Clustering of independent components of the EEG in determining individual characteristics of reactions related to a moral choice

Bocharov A.V.[1,2], *Bogomaz S.A*[3], *Savostyanov A.N.*[1,2,3], *Knyazev G.G.*[1], *Budakova A.V.*[3], *Zaleshin M.S.*[3], *Astakhova T.N.*[2]

[1]*Federal State Budgetary Scientific Institution «Scientific Research Institute of Physiology and Basic Medicine», Novosibirsk, Russia*

[2]*National Research Novosibirsk State University, Novosibirsk, Russia*

[3]*National Research Tomsk State University, Tomsk, Russia*

Abstract—Moral judgment can be defined as the evaluation of actions with respect to norms and values established in a society. In the modern world, morality is considered as the social capital, which determines a level of society well-being. Participants were showed 24 moral dilemma and 24 control task vignettes represented artist-sketched cartoons of control and dilemma scenarios. For all participants and every experimental condition, the model of localization equivalent dipoles EEG components was made. Individual localization of EEG electrodes was matched with a model of localization of electrodes of head, which was used for determining the equivalent dipoles. Event-related spectral perturbations were calculated to estimate induced responses via the EEGLAB toolbox. The dataset was prepared for clustering by the original PCA method. The correction for multiple comparisons was made by the False Discovery Rate method. To determine the correlations cortical sources of EEG activity with Social Intellect, sLORETA was applied to the data. Differences between moral dilemmas and control tasks without moral choice were found in delta, theta, alpha and beta diapasons in clusters localized in temporal and frontal lobe. Social intellect positively correlated with difference between the test interval and the baseline during making moral dilemma choice in theta in the left middle temporal gyrus and beta in the left middle frontal gyrus.

Keywords—moral dilemmas; EEG; independent components; source localization; social intellect

I. INTRODUCTION

The study of factors that determine social cognition and behavior in humans is an actual problem of modern neuroscience. Social cognition is defined as that mental activity through which we can understand and know the social world [1]. The phenomenon of social cognition concerns morality. Moral judgment can be defined as the evaluation of actions with respect to norms and values established in a society (such as not stealing or being an honest citizen). When judging a behavior as morally good or bad, people refer to their internal representations of these norms and values (i.e. emotionally laden internal moral orientations or principles) [2]. In the modern world, morality is considered as the social capital, which determines a level of society well-being.

It is difficult to model real moral situation in laboratory conditions, that is why we used an experimental paradigm was taken from Harrison and collegues (2008) study [3]. Nowadays studies of brain activity during moral choice were made by methods of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) [2, 4, 5, 6].

These techniques allow to evaluate the level of metabolic activity in different parts of brain using as an indicator consumption of glucose or blood oxygenation. fMRI and PET techniques are extremely important and indispensable for the accurate spatial localization of the processes in brain, but have a number of limitations. Nature of the relationship of the metabolic processes and related neurophysiological activity is not always clear. It is not clear as measured these techniques metabolic changes in neurons reflect the processes taking place in them [7]. Due to the low temporal resolution these techniques, which is limited by the speed of blood flow, they do not give opportunities to investigate the dynamics of the processes of brain on a millisecond time scale. Known to date that brain functioning based on the principle of association structures of brain in functional systems required for the performing current function and inhibition of conflict processes are not required at the current moment. The role of integration in functional systems perform oscillations of bioelectrical activity of brain [8, 9]. The aim of the study was to investigate individual differences in oscillatory dynamics of structures of brain related to decision making during moral dilemma.

II. METHODS

A. Subjects

The sample included 26 participants (11 men and 15 women; age range from 17 to 22 years). Sample consisted of healthy, right-handed volunteers with normal or corrected-to-normal vision who received a sum equivalent to about $7 (U.S.) for participation. All subject filled out Social Intellect questionnaire [10, 11]. All applicable subject protection guidelines and regulations were followed in conducting the research in accordance with the Declaration of Helsinki. All participants gave informed consent to the study. The study has been approved by the Tomsk State University ethical committee.

