Independent component analysis for creative versus non-creative task performance

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Abstract: EEG study on creative thinking was carried out on 108 healthy subjects in terms of test-control approach. As the model of creative thinking we used the task demands an overcoming of a long-term memory stereotype, as the control task was used – long-term memory retrieval condition. Results of different methods of source localization (independent component analysis, equivalent dipole source, the LORETA method) and independent component spectra power analysis are presented in the paper. We revealed significant differences in spectral power in high frequency bands (beta and gamma) of independent components (ICs) attributed to the left parietal, right occipital, left and right temporal cortex zones. Values of spectral power in beta and gamma bands were significantly higher for creative task performance. Obtained results support our previous data [1, 2, 3] and bring us to a new, enlarged data in regard to localization of independent components sources.

Key-Words: Creative thinking, EEG, Independent component analysis, LORETA method, ICs spectral power.

1 Introduction

Creative thinking is the complex and integrative mental activity to be defined as the highest human cognitive function and as intrinsic feature of the human being [1,4].

Creative thinking is probably the most varied high mental activity of the person. That is why it is necessary to explore reproducibility of its neurophysiological characteristics by means of different methodological approaches and in the same and different task conditions (for review see Methods, 2007, Vol. 42).

Combined consideration of results received by different methods can bring up to the new data on creative task performance and could be useful for revealing of reproducible stable chains of brain system underling creative thinking, if any.

2 Problem formulation

We carried out four EEG investigations on creative task solutions demanding to overcome a stereotype [2, 3, 5]. Those data were analyzed in terms of EEG spectral power changes and gave stable reproducible effect (wide-spread increase of spectral power for creative task performance) in high frequency bands for different groups of subjects [2].

The observed effect was rather strong and was revealed across all cortex surfaces therefore it was not possible to hypothesize about zones participations in creative task performance.

Recent years evolution of approaches to EEG data analysis achieved the better spatial resolution through different methods of cortex source localization: e.g. Independent Component Analysis - ICA [6-11]. This method is based on EEG signal decomposition into sufficiently independent sources of EEG activity.

In present study we applied ICA for creative task performance in order: to localize the unmixed sources of EEG activity and their attribution to cortex zones by means of LORETA [12]; and to check the possible application of ICA method for creative task performance.

3 Problem solution

3.1 Psychological tasks

Our subjects were to fulfill two tasks: creative and noncreative one. In the task considered to be creative the subjects were asked mentally to recall well-known and then to create a new variant of completion for the proverb or saying. In the noncreative (control) task they were asked just to recall the well-known ends of presented proverbs or sayings [2, 3, 5]. Each task lasted for about 5 minutes and consisted of 40-41 trials. Tasks were pseudo randomized between subjects.

All stimuli (proverbs and well-known sayings without the last word) were presented in the centre of a computer monitor (17` inches). The text was written in Times New Roman, size 48, bold, black. We used white background of the screen. The monitor was placed 1.5 meters in front of a subject in the center of his/her field of sight.

3.2 Subjects

Overall, 108 right-handed (Oldfield, 1971 [13]) participants were tested in the present type of study. Due to extensive EEG artifacts the data of 23 persons had to be excluded from the further analysis. The remaining samples (n=85) consisted of 40 males and 45 females (age ranging from 18 to 36; mean age 23,7 ±4,1).

As the verbal abilities are developed at a certain level in healthy people (subjects were without any current and chronic medication or brain injuries) and our tasks do not need any special abilities we did not divide them into groups.

The EEG study was approved by the Ethics Committee of the Institute of the Human Brain of the Russian Academy of Sciences. All procedures were carried out in accordance with Helsinki declaration (1974). Subjects gave their informed consent for participation in the study.

3.3 EEG registration

Electroencephalogram (EEG) was recorded using Mitsar 21 channel EEG system (Mitsar, Ltd. St. Petersburg, http://www.mitsar-medical.com). We used nineteen silver-chloride scalp electrodes that were located according to the 10–20 international system at sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2) and fixed on the head surface with a conductive paste “Ten20”. Their impedance did not exceed 5 kOhm. The input signals referenced to the linked ears were filtered between 0.53 and 45 Hz and digitized at a rate of 500 Hz. The ground electrode was placed on a left hand wrist. We obtained quantitative data through WinEEG software (copyright Ponomarev V.A, Kropotov Ju.D. The register for the computer programs of RF № 2001610516, data 08.05.2001) using averaged reference montage.

