Independent component approach to the analysis of EEG recordings at early stages of depressive disorders

Vera A. Grin-Yatsenko a,*, Ineke Baas b, Valery A. Ponomarev a, Juri D. Kropotov a

a Institute of the Human Brain of Russian Academy of Sciences, 197376, St. Petersburg, ul. Acad. Pavlova, 9, Russian Federation
b Registered Health Psychologist BIG, Specialisation: Clinical Psychology, Primary Care Psychologist, Member of the NIP (Dutch Organization of Psychologists), Statenweg 92b, 3039 JJ Rotterdam, The Netherlands

A R T I C L E  I N F O
Article info
Article history:
Accepted 17 November 2009
Available online 16 December 2009
Keywords:
Depression
EEG spectra
Independent Component Analysis
Anxiety

A B S T R A C T
Objective: A modern approach for blind source separation of electrical activity represented by Independent Components Analysis (ICA) was used for QEEG analysis in depression.

Methods: The spectral characteristics of the resting EEG in 111 adults in the early stages of depression and 526 non-depressed subjects were compared between groups of patients and healthy controls using a combination of ICA and sLORETA methods.

Results: Comparison of the power of independent components in depressed patients and healthy controls have revealed significant differences between groups for three frequency bands: theta (4–7.5 Hz), alpha (7.5–14 Hz), and beta (14–20 Hz) both in Eyes closed and Eyes open conditions. An increase in slow (theta and alpha) activity in depressed patients at parietal and occipital sites may reflect a decreased cortical activation in these brain regions, and a diffuse enhancement of beta power may correlate with anxiety symptoms playing an important role on the onset of depressive disorder.

Conclusions: ICA approach used in the present study allowed us to localize the EEG spectra differences between the two groups.

Significance: A relatively rare approach which uses the ICA spectra for comparison of the quantitative parameters of EEG in different groups of patients/subjects allows to improve an accuracy of measurement.

© 2009 International Federation of Clinical Neurophysiology. Published by Elsevier Ireland Ltd. All rights reserved.

1. Introduction

Most published literature examining QEEG in depression has used classical algorithms for data analysis such as computations of spectra and coherences in multiple EEG recordings. The most consistent findings from EEG spectra studies of depression are as follows.

A line of research initiated by Davidson’s theory of depression claims frontal asymmetry in the alpha band in depressed patients different from that in healthy subjects. The asymmetry is expressed in increased alpha activity of left relative to right frontal regions (Schaffer et al., 1983; Henriques and Davidson, 1990, 1991; Roemer et al., 1992; Allen et al., 1993; Davidson, 1995, 1998; Tomarken and Keener, 1998; Davidson and Henriques, 2000; Davidson et al., 2002), and according to Davidson’s theory, it reflects left frontal hypoactivation in depression (Henriques and Davidson, 1991).

Some studies found bilaterally increased frontal alpha activity (Schaffer et al., 1983; Brenner et al., 1988; John et al., 1988; Lieber and Newbury, 1988; Pollock and Schneider, 1990), while other studies reported relatively higher alpha activity in the right posterior (parietotemporal) region (Henriques and Davidson, 1990; Bruder et al., 1997; Kentgen et al., 2000; Volf and Passynkova, 2002). The last observation, according to Henriques and Davidson (1990) may correlate with such symptoms of depression, as poor orienting and deficits in social skills. Increase of slow-wave activity in the right hemisphere was also reported (Kwon et al., 1996; Volf and Passynkova, 2002). Among other observations in depressions are: increase of beta power in the frontal region (Suzuki et al., 1996; Volf and Passynkova, 2002; Flor-Henry et al., 2004) as well in posterior cortical areas (Yamada et al., 1995); decrease of inter-hemispheric coherence in theta, alpha and beta bands in anterior cortical areas (Roemer et al., 1992; Yamada et al., 1995); decrease of anterior and posterior interhemispheric coherence in a slow-wave frequency band (Lieber, 1988). Using of the probability-classification analysis of short-term EEG spectral patterns in recent
study of Fingelkurts et al. (2006) discovered considerable reorganization of the composition of brain oscillations in a broad frequency range: 0.5–30 Hz in major depression with maximal effect of depression in the posterior cortex of the brain.