B. Instruments and Procedure

The subjects sat in a soundproof and dimly illuminated room. Participants were showed 24 moral dilemma and 24 control task vignettes represented artist-sketched cartoons of control and dilemma scenarios accompanied by text descriptions. A preliminary instruction was presented at the screen: "You will be presented with different scenarios depicting the hero in a choice situation; please imagine yourself on the hero's place and make the choice pressing 1 for 'yes' and 2 for 'no'". In each trial, the participant viewed a cartoon and accompanying description of a hero in a control or dilemma situation. In the last lines of the description, the participant was asked to press the spacebar when he/she had understood the situation. Next, a prompt appeared that asked: "If you were at hero's place, would you buy the piece of furniture" or "would you push the fat man". For nonmoral dilemmas, response 'yes' implied the choice of an 'active' option (e.g., to purchase something). For moral dilemmas, response 'yes' implied the choice of a utilitarian option (e.g., to sacrifice a fat man in order to save five people).
Moral and control tasks were delivered randomly, and the interstimulus interval randomly varied between 4 and 6 s. For the EEG analysis, 1500 milliseconds from -2000 to -500 before the vignette presentation (vignette presentation was taken as 0) was chosen as the baseline and three seconds before the button-press were chosen as the test interval.

C. EEG recording and analysis

EEG record was collected using 128-channels according to the extended International 10-10 system with sampling rate 1000 Hz. The signals were amplified using BrainVision actiCHamp hardware. In contrast to PET and fMRI, EEG is a two-dimensional time-frequency distribution electric signal. EEG registered from scalp is a bioelectric activity of different areas of whole brain. Independent component analysis was applied to separate this activity. Artifact components connected with eye movements, muscle movements, pulse, artifact local activity of channels were removed. For all participants and every experimental condition, the model of localization equivalent dipoles EEG components was made with DIPFIT function. Individual localization of EEG electrodes was matched with a model of localization of electrodes of head, which was used for determining the equivalent dipoles. The analysis included only those EEG components whose models of equivalent dipole have residual dispersion of cortical maps that is no more than 15% as compared with the most appropriate projection model of equivalent dipole of the head electrodes. Event-related spectral perturbations (ERSP) were calculated to estimate induced responses using timef function of EEGLAB toolbox (http://www.sccn.ucsd.edu/eeglab/). The ERSP [12] shows mean log event-locked deviations from baseline-mean power at each frequency. Method of ERSP calculation realized in EEGLAB toolbox is described in Delorme and Makeig (2004) [13].

Time-frequency decomposition of the signal produced by wavelet transform version of Morlet, overlap time window started from 3-cycle wavelet, the number of cycles increased linearly when reached a half of the number of cycles with the high frequency. This method allowed to obtain better frequency resolution at higher frequencies than the conventional wavelet which used a constant amount of cycles [13]. The dataset was prepared for clustering by the original PCA method [13]. The time-frequency differences between groups and conditions had been estimated with using nonparametric permutation statistic method. The correction for multiple comparisons was made by the False Discovery Rate method [14]. This method is used instead of the Bonferroni correction if variables are highly correlated with each other [15]. Reliable effects were effects which had significance level $p < 0.05$ after False Discovery Rate method was applied.

To determine the correlations cortical sources of EEG activity with Social Intellect, sLORETA [16] was applied to the data. The sLORETA is a linearly distributed solution that is based on standardized values of the current density estimates given by the minimum norm solution. The sLORETA uses a three-shell spherical head model registered to the digitized Talairach and Tournoux (1988) atlas. The solution space is restricted to cortical gray matter and parahippocampal areas. The sLORETA yields images of standardized current source density of 6430 voxels at 5 mm spatial resolution. Statistical analysis of sources of induced oscillations in sLORETA was performed using regression of current source density estimates on Social Intellect scores. Statistical significance was assessed using a randomization test which corrects for multiple comparisons [16]. For this study, the significance level was set to $p < 0.05$.

