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Gamma band changes in children with ASD under neurofeedback training

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Abstract

In neurofeedback-based systems subjects can inhibit or enhance a particular rhythm of brain signal in according to operant conditioning principle and therefore control their EEG changes. Researches have shown that neurofeedback training can decrease symptoms of behavioral level in children with Autism Spectrum Disorder (ASD). In this paper neurofeedback training effects on EEG Gamma band in 9 male children affected with ASD by features such as average, variance and power have been assessed. Subjects were under 40 sessions of neurofeedback training and EEG has been recorded in three stages before neurofeedback training, in 20th and the last neurofeedback training sessions. In addition assessing behavioral level (Symptom Assessment Scale) SAS and (Function Assessment Scale) FAS have been done too, three times, before neurofeedback training and 13 times during the course of training once in every three session and three times after finishing neurofeedback training. Statistical analysis of ANOVA and T-test has shown significant variation ($p<0.05$) in Gamma band SAS and FAS results in children under training. Result shown the significant difference ($p<0.03$) in Gamma band and also in SAS and FAS tests.

Keywords

Electroencephalography (EEG), Autism Spectrum Disorders (ASD), Neruofeedback

1. Introduction

Neurofeedback is the feedback of neurons' reactions or the brain electrical activity of the subject in order to train him to control his brain electrical activities [1]. Some of methods are used to show abnormalities in EEG of autism individuals so far [2,3,4] and using neurofeedback in the form of operant conditioning enables the subject to control his EEG parameters and thus the subject can regulate his own rhythms of brain signals [1]. Numerous studies have shown neurofeedback training has been effective in symptoms modification of attention deficit and hyperactivity in ADHD, stereotyped behaviors in obsessive-compulsive disorder, and anxiety [5]. It has also been used in modifying the symptoms of ASD [5]. The first published study in this field was done by Coben in 1994[5]. Neurofeedback training was performed in an 8 years old girl with high functional of ASD after 21 sessions of therapy her attention and social interactions increased while her repetitive behaviors decreased. Its protocol has been set according to QEEG data which tried to decrease theta and Alpha ratio to Beta in central and parietal regions [5]. In Coben's study in 2006 was used more samples with a wider spectrum of assessment tools which showed 40% decrease in autistic symptoms [6].

Kaiser and Paoletti (2006) have studied an 8 year old boy during 20 sessions of therapy with neurofeedback. In the first 4 sessions they focused on C3 and during the rest of sessions they tried to suppress bandwidth of 2-7Hz and suppress 9-14 Hz a significant decrease in symptoms of the disorders and significant increases in brain function using were observed [7].

The first group study was done by Jarusiewicz in 2002[8]. His aim was to investigate neurofeedback effectiveness in ASD children. 14 children with ASD with age mean of 7 years were undergone neurofeedback training and results were compared with a control group consisting of 12 children with the same disease. Specific frequencies have been interfered according to child's problem. Therapy was started with theta suppression and part of alpha upression in C4 (sensorimotor belt is located in right hemisphere) and after a few sessions location and the frequency would have been changed according to subject's need. Evidence showed that after 36 sessions of training, the test group showed improvement in their axial symptoms. The Diagnostic and evaluation tool used was a questionnaire called "Autism Treatment Evaluation Checklist, ATEC"[8]. According to data collected from the mentioned questionnaire, a 26% decrease in under therapy group symptoms (as reversal or controversial to 3% decrease in control group) was observed. Average of performance scores after therapy compared to before therapy showed a significant increase especially in social and lingual skills [8]. Koujzer et al. in 2008 studied 7 children of 8-12 years which 40 sessions of neurofeedback therapy. Comparing pre and post treatment results with control group showed a significant improvement in executive functions and behaviors associated with three main domain (qualitative problems in bi social interactions, problems in making social communication, having limited, repetitive and stereotyped behavioral patterns and interests) have been observed [9].

Our goal in this study was assessing Gamma band changes in ASD children in neurofeedback training and changes in behavioral levels.

2. Material and Methods

This study was done in four stages: choosing subjects, performing Symptom Assessment Scale (SAS) and Function Assessment Scale (FAS), neurofeedback training and assessing its effectiveness (in SAS, FAS and EEG analysis) before, during and after neurofeedback training.