The diversity and inconsistency of many of the EEG findings for depressed patients can be related to clinical heterogeneity of depression and its comorbidity with other disorders, methodological differences, and instability of the discovered EEG phenomena (Bruder et al., 1997; Davidson, 1998; Heller and Nitschke, 1998; Reid et al., 1998; Debener et al., 2000).

The recently emerged approaches such as the methods of Low Resolution Brain Electromagnetic Tomography (LORETA) and its modifications (sLORETA and eLORETA (Pascual-Marqui et al., 1994; Pascual-Marqui, 2002, 2007)), and methods of blind separation of distinct cortical sources from multi-channel EEGs, including Independent Component Analysis (ICA) (Makeig et al., 1996; Vigário et al., 2000; Debener et al., 2000; Onton and Makeig, 2006; Onton et al., 2006; Congedo et al., 2008) have provided a functionally relevant analysis of brain activity.

The aim of the ICA approach to EEG analysis is to separate independent activities, generated by different cortical sources. ICA is a computational method for separating a multivariate signal into additive subcomponents supposing the mutual statistical independence of the non-Gaussian source signals. It is a special case of blind source separation. When the independence assumption is correct, blind ICA separation of a mixed signal gives very good results. Mathematically ICA is a method of finding an unmixing matrix that, when multiplied by the original vector of potentials, yields the matrix of independent time courses (Makeig et al., 1997; Hyvärinen and Oja, 2000).

Application of ICA method in some clinical studies such as Creutzfeld–Jakob disease (Hung et al., 2007), epilepsy (Leal et al., 2006; Iriarte et al., 2006) and autism (Milne et al., 2009) has been reported. However there are no ICA studies of depression.

The recent success in developing electro-magnetic tomography gives new opportunities in visualization of 3D generators of EEG rhythms. By means of Low Resolution Electromagnetic Tomography (LORETA and sLORETA) it is possible to get a reliable picture of spatial distribution of generators of the scalp potentials.

The goal of our study was to compare the spectral characteristics of the resting EEG between groups of patients with depression and healthy non-depressed subjects using a combination of ICA and sLORETA methods.

In comparison with the majority of the previous studies which dealt with severe and chronic depression in our investigation participated patients who became depressed recently and for the first time approached a psychologist.

2. Methods

2.1. Patients and control subjects

One hundred and eleven adults (mean age 38.5; range 17–60) with early symptoms of depression participated in our study. Subjects were 46 males (mean age 40.6; range 23–58) and 65 females (mean age 36.5; range 17–60) recruited from the private practice of the Primary Care Psychologist Ineke Baas, The Netherlands. All participants were divided into four groups: 1. Major depressive disorder (MDD): 32 patients (mean age 38.9; range 17–56), among whom 11 males (mean age 39.8; range 25–56) and 21 females (mean age 37.3; range 17–53); 2. Adjustment disorder with depressed mood (AD): 37 patients, (mean age 45.5; range 23–58), including 12 males (mean age 50.5; range 34–58) and 25 females (mean age 40.6; range 23–58); 3. Dysthymic (DT): 9 patients (mean age 31.4; range 21–44); 5 males (mean age 35.2; range 24–44) and 4 females (mean age 26.8; range 21–31); 4. Depressive complaints as a component of other disorders, such as addictive disorder, personality disorder, chronic fatigue, anxiety disorder (DC): 33 patients (mean age 38.9; range 22–60), including 18 males (mean age 36.9; range 23–56) and 15 females (mean age 40.9; range 22–60).

Most patients were unmedicated. Those few of them who received psychopharmaca had withheld from taking medicine during the appropriate washout period. The diagnoses were made after careful review of the subject’s history and psychological testing. Subjects were all referred to a so-called Primary Care Psychologist (PCP), a Dutch phenomenon which is quite unique in the world: General Practitioners (G.P’s) send potential clients to a psychologist who offers short psychological help with a threshold as low as possible (e.g. no waiting time, no financial threshold), very close to the living environment of the potential client (Derksen, 2009). One of the criteria for admission to a Primary Care Psychologist is that the complaints have to be linked to an identifiable stressor. 90% of these clients were first referrals. The reasons for referral are mainly anxiety and depression. DSM-IV criteria were used to classify the subjects, this diagnosis was in most cases double checked by experienced psychologists working in private practices.