3.4 EEG data analysis

Assumptions that underlie an application of ICA for analysis of EEG data are as follow: 1) summation of the electric currents induced by separate generators is linear at the scalp electrodes; 2) spatial distribution of component 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 theory, mentioned assumptions do not exactly fit to scalp recorded EEG, but in practice the application of ICA for EEG analysis gives quite reasonable results (for review see [14,15]).

For ICA data analysis [16,17] we used artifacts free intervals of EEG not shorter than 25 seconds. The length of analyzed interval was conditioned due to computational problem.

Excessive high and slow frequency activities were automatically marked as artifacts and then excluded from further analysis. The thresholds were set as follow: 1) 50 μV for slow waves in 0-1 Hz band, 2) 35 μV for fast waves filtered in the band 20-35 Hz.

25 s epochs of artifact-free multichannel EEG recording of each subject in both conditions (creative task and non creative task) were merged into a common time series. Then we transformed those EEGs of all individuals into activation curves (independent components).

For all extracted independent components in each condition for each individual we computed power spectra using averaged referenced montage. Artifact-free continuous EEG was divided into 1,024 s epochs using a Hanning time window (epochs were overlapped by 50 %) and submitted to Fast Fourier Transform (FFT). The absolute power (squared microvolt) was computed for theta (4-7 Hz), alpha1 (7-10 Hz), alpha2 (10-13 Hz), beta1 (13-18 Hz), beta2 (18-30 Hz) and gamma (30-40 Hz) frequency bands for each condition and each subject.

We also evaluated grand average power for each independent component and for the following statistical analysis considered non-artifact ICs with the greatest power.

Obtained data was then transformed using natural logarithm for normalization before further statistical analysis. For better localization of sources of brain activity 3D LORETA equivalent source current density for each extracted independent component was estimated using component topographies as input data (LORETA, R.D. Pascual-Marqui, www.keyinst.unizh.ch/loreta.htm [12])

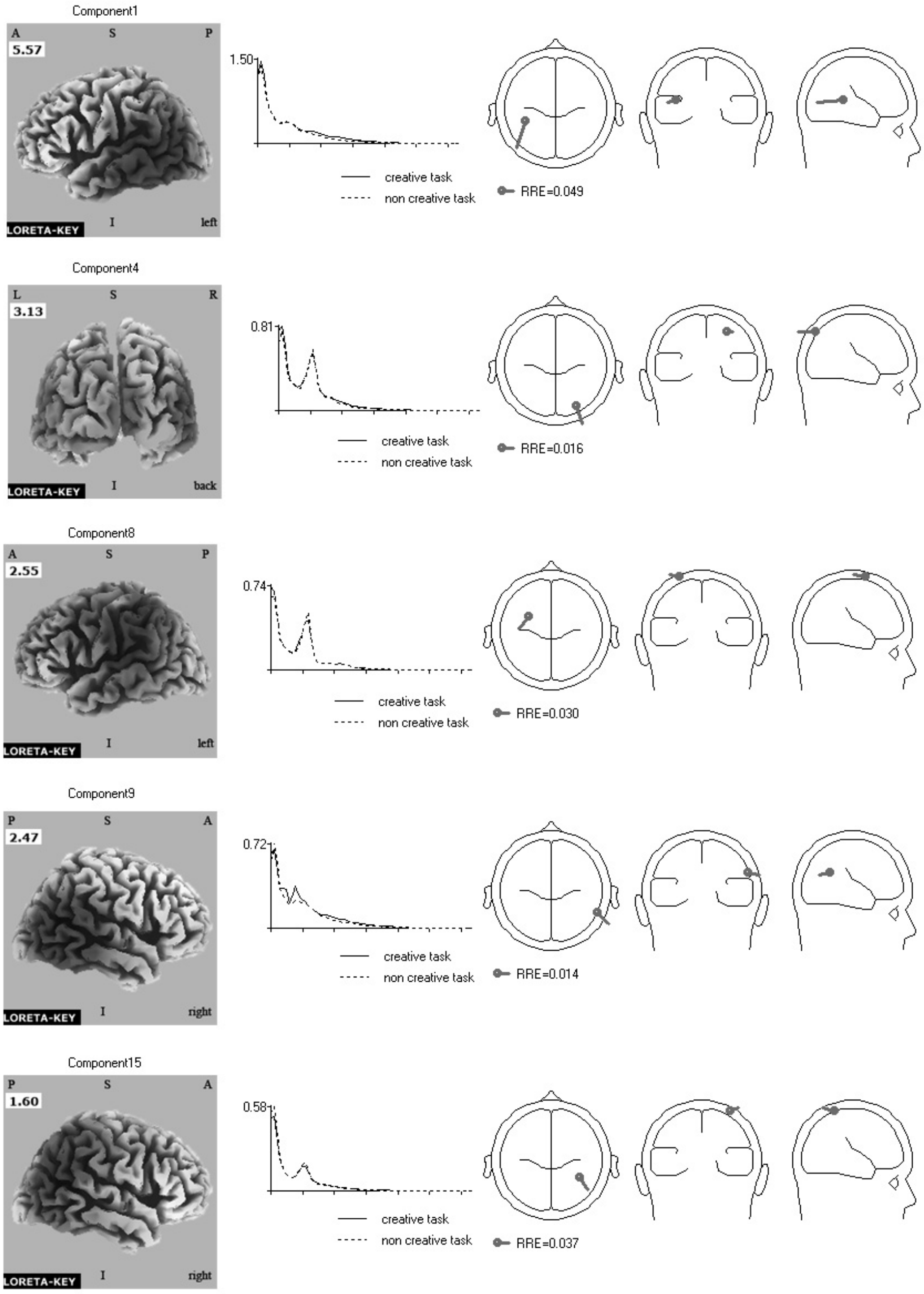
One-way ANOVA was used for assessing statistical significance of differences for ICs EEG spectral power. The statistical analysis was performed for each component in each frequency band separately (54 comparisons). We applied Bonferroni correction to avoid false positive errors in case of multiple comparisons. For the imaging of brain source localization by the LORETA method we used only those ICs, for which spectral power differences after Bonferroni correction were at $p < 0.05$.

