted as the degree of coupling between two signals; coherence of EEG signals from different brain regions is assumed to index anatomic of functional coupling between these signals in frequency domain [9, 10].

The paper is organized as follow. In section 2 we explain the selection of Autism and controls subjects, and the procedure for recording the EEG and selecting artifact-free epochs. Coherence values used to evaluate the differences between autism disorder and control subjects are also introduced in section 2. Section 3 presents our results and compares them in autism disorders. Finally we present our future work and conclusions.

2. Methods

A. Selection of disorders and controls

We studied 10 Autism disorders (9 boy and 1 girl; age = 9.3 ± 1.8 years, mean $\pm$ standard deviation (S.D.)). Patients were diagnosed as having an ASD by DSM-IV-TR criteria [11]. The patients were recruited from the Autism Patient's Relatives Association of Roozbeh Hospital (Tehran), where the EEG was recorded.

The control group consisted 7 age-matched, control subjects without past or present neurological disorder (4 boys and 3 girls; age 9.2 ± 0.7 years, mean $\pm$ S.D.). All control subjects and all caregivers of the demented disorders gave their informed consent for participation in the current study. An EEG was recorded from all disorders and controls.

B. EEG recording

The EEGs were recorded from the 21 scalp loci of the international 10 – 20 system (channels FP1, FP2, F7, FZ, F4, F8, T3, C3, CZ, C4, T4, T5, P3, PZ, P4, T6, O1, O2, A2, A1) with both earlobes chosen as common referential electrodes. Recordings were made with the subjects under a controlled behavioral condition (sustained attention to see the picture of their mother). In order to obtain as many artifact-free EEG data as possible More than 10 minute of data were recorded from each subject. Data were first processed with a low-pass hardware filter at 100Hz, and then they were sampled at 256 Hz and digitized by a 12-bit analogue-digital converter.

The recordings were visually inspected by a specialist physician to reject artifacts. Thus, only EEG data free from electrooculographic and movement artifacts and with minimal electromyography (EMG) activity were selected. Afterward, EEGs were organized in 3 s artifact-free epochs (768 points) that were copied as ASCII files for off-line analysis on a personal computer. An average number of 30.0 ± 12.5 artifact-free epochs (mean $\pm$ S.D.) were selected from each electrode for each subject.

In order to remove the residual EMG activity and the noise owing to the electrical main, all selected epochs were digitally filtered. We used a Hamming window FIR band-pass filter with cut-off frequencies at 0.5 and at 100 Hz and designed with Matlab7.1. The 10-20 International EEG electrode placement system is shown in Figure 1.

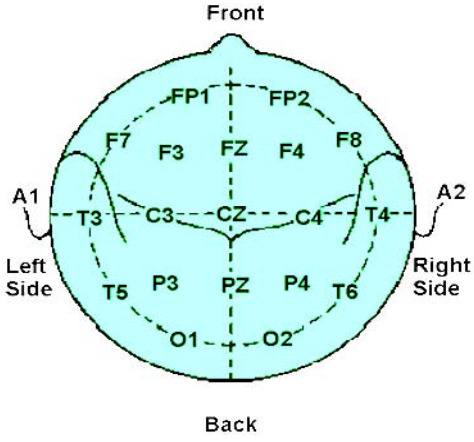

Figure 1: International EEG electrode placement system

C. STFT and STFT-BW values

Fourier analysis decomposes signal into its frequency components and determines their relative strengths. We define the Fourier transform as

$$F(w) = \int_{-\infty}^{+\infty} f(t) e^{-jwt} dt \leftrightarrow f(t)$$

$$= \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(w) e^{jwt} dw \qquad (1)$$

This transform is applied to stationary signals, that is, signals whose properties do not evolve in time. When the signal is non-stationary we can introduce a local frequency parameter so that local Fourier transform looks at the signal through a window over which the signal is approximately stationary. Therefore, we

applied the STFT to the EEG signals under study. The STFT positions a window function $\psi(t)$ at τ on the time axis, and calculates the Fourier transform of the windowed signal as

$$F(w,\tau) = \int_{-\infty}^{+\infty} f(t)\psi^*(t-\tau)e^{-jwt}dt \qquad (2)$$

When the window $\psi(t)$ is a Gaussian function, the STFT is called a Gabor transform are generated by modulation transformation of the window function $\psi(t)$, where w and τ are modulation and translation parameters, respectively. The fixed time window $\psi(t)$ is the limitation of STFT as it causes a fixed time-frequency resolution. This is explained by the uncertainty principle (Heisenberg inequality-meaning one can only trade time resolution for frequency resolution, or vice versa) for the transform pair