The control group included 526 healthy subjects (mean age 35.1; range 18–60): 221 males (mean age 36.1; range 18–60) and 305 females (mean age 34.1; range 18–60). These were subjects who participated in a project of collecting a reference database. The project was sponsored by the Brain and Trauma foundation from Switzerland. Healthy subjects were recruited from several sources: (1) students of Department of Biology of St. Petersburg State University, (2) scientific staff of the Institute of the Human Brain of Russian Academy of Sciences (in both cases recordings were made by Drs. E.A. Yakovenko and I.S. Nikishena from the Institute of the human Brain), (3) students of Department of Psychology of the Norwegian University of Science and Technology, Trondheim (recording were made by S. Hollup and his students from the Department of Psychology), (4) subjects from Chur, a town near Zurich, recruited by Andreas Mueller (recording were made by E.P. Tereshchenko and G. Candrian). The inclusion/exclusion criteria were: (1) an uneventful perinatal period; (2) no head injury with cerebral symptoms; (3) no history of neurological or psychiatric diseases; (4) no convulsions; (5) normal mental and physical development; (6) average or better grades in school; (7) no current medication or drugs.

The investigation was carried out in accordance with the declaration of Helsinki. All subjects gave informed consent after the procedures had been fully explained to them.

2.2. EEG recording

Electroencephalogram (EEG) was recorded using a Mitsar 21 channel EEG system (Mitsar, Ltd.). Nineteen silver-chloride electrodes were applied according to the International 10–20 system. The input signals referenced to the linked ears were filtered between 0.5 and 50 Hz and digitized at a rate of 250 Hz. The ground electrode was placed on the forehead. All electrode impedances were kept below 5 kOhm. EEG was recorded in Eyes closed and Eyes open resting conditions, at least three minutes for each period. Quantitative data were obtained using WinEEG software. Two montages, the first one with an averaged ears reference and the second one with the weighted average reference montage (Lemos and Fisch, 1991) were used.

Eyeblink artifacts were corrected by zeroing the activation curves corresponding to eye blinks. The method is similar to the one described in (Vigário, 1997; Jung et al., 2000). Comparison of this method with an EOG regression technique is presented in (Tereshchenko et al., 2009). In addition, epochs with excessive
amplitude of non-filtered EEG and/or excessive high and slow frequency activity were automatically marked and excluded from further analysis. The thresholds were set as follow: (1) 100 μV for non-filtered EEG, (2) 50 μV for slow waves in 0–1 Hz band, (3) 35 μV for fast waves filtered in the band 20–35 Hz. Such artifacts as horizontal and vertical eye movements, low-voltage electrode movements, low-voltage EMG, and cardiac artifacts have not been removed from raw EEG recording.

2.3. Independent Component Analysis (ICA)

The goal of Independent Component Analysis (ICA) (Bell and Sejnowski, 1995; Makeig et al., 1999) is to utilize the differences in scalp distribution between sources of different EEG activity to separate the corresponding generators of EEG rhythms.

Assumptions that underline the application of ICA for analysis of array of individual EEG are as follow: (1) summation of the electric currents induced by separate generators is linear at the scalp electrodes; (2) spatial distribution of components’ generators remains fixed across time; (3) generators of spatially separated components are temporally independent from each other; (4) distribution of potentials is not Gaussian. In addition to these assumptions we also suggest that cortical localization of components is similar between healthy individuals and depressed subjects, so that it is viable to implement the ICA on array of EEG for both groups. In theory, these assumptions do not exactly fit to EEG recorded from the scalp, but in practice the application of ICA for EEG analysis gives quite reasonable results (for review see Onton et al., 2006; Onton and Makeig, 2006).

Briefly, the method implemented in this paper is as follows. The input data are the collection of individual EEGs arranged in a matrix $W$ of 19 channels (rows) by $N$ time points (columns). The ICA finds an “unmixing” matrix $W$ that, when multiplied by the original data $X$ gives the matrix $S$ of the sources (independent components or activation curves).

$$ S = WX, $$

where $S$ and $X$ are $19 \times N$ matrices, and $W$ is $19 \times 19$ matrix. $S(t)$ are maximally independent.