III. RESULTS

We got 12 clusters and six of them had significant differences.

The first cluster showed significant effect during three seconds before the button-press when making a choice. Delta synchronization was observed for moral condition, in contrast for control condition delta desynchronization was obtained. Central dipole was located in the right superior temporal gyrus (Brodmann area (BA) 22). The second cluster showed significant effect during last 2 sec but one before making a choice. Delta desynchronization was more pronounced for control task. Theta synchronization was more pronounced for moral condition. Central dipole had symmetric localization to first cluster in the left temporal gyrus (BA 22). The third cluster had localization in the right middle temporal gyrus (BA 37). Alpha desynchronization was more pronounced for moral condition during three seconds before making a choice. The fourth cluster localized near rectal gyrus in the right frontal lobe (BA 11). Delta synchronization and alpha desynchronization was more pronounced for moral condition during three seconds before making a choice. Central dipole of the fifth cluster localized near the middle frontal gyrus (BA 6). Delta synchronization was more pronounced for moral condition during last 2 sec but one before making a choice. Beta desynchronization was less pronounced for moral condition during 3 sec before making a choice. The sixth cluster included the posterior cingulate cortex (PCC). Delta and theta synchronization was obtained for moral condition, delta and theta desynchronization was obtained for control task during last 2 sec but one before making a choice. Beta desynchronization was less pronounced for moral condition during last 2 sec but one before making a choice.

sLoreta regression analysis of Social intellect on the difference between the test interval and the baseline during making moral dilemma choice yielded positive correlations for theta and beta2 diapasons. For theta, the strongest effect is observed in the left middle temporal gyrus, BA 21 (MNI coordinates X=-60, Y = 0, Z =-15) r=0.587, Extreme p = 0.007, for beta2 in the middle frontal gyrus, BA 10 (MNI coordinates X=-25, Y = 50, Z =0) r=0.602, Extreme p = 0.007 (Figure 1).

IV. DISCUSSION

The long-standing rationalist tradition in moral psychology emphasizes the role of reason in moral judgment. A more recent trend places increased emphasis on emotion [6]. Results of this study show that oscillatory responses in the moral condition differ significantly from ones in the nonmoral condition. The difference is most strong in delta and theta bands, which are known to be involved in emotion processing, and in brain regions associated with emotion. Many studies show that delta and theta bands are associated with emotional and motivational processes [17, 18]. Cluster 1 and cluster 3 are found in the right ('emotional') hemisphere and in its temporal lobe, which undoubtedly is involved in emotion processing [19]. Our results are in line with Greene et al.'s (2001, 2004) and Knyazev et al.'s (2015) findings [5, 6, 20]. Also higher Social intellect was associated with larger theta synchronization (difference between the test interval and the baseline) in temporal lobe in moral condition. This implies that higher sensitivity to moral issues and it might be essential for understanding the implications choices in moral dilemmas.

Other significant effects were also found in the alpha frequency band (cluster 3 and 4), but they were in the opposite direction. In this case, the difference between the test interval and the baseline was lower (i.e., more negative) in moral than in nonmoral condition. It could be suggested that is related with difficulty of making a decision in moral condition because the degree of desynchronization of alpha correlates with the complexity of the task and reflects the amount resources included in the task [21].

Another clusters (4 and 6) localized in the orbitofrontal prefrontal cortex (OFB) and the PCC. The OFC represents the affective value of primary reinforcers and it learns to associate other stimuli with these to produce representations of the expected reward value, thus, playing a key role in emotion [22]. The OFC activation during moral decision-making has been shown [23, 24]. In this study subject were asked to report his/her prospective behavior in respective situation. This aspect of the task might be responsible for the involvement of the cortical midline structure such as the PCC, because this structure is included in self-processing and social cognition [25, 26].