2.1. Participants

In this stage some subjects affected with ASD were randomly chosen from two exceptional schools in Tehran voluntarily. (Peyke Honar and Besharat schools)Family members were asked to fill up a questionnaire and answer some questions regarding the subjects. The questions were about age, left or right handedness, having a specific talent or some personal information. Then considering three parameters in mind namely clinical interview with one of the parents according to Diagnostic and Statistical Manual-IV (DSM-IV) test [7], observing child's performance in 4 test environment Childhood Autism Rating Scale (CARS)[7] in class situation and in school yard and finally previous diagnosis in earlier ages or at the same time by other psychologists, subjects were chosen.

2.2. Assessing Behavioral Level Tests

In order to assess behavioral level two tests were being used. Symptom Assessment Scale, SAS, which is constructed by the researcher which is repetitively being used by him/her before and during the neurofeedback training and contains 69 short questions. ASD covers a spectrum of cognitive states with disorders in three main domains ,qualitative problems in bidirectional social interactions and problems in making social communication, repetitive or stereotyped behaviors and interests, the fore questions were made about social interactions, making contacts, disorder in imagination (limited or specific interests and behaviors) and finally also about specific problems. From the 69 questions, 21 (37.5%),14 (20%), 26 (37.5%), 4 (5.5%) and 4 (5.5%) of them were derived from Autism Treatment Evaluation Checklist, Autism Spectrum Quotient, Gould J. mentioned points[10], DSM-IV test and mother's and the researcher's observations respectively. In this scale, questions were no more yes or no questions and rather a quantitative scale with 7 Levels was used in order to monitor the tiniest details during the therapy. The content validity of this check list has been confirmed by four specialists in this field, a psychiatrist, two psychologists and a speech therapist.

2.3. Function Assessment Scale Constructed by the Researcher

In this scale, 10 important functions which are consequently changed due to neurofeedback therapy or any other forms of treatment in the autistic spectrum disorder, were considered in a quantitative scale out of 10(numbers from 1 to 10). These 10 functions also include functions which are sensitive to changes in brain arousal. They include cooperation, physical relaxation, mental relaxation, being alert to the environment, concentration, social communications with other (quality or quantity), verbal contact (quality or quantity), learning ability, tolerance threshold, quality and quantity of sleep. The minimum acquired score by the child in this scale is 10 and its maximum is 100. This scale is completed during the baseline and the therapy by the researcher, mother and the teacher. In order to increase the validation coefficient of marking, all used vocabularies in this scale were carefully defined for mother and the teacher in order to have identical perceptions in the three mentioned grading sources. It is worth mentioning that the teacher who was one of the graders of this system was blind toward the therapy and thought that subjects has not undertaken the neurofeedback training. The content validity of this check list has been confirmed by four specialists in this field (a psychiatrist, two psychologists and a speech therapist).

In all stages, the SAS and the FAS were used to assess the behavioral level compared to data from EEG signal analysis for assessment in the brain level.

2.4. Data Acquisition

Three EEGs were recorded from all subjects (9 childeren)

before starting the neurofeedback training sessions, and once in the 20th session and another one after finishing all sessions from 19 channels (Fp1, Fp2, Fz, F3, F4, F7, F8, Cz, C3, C4, T3, T4, T5, T6, Pz, P3, P4, O1, O2) on scalp skin according to 10-20 international system for two minutes and 10 seconds. Reference electrodes were attached to ears (using two 1 KΩ resistance and connecting the middle point to the reference electrode) and the earth electrode to head front between Cz and Fz electrodes. The skin impedance was kept below 10KΩ.

the signal was filtered by a Low pass hardware filter with low cutoff frequency of 64 Hz after amplification by the instrument and then the 50 Hz noise was eliminated using a band stop filter and was down sampled with 512 Hz sampling frequency. As mentioned before, SAS and FAS tests were performed three times with 3 days before and 13 times during and 3 times after the neurofeedback training sessions which a 3 day gap between them. 19 channels EEG was recorded using Mistar EEG 201 and the neurofeedback training were done using the biofeedback equipment with 4 double montage channels by Thought Technology Company. The used software in the neurofeedback system was BioGraph Infiniti Software.

In this research, variance, mean and power have been extracted as the features. These features were used to compare same channels in different stages of signal recording to study Gamma band neurofeedback training effectiveness.