In our paper, matrix $W$ is found by means of infomax algorithm, which is an iteration procedure that maximizes the mutual information between $S$. According to the linear algebra,

$$ X = W^{-1}S, $$

where $W^{-1}$ is the inverse matrix of $W$ (also called mixing matrix).

Further, according to the linear algebra

$$ X = \sum W_i^{-1}S_i, $$

where $W_i^{-1}$ is the $i$-th column of the mixing matrix $W^{-1}$ (represents the topography of independent component) and $S_i$ – is the raw of $S$ (i.e. time course of the independent component).

The ICA decomposition of the array of individual EEGs was performed as follows: 20 s epochs of artifact-free multi-channel EEG recording of each healthy subject were merged into a common time series. This time series was used for assessment of $W$ matrix. Applying this matrix we transformed the EEGs of both groups (526 control subjects and 111 patients) into activation curves (independent components).

For each individual, each condition and for each independent component the power spectra were computed as follows: Artifact-free continuous EEG was divided into 4,096 s epochs using a Hanning time window (epochs were overlapped by 50%) and submitted to Fast Fourier Transform (FFT). Power spectra with a number of averaged epochs less then 30 were eliminated from further analysis, therefore the numbers of subjects were slightly different for Eyes closed and Eyes open conditions. Taking into account the large inter-individual differences of alpha frequency (Klimesch, 1999) the frequency window for alpha band for our population of participants was chosen after a visual inspection of the individual row EEG data. For theta and beta frequencies the conventional frequency bands were chosen. The Absolute theta (4–7.5 Hz), alpha (7.5–14 Hz), and beta (14–20 Hz) power (squared microvolt) for each condition, each frequency band and each subject separately were computed and transformed using natural logarithm for normalization before further statistical analysis.

We computed also the grand average power spectra for each independent component, for each group (control subjects and patients) and each condition separately.

For better localization of sources of brain activity 3D sLORETA equivalent source current density for each extracted independent component was estimated using component topographies as input data (Pascual-Marqui, 2002). The sLORETA imaging gives more accurate location of brain sources in comparison with 2D mapping.

2.4. Statistical analysis

In our previous study which included the same groups of patients and control subjects (Grin-Yatsenko et al., 2009) we performed the inter-group comparison of spectra powers in theta (4–7.5 Hz), alpha (7.5–14 Hz) and beta (14–20 Hz) frequency bands which did not reveal any statistical differences between groups: MDD, AD, DT and DC ($p > 0.05$). Taking into account these results we assessed the differences of the ICA EEG components between the two groups: (1) the joint group of patients with depressive symptoms, and (2) the normative group. t-Test was used for assessing statistical significance of differences of spectral characteristics of the ICA EEG components between depressed patients and healthy controls. The statistical analysis of independent component power spectra was performed separately for each component and each frequency band (54 comparisons). Bonferroni correction was applied to eliminate false positive errors in case of multiple comparisons. The statistically significant results (Type II error = 0.01; threshold of significance for $p$-values <0.01/54 = 0.000185) are reported only.

3. Results

The results of decomposition of EEGs into independent components are presented in Fig. 1. Nine independent components from total amount of 19 were taken for analysis. The criteria of selection were as follows:

1. Relatively high component’s power;
2. Component is not identified as artifact: eye blinks, horizontal eye movements and EMG artifacts;
3. Similarity of the component’s topographies in both Eyes closed and Eyes open conditions.

For Eyes closed condition 74.6% of row EEG power was related to EEG signal, and 25.4% – to artifacts (horizontal and vertical eye movements, low-voltage electrode movements, low-voltage EMG, and cardiac artifacts). Nine independent components associated with EEG signal sources have described 86.9% of total signal power; the rest 13.1% of total power not described by identified components was related to low-power signals or signals non-corresponding to the third criterion of selection. For Eyes open condition 75.1% of row EEG power was related to EEG signal, and 24.9 – to artifacts. Nine independent components constituted 78.8% of the total EEG signal power, and 21.1% was associated with small signal components.
The correlation coefficients between topographies for each component in Eyes closed and Eyes open states are presented in Table 1. The topography of selected components with their variance (power) and grand average spectra are presented in Figs. 1a and 1b at the left. Power spectra for all components, with the exception of that one localized in orbito-frontal area, have the distinct local maximum in alpha frequency band. One can see the differences of power spectra of independent components between two groups (depressed patients and healthy subjects) in both Eyes closed and Eyes open states. It should be stressed here that the amplitude of an ICA component in microvolts is obtained by a product of the corresponding ICA topography and the component waveform (time course). Consequently, values at Y-axis of the component spectra in Figs. 1a and 1b are presented in standard units that only roughly correspond to microvolts.