In our study, higher Social intellect was associated with larger difference between the test interval and the baseline during moral condition in theta in the left temporal lobe and beta2 diapason in the left OFC. The right OFC was found to be activated during passive viewing of moral stimuli compared with nonmoral stimuli [27], while the activation of the left OFC has been related to processing of emotionally salient statements with moral value [28]. In recent years, we have witnessed a surge of interest to the question of so-called cross-frequency coupling of brain oscillations. It has been repeatedly shown that low-frequency oscillations of mostly delta and theta bands are able to affect high-frequency oscillations of beta and gamma bands [29]. This coupling is functionally relevant [30] and some evidence shows that it might increase in emotionally engaging states [31, 32, 33].

In this study, more effects were found in low delta, theta and were located in emotional areas such as temporal cortex, while more higher frequency (alpha and beta) effects were located in frontal cortex which related with decision making. Overall, the pattern of results is in line with the idea that in moral condition, the subject appears to be in a state of higher emotional engagement and perceives this situation as more self-related than in nonmoral conditions.

ACKNOWLEDGMENT

Contribution to this work of Bocharov A.V., Savostyanov A.N. and Knyazev G.G. was supported by the Russian Science Foundation (RSCF) under Grant № 14-15-00202; contribution to this research of Bogomaz S.A, Budakova A.V. and Zaleshin M.S. was carried out on the instructions №2014 / 233 to perform public works in the framework of the basic tasks of the State Ministry of Education of Russia, the project «Psychotechnological ensuring the process of the development of cognitive and communicative potential».

REFERENCES

1. Mitchell, J. P. (2006). Mentalizing and Marr: an information processing approach to the study of social cognition. *Brain research, 1079* (1), 66-75.
2. Prehn, K., Wartenburger, I., Mériau, K., Scheibe, C., Goodenough, O. R., Villringer, A., ... and Heekeren, H. R. (2008). Individual differences in moral judgment competence influence neural correlates of socio-normative judgments. *Social Cognitive and Affective Neuroscience*, 3 (1), 33-46.
3. Harrison, B. J., Pujol, J., López-Solà, M., Hernández-Ribas, R., Deus, J., Ortiz, H., ... and Cardoner, N. (2008). Consistency and functional specialization in the default mode brain network. *Proceedings of the National Academy of Sciences, 105* (28), 9781-9786.
4. Ciaramelli, E., Muccioli, M., Ladavas, E., and di Pellegrino, G. (2007). Selective deficit in personal moral judgment following damage to ventromedial prefrontal cortex. *Social cognitive and affective neuroscience, 2* (2), 84-92.
5. Greene, J. D., Nystrom, L. E., Engell, A. D., Darley, J. M., and Cohen, J. D. (2004). The neural bases of cognitive conflict and control in moral judgment. *Neuron, 44* (2), 389-400.
6. Greene, J. D., Sommerville, R. B., Nystrom, L. E., Darley, J. M., and Cohen, J. D. (2001). An fMRI investigation of emotional engagement in moral judgment. *Science, 293*(5537), 2105-2108.
7. Debener, S., Ullsperger, M., Siegel, M., and Engel, A. K. (2006). Single-trial EEG–fMRI reveals the dynamics of cognitive function. *Trends in cognitive sciences, 10* (12), 558-563.
8. Buzsáki, G., and Draguhn, A. (2004). Neuronal oscillations in cortical networks. *Science, 304* (5679), 1926-1929.
9. Nunez, P. L. (2000). Toward a quantitative description of large-scale neocortical dynamic function and EEG. *Behavioral and Brain Sciences, 23* (03), 371-398.
10. Shcherbakov S.V. Diagnostika socialnogo intellecta studentov. Actualnye voprosy phyziologii, psihofiziologii i psihologii. Sbornik nauch. statei. Red. kol. d. med. n., prof. prof. Kayumov F.F. i dr. – Ufa. RIC Bash-IFC, 2010. - P. 122-126.
11. Matsuta V.V., Bogomaz S.A., Sudneva O.Yu. (2014). The role of intellectual and personal factors in achieving high performance in the use in mathematics. *Siberian Journal of Psychology*, 52, 52-66.
12. Makeig, S. (1993). Auditory event-related dynamics of the EEG spectrum and effects of exposure to tones. *Electroencephalography and clinical neurophysiology, 86*(4), 283-293.
13. Delorme, A., and Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods, 134*(1), 9-21.
14. Holm S. A simple sequentially rejective multiple test procedure // Scandinavian J. Stat., 1979, V. 6, P. 65-70.
15. Tanji, K., Suzuki, K., Delorme, A., Shamoto, H., and Nakasato, N. (2005). High-frequency γ-band activity in the basal temporal cortex during picture-naming and lexical-decision tasks. *The Journal of neuroscience, 25* (13), 3287-3293.
16. Pascual-Marqui, R. D. (2002). Standardized low-resolution brain electromagnetic tomography (sLORETA): technical details. *Methods Find Exp Clin Pharmacol, 24* (Suppl D), 5-12.