2.5. Statistical Analysis

In this research statistical based methods and SPSS software were used for assessing the percentage of answer separation. Due to normal distribution of the data, parametric methods have been used. In this research changes in subject's data in 3 different stages (before, during and after neurofeedback training) were compared and paired t-test and ANOVA were used. Paired t-test was used to compare recorded EEG in the first with 20th and 20th with 40th and the 40th with the first session and ANOVA was used for overall comparison between three stages.

In order to asses and analyze data in behavioral level using statistical analysis, effect size, improvement percentage (in cases which our goal has been increasing the behavior) and mean percentage reduction (in cases which our goal has been decreasing the behavior) were calculated using the below equations in the two tests. Then p-value will be assessed according to statistical analysis (T-test and ANOVA) [12].

MPI = [(Baseline Mean – Treatment Phase Mean) / Treatment phase Mean] × 100

MPR = [(Baseline Mean – Treatment Phase Mean) / Baseline Mean] × 100

Cohen's $d = M_1 - M_2 / \sigma_{pooled}$, where $\sigma_{pooled} = \sigma [(\sigma_1^2 + \sigma_2^2) / 2]$

PND = (Non-overlapping Data / Total treatment Data) × 100

PZD = (Zero Data / Total treatment Data) × 100

In this research effect size has been calculated in two different ways; one based on data frequency and the other based on average and standard deviation (d-Cohen). The data frequency based method is in two forms. When our goal is increasing the behavior percentage of non-overlapping data is calculated and when the decreasing behavior is aimed the percentage of zero data will be calculated [13].

2.6. Neurofeedback Training Protocol

All subjects participated a total of 40 sessions of 30 minutes, two times in a week in the neurofeedback training sessions. The used protocol for neurofeedback training was based on brain arousal aiming as enhancing 5-8 frequency and suppressing higher frequencies (8.5-30Hz) and lower frequencies (0.5-4.5Hz).This protocol was based on infrastructure theories which don't believe in classifying brain waves and consider the whole neural network [11].

After baseline recording, each subject starts neurofeedback training stage. Each subject participates in 3 stages of 10 minute neurofeedback training process. The subject is asked to move the shown image in the monitor continuously. A voice with a specified tone was simultaneously was guiding the subject in the process. Moving and hearing the voice were related to the specific band which is meant to be amplified by the researcher according to the protocol, i.e. when the Theta band power is higher than the defined threshold, the image is moved and the appropriate voice is played. The threshold is defined in a way that 60% of the times the theta band power is higher than the threshold.

Figure 1 shows the neurofeedback window. This window is consisted of two parts which are shown in separate screens. The right side is shown in front of the subject so that s/he can see the image and his scores. In the left side of the image the power of Cz and Fz montage and also the evaluation of the power spectrum in columnar fashion are shown in the lower part of the window. Using this window the researcher can monitor the subject's situation and can alter the theta threshold if needed during training. A 17 inch and a 13 inch monitors are used for training the subjects and simultaneous signal display and parameter change.

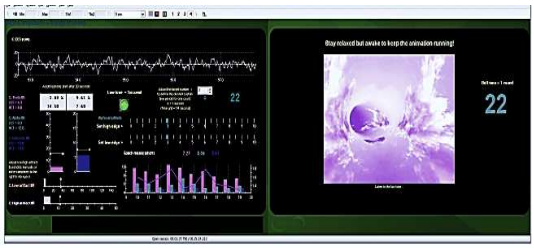

Figure 1. *Neurofeedback window*

3. Results

Statistical analysis (paired t-test) was done on data derived from SAS and FAS in 3 different modes of baseline, during neurofeedback training and results follow up which is tabulated in table 1.

Table 1. *Statistical Analysis in SPSS by SAS test*

The following steps are compared	Mean ± SD	p-value
At baseline mean - mean during neurofeedback	100.2970±5.193 & 96.2720±4.5355	.016
Posts during neurofeedback training - an average follow-up period	96.2720±4.5355 & 94.4310±4.40708	.007
At baseline mean - mean follow-up period	94.4310±4.40708 & 100.2970±5.1932	.010

The first row of table 1 shows that SAS has been significantly reduced before and during neurofeedback training (p=0.016). Likewise rows two and three show similar trends.

In the second table average increase in FAS scores before and during neurofeedback training and also in follow up is observed but only the latter two stages had significant improvement in comparison (p=0.032).

ANOVA results from 19 channels of closed eye EEG signal in 3 stages are shown in table 3.