The correlation coefficients between topographies for each component in Eyes closed and Eyes open states are presented in Table 1. The topography of selected components with their variance (power) and grand average spectra are presented in Figs. 1a and 1b at the left. Power spectra for all components, with the exception of that one localized in orbito-frontal area, have the distinct local maximum in alpha frequency band. One can see the differences of power spectra of independent components between two groups (depressed patients and healthy subjects) in both Eyes closed and Eyes open states. It should be stressed here that the amplitude of an ICA component in microvolts is obtained by a product of the corresponding ICA topography and the component waveform (time course). Consequently, values at Y-axis of the component spectra in Figs. 1a and 1b are presented in standard units that only roughly correspond to microvolts.

s-LORETA images of the independent components are presented in Figs. 1a and 1b at the right. One can see that maximal densities of cortical generators of the components are located in distinct cortical areas. One component is generated in occipital area, two components – at the parietal regions at both sides, one component is generated in the middle parietal lobe, other two components – in posterior temporal–occipital regions, two components are generated in central areas, and one – in orbito-frontal area. It should be stressed here that sLORETA imaging helps to localize more precisely the sources of activity. For example, for the 6th component localization of the sources in the orbito-frontal cortex cannot be deduced from the two-dimensional map.

Statistical analysis using t-statistics has revealed significant differences between groups of depressed patients and healthy controls in the power spectra of the independent components localized at the temporal–parietal–occipital areas and in the orbito-frontal cortex.

![Fig. 1a. Scalp maps, grand average spectra and s-LORETA images of four independent components localized in parieto-occipital region. From left to right: topographies if ICA components in Eyes closed condition, spectra of the ICA components in Eyes closed and Eyes open conditions, topographies of the ICA components in Eyes open condition, and s-LORETA images of the components. From top to bottom – different ICA components. Y axis – amplitude of ICA components in μV, X axis – frequency in Hz. Thin curve – depressed patients, thick line – healthy subjects. Grey color in the amplitude spectra indicates areas of statistically significant (p < 0.01) differences between the depressed and healthy subjects.](image-url)
midline parietal area in both (Eyes closed and Eyes open) states. These differences consisted of higher amplitudes in theta, alpha and beta bands for the components localized at the parietal regions at both sides in depressed patients in Eyes closed condition and on the right side — in Eyes open condition. For the component generated on the left side in Eyes open state an increasing of power was observed only in beta band. Power of the component in the midline parietal area was higher in depressed group in beta band in both states. For the component generated in occipital area the differences were found in Eyes closed state only (higher power in theta and beta bands in depressives). For the components localized in posterior temporal–occipital regions the differences were discovered in Eyes open state only: higher power in theta, alpha and beta bands on the right side, and only in beta band – on the left side in
Table 1
The correlation coefficients between topographies for independent components in Eyes closed and Eyes open states.

<table>
<thead>
<tr>
<th># of ICA component</th>
<th>Localization of component</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Occipital</td>
<td>0.94</td>
</tr>
<tr>
<td>2</td>
<td>Middle parietal</td>
<td>0.97</td>
</tr>
<tr>
<td>3</td>
<td>Left parietal</td>
<td>0.99</td>
</tr>
<tr>
<td>4</td>
<td>Right parietal</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>Left central</td>
<td>0.87</td>
</tr>
<tr>
<td>6</td>
<td>Right central</td>
<td>0.92</td>
</tr>
<tr>
<td>7</td>
<td>Orbito-frontal</td>
<td>0.995</td>
</tr>
<tr>
<td>8</td>
<td>Left posterior temporal–occipital</td>
<td>0.97</td>
</tr>
<tr>
<td>9</td>
<td>Right posterior temporal–occipital</td>
<td>0.90</td>
</tr>
</tbody>
</table>

r – coefficient of correlation in Eyes closed and Eyes open state.

depressed group. Increased power in beta band for the component generated in central area of left hemisphere in depressed group was also observed only in Eyes open condition. No differences were found in the power spectra of the components localized in orbito-frontal area and in central area of right hemisphere. The results of t-statistics for three frequency bands and two states (Eyes closed and Eyes open) are presented in Table 2.

