The EEG Correlates of the Allocentric and the Egocentric Spatial Reference Frames Processing

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Abstract— **In the paper we describe current results of our ongoing research, concerning the navigation in the virtual tunnel task and its EEG correlates. We searched for the features in the EEG signal to discriminate the employment of the allocentric and the egocentric reference frames. These two reference frames differ in the center of deixis (the origin of the coordinating system). Our sample comprised groups that tend to solve the task by adopting one of the mentioned reference frames. We decomposed the EEG signal to the basic features and used this data as the input for the neural networks. The classification task is to select the best features to discriminate between these reference frames. The result was congruent with the similar study (Gramann et al., 2006) in the Brodmann area 7 differences, but we also detected other brain areas involved in this task.**

Keywords— **spatial navigation, reference frames, EEG, feature selection, SOM**

Introduction

Our research is focused on the representation of space and the employment of the reference frames. In the area of spatial cognition the reference frame is considered as orthogonal system with the origin (the deixis center) in the retina, head, body or other points, objects, or array in space (Behrmann, 2000; Colby a Goldberg, 1999; McCloskey, 2001).

The research of neural correlates in the area of spatial cognition confirmed differences between utilization of egocentric (relative frame and the center of deixis is identical with observer) and allocentric (fixed absolute system) reference frame (Fink et al., 2003). Experiment with monkeys proved the existence of representation based on center of deixis in observer or in the object (Breznen et al., 1999). Researchers focused on the human processing identified the brain areas involved in the processing of the egocentric reference frames. These are frontal parietal areas including the posterior parietal cortex and the premotor cortex in the right hemisphere. There is only part of these areas activated for the allocentric reference frame processing (Galati et al., 2000). The problem of these results is in the way of administrating the experiments. There were only static stimuli presented to the participants. It should decrease the ecological validity of the results because people normally perceive the space in the dynamic 3D environment. There are some recent studies that improve this insufficiency by presenting virtual environment as stimuli (Gramann et al., 2005, 2006). They presented only the visual flow without any objects to the participants, because the objects in space should affect the way of representing the environment. We presented modified version of this scenario to our participants to identify differences in the allocentric and egocentric reference frame processing.

Method

The main goal of the study is to administrate version of the Gramann study, with the extension to the vertical direction. Gramann presented only the tunnels in the horizontal plane, so we extended the task with the upward and downward turned tunnels, to measure the horizontal and vertical navigation. We wanted to identify the differences in the EEG signal.

We adopted the psychological experiment as the research method. There were presented several traverses through the virtual tunnel to the subject and his/her answer after the traverse determines the reference frame. This is the input for the classification algorithms for the identification of the brain areas responsible for the processing of different reference frames. According to the hypothesis there is the difference in the EEG signal between the subjects adopting allocentric and egocentric reference frame.

Results

A. Experiment

The experiment design consists of 20 traverses through the virtual tunnel. Subject is informed that the experiment is focused on spatial navigation. He or she has to decide after each traverse, which arrow (there are two arrows on the screen) is pointing to the origin of the tunnel (the place he/she started the journey). His/her choice is the answer to the question, what reference frame he/she adopted as the navigation system. The differences for the separate reference frames are explained in Fig. 1.

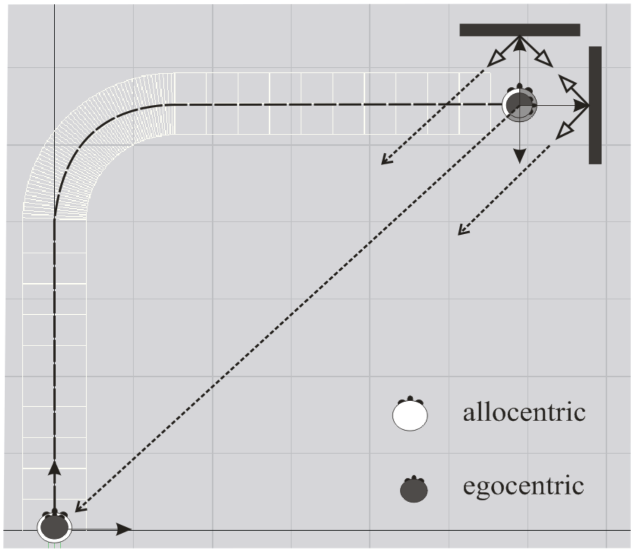

Fig. 1. The difference between the egocentric and allocentric reference frame. The both frames are identical at the beginning of the tunnel. The egocentric frame at the end of the tunnel is turned the same angle as the head turns within the curved segment of the tunnel.