$\psi(t) \leftrightarrow \Psi(w)$

$$\Delta t \Delta w \geq \frac{1}{2} \qquad (3)$$

Where Δw and Δt are the bandwidth and time spread (i.e. two pulses in time can be discriminated only if they are more than Δt apart) of $\psi(t)$, respectively, and

$$\Delta t^2 = \frac{\int t^2 \left|\psi(t)^2\right| dt}{\int \left|\psi(t)\right|^2 dt} \qquad (4)$$

$$\Delta w^2 = \frac{\int w^2 \left|\psi(w)\right|^2 dw}{\int \left|\psi(w)\right|^2 dw} \qquad (5)$$

When t increases, the window function translates in time. On the other hand, the increase in w causes a translation in frequency with a constant bandwidth [12, 13].

Spectral edge frequency 95% (SEF) and median frequency (MED) are variables derived from EEG. These variables have used in several studies [14, 15]. In the STFT-BW we calculated mean of components STFT at bandwidth of total power spectrum [16]. This is sign of contributed peak of STFT in duration of time. This trend is designed with Matlab.

STFT_BW has quality information of signal that we used at this study for discriminate of autism and control subjects.

D. Coherence values

Coherences and connectivity between channels Calculation of coherence variables averaged periodogram was calculated over the ten 3-second epochs for each recording. A hanning window without overlapping was used in order to prevent spectral leakage. Auto and cross-power spectra were estimated for the 112 channel pairs in order to obtain MSC function. For two signals $\xi(t)$ and $\eta(t)$ with respective auto spectra $P_{\xi\xi}(f)$ and $P_{\eta\eta}(f)$, and cross-spectrum $P_{\xi\eta}(f)$, MSC is given at each frequency bin by the following Equation [17]:

$$MSC(f) = \frac{\left|P_{\xi\eta}(f)\right|^2}{P_{\xi\xi}(f)P_{\eta\eta}(f)} \qquad (6)$$

Where MSC is the estimated coherence range between 0 and 1. For a given frequency (f_0), $MSC(f_0) = 0$ indicates that the activities of the signals in this frequency are linearly independent, whereas a value of $MSC(f_0) = 1$ gives the maximum linear correlation for this frequency [18]. This trend is designed with Matlab7.1.

E. Statistical analysis

One-way ANOVA tests were used to evaluate the statistical differences between the estimated coherence values at 112 pair's electrodes for ASD disorders and control subjects. If significant differences between groups were found, the ability of these analysis method to discriminate ASD disorders from control subjects was evaluated using receiver operating characteristic (ROC) plots [19,20].

The value for the area under the ROC curve can be interpreted as follows: an area of 0.90(electrode FP1 for example) means that a randomly selected individual from the control subject's group has a coherence value larger than of a randomly chosen individual from the ASD disorder's group in 90% of the time. A rough guide to classify the precision of a diagnostic test is related to the area under the ROC curve. With values between 0.90 and 1 the precision of the diagnostic test is considered to be excellent, good for values between 0.80 and 0.90. Far fair if the results are in the range 0.70-0.79, poor when the value of the area under the ROC curve is between 0.60 and 0.69, and bad for values between 0.50 and 0.59.

For classification between autism and control subject's we used nearest neighbor classifiers. They consist in assigning a feature vector to a class according to its nearest neighbor(s). This neighbor can be a feature vector form the training set as in the case of k nearest neighbors (KNN), or a class prototype as in Mahalanobis distance. They are discriminative nonlinear classifiers. According to the so-called Mahalanobis distance $d_c(x)$ [21]:

$$d_c(x) = \sqrt{(x-\mu_c)M_c^{-1}(x-\mu_c)^T} \qquad (7)$$

This lead to a simple yet robust classifier, which even provide to be suitable for multicasts [22].

3. Results and discussion

STFT-BW [16] were estimated for channels FP1, FP2, F7, FZ, F4, F8, T3, C3, CZ, C4, T4, T5, P3, PZ, P4, T6, O1, O2, A2, A1. The results have been averaged based on all the artifact-free 3s epochs (N = 768 points) within the 10-min period of EEG recordings.

The average of STFT-BW values evaluate for the ASD disorders and control subjects were the 19 electrodes [16]. STFT-BW values (means $\pm$ S.D.) summarized in Table I. The ASD disorders have significantly values ($p < 0.01$) at electrodes FP1, F3 and T5 and with ($p < 0.05$) at electrodes F7, T3 and O1 in Table I.