4. Discussion

This study is a descriptive one by nature. We compared spectral parameters of ICA components between two groups: depressed patients and healthy controls. However, our study differs from the numerous previous studies in two aspects.

The first distinguished feature of the present paper is a special group of patients. The group of patients participated in our research characterized by symptoms of depression in the first stages of this pathologic process.

The second distinguished feature of our approach is the application of Independent Component Analysis. We decomposed a collection of raw multi-channel EEG traces into independent components for each resting condition (Eyes open and Eyes closed) separately. According to the ICA methodology, it is suggested that each ICA component is generated by a group of closely spaced interconnected neurons. The activity of a group of neurons sharing their inputs and sending or receiving the same information forms an independent source signal and defines physiological meaning of a component.

In the process of ICA we merged 20 s epochs of artifact-free 19-channel EEG recording of each healthy subject into a common time series which was used then for assessment of Unmixing matrix. This matrix was further applied to transform the EEGs of both groups into independent components. For each independent component in every individual in both conditions we computed the power spectra in theta, alpha and beta frequency bands. Further on, the grand average power spectra for each independent component, for each group and each condition were computed separately.

For analysis we selected nine independent components associated with EEG signal sources which described 86.9% of total signal power for Eyes closed condition and 78.8% of total signal power for Eyes open condition.

Comparison of independent components in depressed patients and healthy controls has revealed significant differences in power spectra of components between these two groups, both in Eyes closed and Eyes open conditions. All nine components can be conventionally separated into two groups on the basis of the character of these differences.

The four components belonging to the first group revealed increased power in theta, alpha and beta bands in depressed patients in both Eyes closed and Eyes open conditions. These were the components localized in parietal and occipital areas.

Our data support findings of abnormally large alpha in the posterior region in Eyes closed state reported in depressed patients in some previous studies (Henriques and Davidson, 1990; Volf and Passynkova, 2002; Flor-Henry et al., 2004). Higher than normal theta values in depression were also found (Roemer et al., 1992; Kwon et al., 1996; Volf and Passynkova, 2002). The features of cortical hyperventilation in right parieto-temporal region were discovered in adolescents and adults having a depressive disorder (Davidson et al., 1987; Bruder et al., 1997; Reid et al., 1998; Kentgen et al., 2000). An increase in beta activity over the parietal and occipital areas was observed in patients with an anxiety type depression (Yamada et al., 1995) in elderly depressed patients. The reorganization of brain oscillations in a broad frequency range including theta, alpha and beta bands in Eyes closed condition was reported in study of Fingelkurts et al. (2006). Using the probability-classification analysis of EEG spectra in patients with MDD the authors discovered the

Table 2
The statistically significant differences of spectra power of independent components between the groups of depressed patients and normal subjects.

<table>
<thead>
<tr>
<th># of ICA component</th>
<th>Eyes open</th>
<th>Eyes closed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theta</td>
<td>Alpha</td>
</tr>
<tr>
<td>1</td>
<td>t = 2.55, NS</td>
<td>t = 0.37, NS</td>
</tr>
<tr>
<td>2</td>
<td>t = 0.81, NS</td>
<td>t = 0.42, NS</td>
</tr>
<tr>
<td>3</td>
<td>r = 5.50, p = 0.01</td>
<td>t = 4.75, p &lt; 0.001</td>
</tr>
<tr>
<td>4</td>
<td>r = 1.34, NS</td>
<td>t = 0.53, NS</td>
</tr>
<tr>
<td>5</td>
<td>r = 1.30, NS</td>
<td>t = 0.33, NS</td>
</tr>
<tr>
<td>6</td>
<td>r = 0.54, NS</td>
<td>t = 1.14, NS</td>
</tr>
<tr>
<td>7</td>
<td>r = 2.15, NS</td>
<td>t = 0.99, NS</td>
</tr>
<tr>
<td>8</td>
<td>r = 5.31, NS</td>
<td>t = 1.91, NS</td>
</tr>
<tr>
<td>9</td>
<td>r = 5.43, p = 0.01</td>
<td>t = 4.72, p &lt; 0.001</td>
</tr>
</tbody>
</table>

*r* – the Student’s statistic, a positive *r*-value indicate that the mean of natural logarithm of component power in selected frequency band for depressive group is higher than the mean of this parameter for controls.