Table 2. *Statistical Analysis in SPSS by FAS test*

The following steps are compared	mean±SD	p-value
At baseline mean - mean during neurofeedback	100.2970±5.193 & 96.2720±4.5355	.016
Posts during neurofeedback training - an average follow-up period	96.2720±4.5355 & 94.4310±4.40708	.007
At baseline mean - mean follow-up period	94.4310±4.40708 & 100.2970±5.1932	.010

Table 3. *Characteristics of mean, variance and power in the gamma band EEG recorded in the third phase for children with ASD is a significant difference in the ANOVA test.*

p-value	Power			p-value	Var			p-value	Mean			
.095	EEG3 .382±.320	EEG2 .130±.100	EEG1 .373±.316	.096	EEG3 .740±.622	EEG2 .250±.192	EEG1 .721±.621	.038	EEG3 .149±.065	EEG2 .93±.38	EEG1 .157±.054	Fz
.108	.292±.244	.120±.087	.286±.196	.112	.563±.473	.233±.159	.549±.380	.027	.136±.059	.87±.26	.146±.045	Cz
.087	.387±.403	.105±.065	.335±.237	.087	.745±.775	.203±.125	.643±.456	.044	.152±.092	.84±.306	.158±.055	F_7
.056	.222±.271	.106±.067	.635±.725	.056	.426±.521	.199±.130	.121±.143	.029	.119±.071	.83±.27	.204±.140	F_8
.039	.348±.320	.96±.795	.364±.237	.040	.672±.621	.183±.151	.700±.406	.008	.151±.065	.88±.36	.108±.048	P_4
.087	.387±.403	.106±.061	.335±.237	.087	.745±.775	.203±.125	.643±.456	.044	.152±.092	.84±.30	.158±.055	F_4

Table 4. *Characteristics of mean, variance, and power in the gamma band EEG recorded in the three-stage test for children with ASD in the T-TEST is a significant difference*

p-value	Power			p-value	var			p-value	Mean			Name canal
	EEG3	EEG2	EEG1		EEG3	EEG2	EEG1		EEG3	EEG2	EEG1	
- .011	- .31±.234	.139±.119 .139±.119	.345±.066 -	- .011	- .596±.450	.268±.215 .268±.215	.664±.127 -	.042 .007	- .144±.064	.998±.417 .998±.417	.158±.043 -	C_3
-	.31±.234	-	.345±.066	-	.596±.450	-	.664±.127	-	.144±.064	-	.158±.043	
-	- .265±.094	.130±.034 .130±.034	.263±.041 -	-	- .511±.018	.251±.065 .251±.065	.505±.080 -	- .039	- .131±.024	.935±.393 .935±.393	.145±.032 -	F_3
	.265±.094	-	.263±.041		.511±.018	-	.505±.080		.131±.024	-	.145±.032	
.023	- .387±.134	.105±.061 .105±.061	.335±.237 -	.023	- .745±.258	.203±.125 .203±.125	.643±.456 -	.010 .046	- .152±.092	.841±.306 .841±.306	.158±.055 -	F_4
	.387±.134	-	.335±.237		.745±.258	-	.643±.456		.152±.092	-	.158±.055	
.023	- .387±.134	.105±.065 .105±.065	.335±.237 -	.023	- .745±.258	.203±.125 .203±.125	.643±.456 -	.010	- .152±.090	.847±.306 .847±.306	.158±.055 -	F_7
	.387±.134	-	.335±.237		.745±.258	-	.643±.456	.046	.152±.090	-	.158±.055	
-	- .222±.096	.103±.022 .103±.022	.635±.250 -	-	- .426±.173	.199±.043 .199±.043	.121±.047 -	.029	- .119±.023	.831±.271 .831±.271	.204±.140 -	F_8
	.222±.096	-	.635±.250		.426±.173	-	.121±.047		.119±.023	-	.204±.140	
.012	- .382±.320	.130±.101 .130±.101	.373±.105 -	.012	- .740±.192	.250±.192 .250±.192	.721±.205 -	.046 .004	- .149±.065	.939±.388	.157±.054 -	Fz
	.382±.320		.373±.105		.740±.192	-	.721±.205		.149±.065	.939±.388	.157±.054	
.038	- .292±.244	.120±.081 .120±.081	.286±.065 -	.039	- .563±.473	.233±.159 .233±.159	.549±.126 -	.014	- .136±.059	.875±.269 .875±.269	.146±.045 -	Cz
	.292±.244	-	.286±.065		.563±.473	-	.549±.126	.005	.136±.059		.146±.045	
.015 .015	- .348±.320	.960±.795 .960±.795	.364±.237 -	.015	- .672±.151	.183±.151 .183±.151	.700±.461 -	.006	- .151±.065	.885±.368 .858±.386	.168±.048 -	P_4
	.348±.320	-	.364±.237	.016	.672±.151	-	.700±.461	.001	.151±.065	-	.168±.048	
-	- .373±.101	.143±.036 .143±.036	.411±.103 -	.008	- .716±.593	.274±.211 .274±.211	.799±.201 -	.047	- .154±.070	.105±.042 .105±.042	.171±.054 -	P_3
	.373±.101	-	.411±.103		.716±.593	-	.799±.201	.003	.154±.070	-	.171±.054	
.037	- .480±.201	.185±.020 .185±.020	.715±.425 -	.037	.924±.899 .924±.899	.356±.386 .356±.386	.137±.082 -	- .025	- .173±.0961	.108± .064 .108± .064	.200±.145 -	Fp_2
	.480±.201	-	.715±.425			-	.137±.082		.173±.0961	-	.200±145	