We evaluated the ability of the STFT-BW to discriminate ASD disorders from control subjects at the electrodes in which significant differences were found using ROC plots. Table II summarizes the results.

It can be seen from Table II that the values of ROC for FP1, F7, F3, T3, T5 and O1 have significant with STFT-BW. We used nearest neighbor classifiers for classification between autism and control subject's for STFT-BW at the 19 electrode. Using STFT-BW we obtained the highest classification (82.4%). Results are summarized in Table III.

The functional connectivity was investigated by computing coherence with 112 pair's electrodes. The results have been averaged based on all the artifact-fee 3s epochs (N=768) within the 10 minute period of EEG recordings. The Coherence values (mean $\pm$ S.D.) for ASD disorders and control subjects that have significantly difference values ($p < 0.01$) and ($p < 0.05$) are summarized in Table IV.

TABLE I: The average STFT-BW values of the EEGs for the ASD disorders and control subjects for all channels in beta band (14-34Hz)

Electrode	ASD disorders (mean $\pm$S.D)	CONTROL SUBJECTS (mean $\pm$S.D.)	STATISTICAL ANALYSIS (p- value)
FP1*	0.184 $\pm$0.114	0.384 $\pm$0.121	0.003
FP2	0.260 $\pm$0.161	0.355 $\pm$0.175	0.266
F7*	0.170 $\pm$0.113	0.371 $\pm$0.172	0.011
F3*	0.185 $\pm$0.115	0.342 $\pm$0.072	0.006
Fz	0.203 $\pm$0.109	0.294 $\pm$0.127	0.134
F4	0.278 $\pm$0.134	0.257 $\pm$0.115	0.744
F8	0.280 $\pm$0.161	0.216 $\pm$0.097	0.367
T3*	0.178 $\pm$0.143	0.311 $\pm$0.086	0.046
C3	0.244 $\pm$0.174	0.369 $\pm$0.082	0.100
Cz	0.267 $\pm$0.147	0.278 $\pm$0.114	0.868
C4	0.331 $\pm$0.158	0.201 $\pm$0.119	0.088
T4	0.253 $\pm$0.157	0.280 $\pm$0.153	0.726
T5*	0.166 $\pm$0.086	0.309 $\pm$0.102	0.007
P3	0.188 $\pm$0.097	0.282 $\pm$0.151	0.139
Pz	0.231 $\pm$0.194	0.294 $\pm$0.147	0.482
P4	0.251 $\pm$0.161	0.250 $\pm$0.069	0.996
T6	0.244 $\pm$0.099	0.354 $\pm$0.120	0.278
O1*	0.189 $\pm$0.111	0.327 $\pm$0.132	0.034
O2	0.214 $\pm$0.149	0.313 $\pm$0.146	0.194

Significant group differences are marked with an asterisk

TABLE II: Test results STFT-BW method on channels in which the differences between both groups were significantly with ROC curve in beta band (14-34Hz).

COMPONENT	ELECTRODE	AREA UNDER THE ROC CURVE
STFT-BW	FP1	0.900
	F7	0.814
	F3	0.914
	T3	0.814
	T5	0.843
	O1	0.800

TABLE III: Classification Results with STFT-BW component in beta band (14-34Hz)

Cases	Predicted group membership		Total
	Autism	Control	
Autism	8	2	10
Control	1	6	7
Autism	80.0	20.0	100.0
Control	14.3	85.7	100.0

An 82.4% of original grouped cases correctly Classified

Figure 2 shows the obtained results for calculated MSC variables. In figure 2 we see that abnormality related to parietal lobe and frontal lobe and connection these regions with central lobe. In figure 2-b we see that connectivity at pairs electrodes (C3, F3), (CZ, F3) and (C4, F4) have significantly difference with ($p < 0.01$) in two groups subjects controls and Autism disorders that are shown with solid lines. And also in this lobe pairs electrodes (C3, FZ), (C4, F3) and (C4, FZ) have significantly difference with ($p < 0.05$) that are shown with dot lines.

Some limitations of our study merit consideration. First of all, the sample size was small. As a result, our findings are preliminary and require replication in a larger disorder population before any conclusion can be made of its clinical diagnostic value. Moreover, the significant differences of EEG are seen in autism disorders with coherence values.