$p = p < 54$, where *p* – the significance level.

$SE = \sqrt{\text{SE}(\log P_d) + \text{SE}(\log P_n)}$, where $\log P_d$ denotes natural logarithm of component power in selected frequency band for individual depressive patients, and $\log P_n$ – for individual controls.
maximal changes of EEG pattern as compared to the norm in the posterior cortex of the brain.

For the three components, we found significant differences between the two groups only in Eyes open state. The component localized in the sensori-motor area of the left hemisphere was characterized by enhanced amplitude in the beta band in the depressed group. An increase in beta power in depression in anterior cortical areas is reported to be found in some previous studies (Suizuki et al., 1996; Volf and Passynkova, 2002; Flor-Henry et al., 2004). In the depressed group, we discovered higher power in the theta, alpha, and beta bands for the component generated in the right posterior temporal–occipital region, and in the beta band for the component generated in the left posterior temporal–occipital region.

We did not find any inter-group differences in the power spectra of the components localized in the sensori-motor region of the right hemisphere and in the orbito-frontal area. ICA does not allow performing the direct measurement of alpha power asymmetry. However, the result of previous studies of EEG power spectra (Grin-Yatsenko et al., 2009) and visual analysis of topographies of components and power spectra of components seem to disagree with a number of studies pointing to increased left frontal alpha (Schaffer et al., 1983; Davidson et al., 1985; Henriques and Davidson, 1983, 1990; Roemer et al., 1992; Allen et al., 1993) or bilaterally increased frontal alpha (Schaffer et al., 1983; von Knorring et al., 1983; Brenner et al., 1988; John et al., 1988; Lieber and Newbury, 1988; Pollock and Schneider, 1990) in depression caused by frontal hypoactivity in this disorder. Left frontal prevalence in alpha increased frontal alpha (Schaffer et al., 1983; von Knorring et al., 1983; Brenner et al., 1988; John et al., 1988; Lieber and Newbury, 1988; Pollock and Schneider, 1990) in depression caused by frontal hypoactivity in this disorder. Left frontal prevalence in alpha power in depressed patients was not found also in some other studies (Reid et al., 1998; Flor-Henry et al., 2004). One of the possible explanations of this discrepancy can be the fact that not all depressed subjects have the left frontal hypoactivation diathesis (Henriques and Davidson, 1990). We suppose that most of the patients in our sample lacked this diathesis. Comparison of our findings with other studies is shown in Table 3.

The phenomenon of prevalence of beta activity in both anterior and posterior brain areas in the depressed group can be explained by the presence of anxiety symptoms in the clinical picture (Shankman and Klein, 2003). It is well known that there is a high comorbidity in depression and anxiety disorders (Fawcett and Kravitz, 1983; Goldberg, 1995; Zuckerman, 1999; Lenze et al., 2001; Shankman and Klein, 2003; Gorman, 2005). A dominant clinical symptom in the participants of our study was the depressive mood, which emerged as a reaction to identifiable stressors they were not confronted with before. In this situation anxiety appears an important component in the structure of the disease (Derkxen, 2009).

In sum, the results of the current study indicate an increase in EEG power in a broad range in parietal, occipital, posterior temporal, and central areas in patients in the first stage of depression. An increase in slow (theta and alpha) activity in the EEG pattern may reflect a decreased cortical activation in occipital and parietal brain regions. Enhancement of beta power over anterior and posterior areas of the brain may correlate with anxiety symptoms which will most likely play an important role on the onset of depressive disorder emerged as a reaction to the stressors. Beta excess may reflect a cortical excitation of these regions (Porjesz et al., 2002; Mccarthy, 2007) and increase of metabolic activity (Cook et al., 1998).

Thus, the ICA approach used in the present paper allowed us to localize the differences between the two groups.