17. Knyazev, G. G. (2007). Motivation, emotion, and their inhibitory control mirrored in brain oscillations. *Neuroscience & Biobehavioral Reviews*, 31, 377-395.
18. Knyazev, G. G. (2012). EEG delta oscillations as a correlate of basic homeostatic and motivational processes. *Neuroscience & Biobehavioral Reviews*, 36, 677-695.
19. Lang, P. J. (2010). Emotion and motivation: Toward consensus definitions and a common research purpose. *Emotion Review, 2*, 229-233.
20. Knyazev, G. G., Savostyanov, A. N., Bocharov, A. V., Dorosheva, E. A., Tamozhnikov, S. S., and Saprigyn, A. E. (2015). Oscillatory correlates of moral decision-making: Effect of personality. *Social neuroscience*, 1-16.
21. Gevins, A., Smith, M.E., McEvoy, L., Yu, D., High-resolution EEG mapping of cortical activation related to working memory: Effects of task difficulty, type of processing, and practice // Cerebral Cortex, 1997, V. 7, P. 374-385.
22. Rolls, E. T., and Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology, 86*, 216-244.
23. Bechara, A., Damasio, H., and Damasio, A. (2000). Emotion, Decision Making and the Orbitofrontal Cortex. *Cerebral Cortex, 10*, 295-307.
24. Shenhav, A., and Greene, J. D. (2010). Moral judgments recruit domain-general valuation mechanisms to integrate representations of probability and magnitude. *Neuron, 67*, 667-677.
25. Northoff, G., and Bermpohl, F. (2004). Cortical midline structures and the self. Trends in *Cognitive Sciences, 8*, 102-107.
26. Knyazev, G. G. (2013). EEG correlates of self-referential processing. *Frontiers in human neuroscience, 7.*
27. Harenski, C. L., and Hamaan, S. (2006). Neural correlates of regulating negative emotions related to moral violations. *Neuroimage, 30*, 313-324.
28. Moll, J., de Oliveira-Souza, R., Eslinger, P. J., Bramati, I. E., Mourão-Miranda, J., Andreiuolo, P. A., and Pessoa, L. (2002). The neural correlates of moral sensitivity: a functional magnetic resonance imaging investigation of basic and moral emotions. *Journal of Neuroscience, 22*, 2730-2736.
29. Jensen, O., and Colgin, L. L. (2007). Cross-frequency coupling between neuronal oscillations. *Trends in Cognitive Sciences, 11*, 267-269.
30. Tort, A. B., Kramer, M. A., Thorn, C., Gibson, D. J., Kubota, Y., Graybiel, A. M., and Kopell, N. J. (2008). Dynamic cross-frequency couplings of local field potential oscillations in rat striatum and hippocampus during performance of a T-maze task. *Proceedings of the National Academy of Sciences, 105*(51), 20517-20522.
31. Knyazev, G. G. (2011). Cross-frequency coupling of brain oscillations: An impact of state anxiety. *International Journal of Psychophysiology, 80*, 236-245.
32. Knyazev, G. G., Slobodskoj-Plusnin, J. Yu. (2007). Behavioural approach system as a moderator of emotional arousal elicited by reward and punishment cues. *Personality and Individual Differences, 42*, 49-59.
33. Schutter, D. J. L. G., van Honk, J. (2004). Decoupling of midfrontal delta-beta oscillations after testosterone administration. *International Journal of Psychophysiology, 53*(1), 71–73.