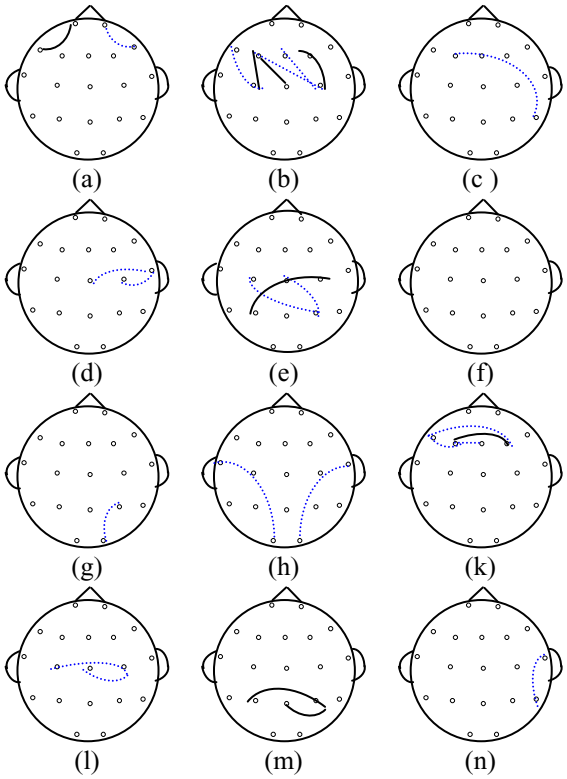

Figure 2: Results of coherence values and connectivity in channels brain. a)frontal and prefrontal lobes, b)frontal and central lobes, c)frontal and temporal lobes, d)central and temporal lobes, e)central and temporal lobes, f)temporal and parietal lobes, g)parietal and occipital h)occipital and temporal lobes, k) frontal lobe, l) central lobe, m)parietal lobe, n)temporal and occipital lobe

TABLE IV: The average coherence values of the EEGs for the ASD disorders and control subjects for all channels with significant difference in beta band (14-34Hz)

Electrode	ASD patients (mean ±S.D)	Control subjects (mean ±S.D)	Statistical analysis (p-value)
FP1-F7	0.529±0.185	0.245±0.208	0.003
Fp2-F8	0.448±0.184	0.240±0.162	0.017
F7-C3	0.561±0.224	0.348±0.128	0.029
F7-CZ	0.462±0.218	0.296±0.125	0.075
F3-C3	0.717±0.124	0.486±0.216	0.003
F3-CZ	0.598±0.161	0.386±0.180	0.010
F3-C4	0.454±0.209	0.256±0.127	0.030
FZ-C4	0.628±0.200	0.438±0.141	0.033
F4-C4	0.719±0.184	0.453±0.227	0.007
F3-T6	0.315±0.174	0.185±0.162	0.015
CZ-T4	0.414±0.216	0.244±0.113	0.047
C4-T4	0.488±0.179	0.320±0.135	0.038
C3-P4	0.589±0.182	0.385±0.232	0.031
CZ-P4	0.696±0.184	0.460±0.215	0.013
C4-P3	0.601±0.195	0.354±0.194	0.010
P3-T4	0.397±0.201	0.195±0.065	0.018
P4-T6	0.554±0.154	0.391±0.231	0.050
P4-O2	0.696±0.161	0.455±0.269	0.020
O2-T4	0.456±0.200	0.260±0.157	0.031
O1-T3	0.444±0.183	0.283±0.139	0.048
FP1-FP2	0.341±0.217	0.170±0.089	0.060
F3-F7	0.557±0.198	0.329±0.236	0.015
F3-FZ	0.634±0.162	0.439±0.168	0.015
F3-F4	0.464±0.177	0.241±0.148	0.008
F4-F7	0.348±0.197	0.158±0.050	0.021
C3-C4	0.571±0.208	0.378±0.139	0.049
CZ-C4	0.725±0.146	0.550±0.140	0.014
P3-P4	0.684±0.187	0.397±0.231	0.004
PZ-P4	0.769±0.134	0.512±0.263	0.003
T4-T6	0.527±0.183	0.326±0.179	0.013

CONCLUSIONS

We evaluated connectivity in EEG channels with coherence values for ASD disorders from control subjects. Using coherence values we obtained the channels those had significantly differences. Further work will be used other EEGs analysis for having a better discrimination both two groups, control and autism disorders.

Diagnosis Autism with quantitative EEG (qEEG) is the best of our knowledge, because it is available and non-expensive procedure and also it's non –invasive method especially for children.

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