From clinical point of view, the most important are differences between depressed patients and healthy subjects that are not only statistically significant but also are characterized by large effect sizes. Among all deviations from normality found in the present paper, the depressed group the largest effect sizes (around 1.0 on average) were observed in the components 3 and 4. These effect sizes are largest for the beta band and are present in both Eyes open and Eyes closed conditions (see Table 2). The components are distributed over the left and right parietal areas respectively. Similar findings of excessive beta over occipital–parietal areas were found in earlier studies in depressed patients comorbid with anxiety (Yamada et al., 1995; Fingelkurts et al., 2006). Thus, our data indicate that increasing of beta power over the parietal region may serve as an informative parameter in diagnostics of the first stage of depressive disorder.

Table 3
Comparison of our findings with other EEG spectra studies of depression.

<table>
<thead>
<tr>
<th>EEG findings</th>
<th>Psychiatric characteristics of the patients group</th>
<th>Example reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fit our findings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bilaterally increased occipital alpha activity</td>
<td>MDD comorbid with anxiety</td>
<td>Fingelkurts et al. (2006)</td>
</tr>
<tr>
<td>Relatively higher alpha activity in the right parieto-temporal region</td>
<td>Normothymic depressives</td>
<td>Henriques and Davidson (1990)</td>
</tr>
<tr>
<td></td>
<td>Unipolar MDD</td>
<td>Bruder et al. (1997)</td>
</tr>
<tr>
<td></td>
<td>MDD female adolescents</td>
<td>Kentgen et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Depressed SAD</td>
<td>Volf and Passynkova (2002)</td>
</tr>
<tr>
<td>Increase of beta 1 power in parietal and occipital cortical areas</td>
<td>MDD, anxiety type</td>
<td>Yamada et al. (1995)</td>
</tr>
<tr>
<td></td>
<td>MDD comorbid with anxiety</td>
<td>Fingelkurts et al. (2006)</td>
</tr>
<tr>
<td>Increased beta values over the left hemisphere</td>
<td>Elderly depressive patients</td>
<td>Roemer et al. (1992)</td>
</tr>
<tr>
<td>Increase of theta power in the right hemisphere</td>
<td>Unipolar MDD</td>
<td>Kwon et al. (1996)</td>
</tr>
<tr>
<td></td>
<td>Depressed SAD</td>
<td>Volf and Passynkova (2002)</td>
</tr>
<tr>
<td>Increased theta values over the left hemisphere</td>
<td>Elderly depressive patients</td>
<td>Roemer et al. (1992)</td>
</tr>
<tr>
<td><strong>Do not fit our findings</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased alpha activity of left relative to right frontal regions</td>
<td>Acutely depressed patients</td>
<td>Schaffer et al. (1983)</td>
</tr>
<tr>
<td></td>
<td>Normothymic depressives</td>
<td>Henriques and Davidson (1990)</td>
</tr>
<tr>
<td></td>
<td>Unipolar MDD, chronic and recurrent depression</td>
<td>Henriques and Davidson (1991)</td>
</tr>
<tr>
<td></td>
<td>Elderly depressive patients</td>
<td>Roemer et al. (1992)</td>
</tr>
<tr>
<td></td>
<td>Seasonal depression</td>
<td>Allen et al. (1993)</td>
</tr>
<tr>
<td>Bilaterally increased frontal alpha activity</td>
<td>Unipolar MDD</td>
<td>Lieber and Newbury (1988)</td>
</tr>
<tr>
<td></td>
<td>Elderly depressed subjects</td>
<td>Pollock and Schneider (1990)</td>
</tr>
<tr>
<td>Increase of beta power in the bilateral frontal regions</td>
<td>MDD chronic and remission</td>
<td>Suzuki et al. (1996)</td>
</tr>
<tr>
<td></td>
<td>Depressed SAD</td>
<td>Volf and Passynkova (2002)</td>
</tr>
</tbody>
</table>
Acknowledgements

The authors wish to thank Stig Hollup, As. Prof., Department of Psychology of the Norwegian University of Science and Technoloy, Trondheim, and Dr. Andreas Mueller, Director of the Research Clinic, Chur, Switzerland for providing us with EEG spectra obtained in healthy subjects. All the authors have nothing to disclose and have no conflicts of interest.

References