3.5 Results and discussion

We explored spectra power of 9 non-artifact independent components. Five of them (IC1, IC4, IC8, IC9, IC15, see Fig.1): attributed to the left parietal zone, right occipital, left and right temporal zones, showed significant spectral power differences between creative and non-creative task performance (Table 1).

Spectral power values of independent components in beta1,2 and gamma frequency bands were higher for creative task performance than for noncreative task in all mentioned ICs.

Fig.1. Power spectra of ICs and their topography



A **B** **C**

A- distribution of equivalent density of activity to LORETA method
B-spectral power values of ICs. Abscissa- frequency (Hz), ordinate-absolute power of independent component.
C-results of equivalent dipole sources localization, RRE– relative residual energy.

Applied signs:
R-right side, L-left side, A-anterior, P-posterior, S-superior, I-inferior.
5.57 – absolute power value of independent component uV*2

Table 1. Significantly different independent component spectral power during creative versus non-creative task performance and LORETA localization results

Independent component name	Bonferroni corrected p values, obtained in One – way ANOVA (p< , F[1,84]=) in beta and gamma bands			LORETA localization, coordinates of equivalent current density maximum {x,y,z}, BA, gyrus
	Beta1	**Beta2**	**Gamma**	
IC1	-	0.002, 19,25	0.002, 19,66	-39, -39, 1 Middle temporal gyrus (GTm) BA22L
IC4	-	0.04, 12,32	0.008, 15,7	4, -74, 8 Cuneus (Cu) BA 23R
IC8	-	-	0.02, 14,01	-59, -32, 22 Inferior parietal lobule (Lpi) BA40L
IC9	0.03, 12,6	0.00005, 28,33	0.0002, 25,35	53, -60, 8 Middle temporal gyrus (GTm) BA39R
IC15	-	-	0.009, 12,13	53, -60, 22 Superior temporal gyrus (GTs) BA39R

BA –Brodmann area, R-right hemisphere, L-left hemisphere.

In our previous studies on EEG spectra power analysis [2,3,5] and present one we attributed this effect to the role of high frequency bands (beta >20 Hz and gamma > 30 Hz) in non-stereotypic task performance (especially gamma) and necessity of high speed data processes for heuristic, associative search during creating new endings for well-known sayings and proverbs. As it is known the increases of power and coherence in beta [18-21] and in gamma frequency bands characterize an index of brain activation and are related to different aspects of cognitive activity: from attention and perception of visual images to learning and memory [22-25]. Studies of our colleagues on verbal and non-verbal creative thinking also stress the changes in high frequency bands (beta [26, 27], gamma [28, 29]) as correlating with creative task performance.