Table 3 compares average, variance and power calculated from recorded EEG Gamma Bands of affected ASD children in 3 stages using variance based analysis. As shown from table 3 there is a significant difference ($P<0.05$) in averages of Fz, Cz, F7, F8, F4, P4 channels. P4 Chanel shows significant difference in other features namely variance and power. Other charnels which have not been mentioned showed no significant difference in none of the features.

Statistical analysis (paired sample t-test) was done on 19 channels of closed eye EEG signal in 3 stages (EEG recorded in the first with 20^{th} and 20^{th} with 40^{th} and the 40^{th} with the first session) and are shown in table 4.

Average, variance and power calculated from EEG Gamma band in 3 states were compared pair wise (the first with 20^{th} and 20^{th} with 40^{th} and the 40^{th} with the first session) and had significant difference of neurofeedback training $p=0.042$ and $p=0.007$ respectively but the latter one showed no significant difference. Variance and power of C3 channel only showed significant difference between 20^{th} and 40^{th} session.

All considered features in P4 channel, showed significant difference between 1^{st} and 20^{th}, 20th and 40^{th} session. No significant difference is observed between 1^{st} and 40^{th} session features derived from Gamma Band. Other channels not being mentioned in the table showed no significant difference. Paired t-test results show that during 20 sessions of neurofeedback training average, variance and power of Gamma band have significantly reduced and during the next 20 session the opposite trend is observed so that no significant difference is observed between the 1^{st} and the 40^{th} session.

4. Discussion

This research was aimed to assess neurofeedback training effect on behavioral and brain level of children affected with ASD.

A group research by Jarusiewicz (2002) showed 26% decrease in interference group symptoms using ATEC checklist [8]. Coben (2006) also used the same tool to measure behavior and reported 40% decrease in symptoms intensity after neurofeedback training [6]. Koujzer (2008) not also observed some changes in variables associated with executive functions, but also reported that there is a decrease in axial symptoms of ASD after neurofeedback training [9]. Different Case studies by Coben (1994), Fahmi (1995) [14], Kaiser and Paoletti (2006) [7] also shows decrease in symptoms intensity such as social interaction and making social communication. In this research, symptoms intensity was lower compared to Jarusiewicz (2002) [8] and Coben (2006) [6] (16.5%) which could be due to considering a huge spectrum of devious in scaling tools.

Coben (2006) [6] and Kaiser & Paoletti (2006) [7] observed a significant difference in brain functions of ASD children using QEEG after neurofeedback training compared to first and last record in a limited channels, while in over research assessed this improvement in 3 stages of EEG recording namely first, middle and last recording in the 19 channels.

In this research there is a significant difference between the initial and middle and the middle and the last stages of Gamma band while there has been no increase between the first and the last stage. This latter is consistent with Koujzer (2008) [9] finding that there is no significant difference between the first and the last stage.

In this research a protocol based on brain awareness is used. In future researches other neurofeedback training protocols with correlation analysis between different channels could be used. Significant difference between three channels with similar names in 3 states of signal recording has been compared which could be improved to analyzing correlation and channel associations.

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