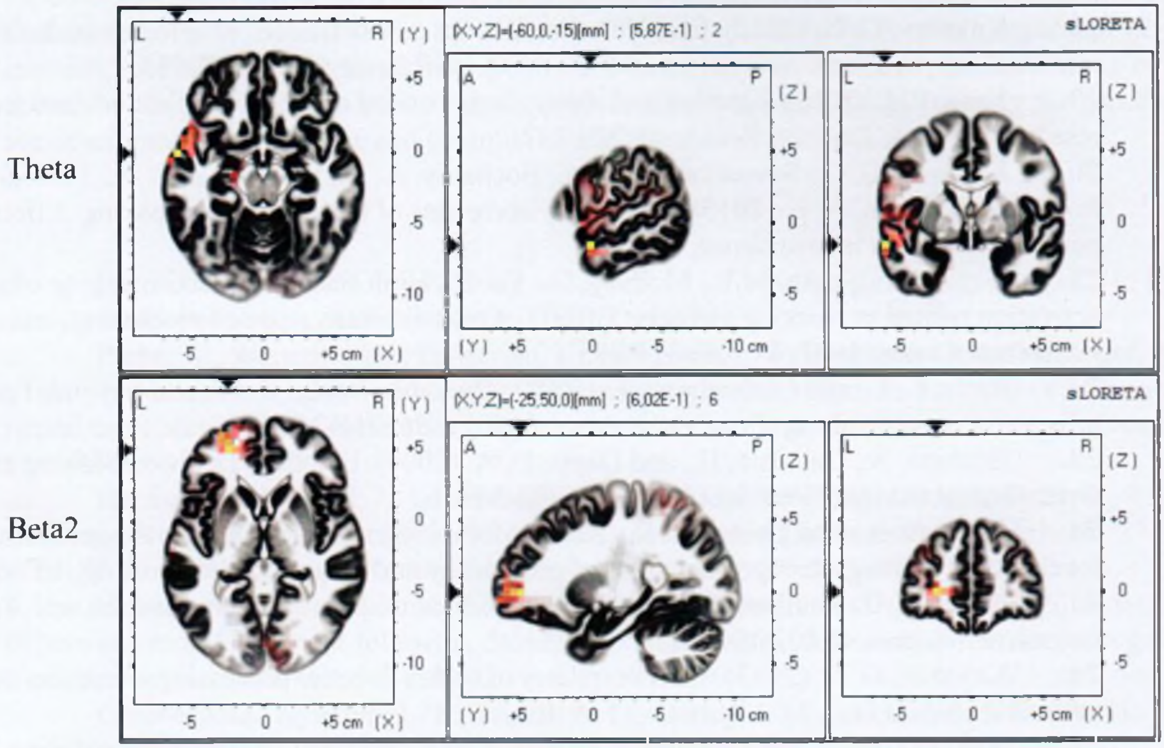

Figure 1. sLORETA results of a regression analysis of Social intellect scores on the difference between the test interval and the baseline during making moral dilemma choice. The strongest effect is observed in the left middle temporal gyrus, BA 21, X=-60, Y = 0, Z =-15 for theta, for beta2 in the middle frontal gyrus, BA 10, X=-25, Y = 50, Z =0.