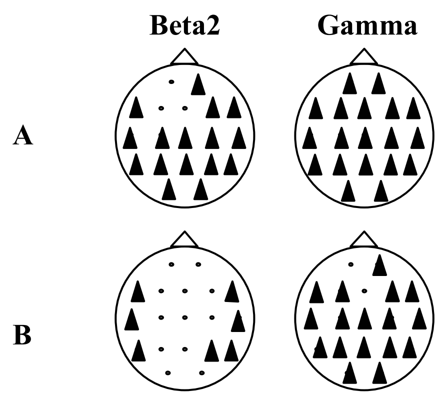
Our previous data demonstrated wide-spread effect of high-frequency EEG activity changes, especially in gamma band (Fig.2) by means of oscillatory EEG spectral analysis. Because of applied method (more and less severity of post-hoc analysis for visualization) it was rather hard to judge about cortex areas involvement in creative task performance and it was not the aim of the study.

Application of independent component analysis for our EEG data gives an opportunity to consider more exactly outlined areas (temporal zones bilaterally, right cuneus and left inferior parietal cortex) as involved in supporting of verbal creative search (see Table 1).

Mentioned areas have wide-spread connections with other brain zones participating in informational processes of different modality and meaning [30,31]. For example it is known that stimulation of secondary and associative acoustic zones (i.e. BA 22, 21) extends to the inferior frontal areas (see Luria, [31]) that supports availability of strong connections between these areas, important for complex analytical-synthetic activity, language processes, semantic processing [32,33] and verbal memory [34].

In our case we suppose that the localization of sources of independent components in left middle

Fig. 2. Significant differences (repeated measures ANOVA) in the EEG spectral power for creative versus non-creative task.



(A) LSD Fischer test; (B) HSD Tukey test applied in terms of post-hoc analysis (p<0.05). A triangle with upward vertex – higher spectral power value for the creative task versus non-creative task. Adopted from [2].

temporal gyrus and bordering areas could be attributed to the memory load and process of inner speech during production of original endings for the proverb or the saying in condition of stereotype overcoming.

Due to obtained localization of IC sources in right middle and superior temporal gyri our results support the role of both hemispheres in verbal creative task performance.

Localizations of equivalent current density maximum of independent components in left parietal lobe and right temporal gyri (see Table 1), obtained in this study are very close to localizations of cerebral blood flow increases, that were revealed in PET studies of verbal creativity using non-insight (creating a story using words from different semantic fields) and insight strategies (creating of associative chain using nouns) [1, 35, 36]. Topography of obtained ICs is also close to results of fMRI study on perception of both novel and convention metaphoric expressions [37]. Left parietal and right temporal brain zones as it was shown could be involved in visual mental imagery processes [38, 39] and switching from one task to another [40]. In our case it could be switching from one idea to another that is necessary for flexible and successful creative processes.

The inferior-parietal lobule is involved in integrating information over multiple modalities [41]. According to the results considered in Cabeza and Nyberg [42] meta-analysis, activation of parietal lobe in the left hemisphere could be attributed to verbal, objects, spatial working memory and problem solving.

Viewing the brain as the system with distributed functional networks it is known the importance of supra modal brain areas (i.e. temporal-parietal-occipital) for visual – spatial and symbolic information synthesis. Damage of these zones leads to impairment of visual representation of named objects [43]. Our findings of IC localizations in these zones as the assumption could be attributed to visual presentation of ideas “how to complete the text” in verbal creative task.

In several EEG studies the important role of parietal - frontal associative cortex connections for creative thinking was also highlighted [44-46].

Taking into account neurophysiological data on parietal and temporal areas engagement in attention processes [42, 47], we assume that these areas might be also involved in temporal distribution of attention necessary for creative thinking [4, 44, 48] and as it was already mentioned for switching from one idea to another.

4 Conclusions

We obtained effect of spectra power increase in beta and gamma frequency bands for five independent components during creative in comparison with non-creative task performance. These data are in good agreement with our previous EEG results and confirm their reproducibility by applying different methodological approaches.

Increase of EEG spectral power in high frequency bands seems to be informative indices for the type of verbal creative task we used.

Advantages of applied independent component analysis gave us an opportunity to reveal more localized EEG activity sources (ICs) than using spectral analysis for oscillatory EEG.

IC sources were attributed to the left parietal zone, right occipital, left and right temporal cortex zones involved in creative thinking. Left parietal, right occipital and both hemisphere temporal cortex zones might be considered as involved in solving of verbal creative task on overcoming a stereotype demanding high-speed associative search and flexible switching from one idea to another.

We suppose independent component analysis taken together with LORETA method seems to be a promising combination for EEG data analysis and estimation of both: changes of spectral power of independent components and localization of unmixed sources of oscillatory EEG activity in creative thinking investigations.

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