We recorded the EEG activity within traversing the tunnel by the 19 electrodes system (the international system 10-20). The sampling rate is 250 Hz and the reference electrode is Cz. There were totally 20 tunnels, specifically 5 tunnels with the variable curvature for each of 4 directions (up, down, left right). The tunnels were presented randomly to the subject, and there were not 2 tunnels of the same direction presented consequently. The subject traverse 26s through the virtual tunnel and at the end there are two arrows. The subject has to decide, which one is pointing to the beginning of the tunnel.

The answers are evaluated after the first part of the experiment and we should decide what type of reference frame the subject prefers. The criterion was the percentage of answer consistent with one type of the reference frame. If the subjects chose the same frame at the level of 85 percent (17 of 20 answers) he or she was considered as the representative user of the particular reference frame.

B. *EEG processing*

At the first stage we process the raw signal by the adaptive segmentation method. This algorithm divides the signal to the segments of the variable length, but the same type of signal (Krajca, 1991). Then we process this data and decompose the segments from each electrode to the signal features. There are 103 features for every electrode and we did the calculation of the interhemispheric and intrahemisperic correlation and coherence of electrode pairs too. The result of this processing is the matrix of 1903 features and coherences (1s resolution) for the duration of the first part of experiment (800s). Then we analyzed this data to select the best features discriminating between the allocentric and egocentric reference frame.

C. *SOM*

The SOM architecture categorizes input data to selected number of clusters. The main advantage is the learning process that improves the categorization results comparing to the classical clustering. We adopted the classical dual layer SOM network for the purpose of the analysis. The input layer contains 6 to 26 neurons according to the length of the input segment (6 neurons for the turned segment, 10 neurons for both straight segments and 26 neurons for the whole tunnel). The output layer consists of two neurons representing separate reference frames. The network was trained for 500 epochs and the initial learning rate was set to1.

The network processes every input (representing the features time series of one traverse) and respond to them by assigning one neuron in the output layer. Then the algorithm compares the network output to the ideal values (preferred reference frame based on the answer after the tunnel traverse or the concrete answer to the separate tunnel) and calculates the percentage accuracy of every feature. You can see the results of the analysis for the separate parts of the tunnel and the tunnel as a whole in the Tab.1-2.

Turn (6s)	1-ego	6-ego	7-ego	11-allo	13-allo	Mean
F8-T4-coher.aplha	90	70	80	55	65	69,6
1st straight (10s)						Mean
T6-02-corel.	30	85	85	90	60	63,8
2nd straight (10s)						Mean
F8-T4-coher.apha	100	85	90	55	60	68,5
T3-rel-beta	85	55	95	95	60	67,7
T6-02-corel.	40	70	90	85	60	66,2
Tunel (26s)						Mean
F3-mean	80	75	90	70	60	64,2
T6-wav.alpha	0	85	85	80	100	63,1

Tab. 1. SOM results. Comparison of the network outputs to the preferred frame.

Turn (6s)	1-ego	6-ego	7-ego	11-allo	13-allo	Mean
T3-T4-coher.delta	90	55	70	95	55	65,8
1st straight (10s)						Mean
T6-02-corel.	35	60	85	80	65	63,8
2nd straight (10s)						Mean
F8-T4-coher.alpha	95	60	90	65	65	68,5
T6-02-corel.	35	65	90	75	65	66,2
Tunel (26s)						Mean
F8-T4-coher.apha	95	65	95	75	75	73,5
O1-02-coher.beta	20	75	90	90	60	63,8
T6-wav.alpha	5	60	85	80	95	63,1

Tab.2. SOM results. Comparison of the network outputs to the concrete answer to separate tunnel traverse.

The accuracy of classification for the best features was 65 percent in average and the best features are similar for the analysis of ideal answers (network output to the preferred reference frame) and the concrete answers (network output to the concrete answer to the separate tunnel). The most frequent feature for all parts of the tunnel was the coherence between electrode F8 and T4 in the alpha band wave. This best feature for the turned passage and the tunnel as the whole is the F8-T4 coherence again. For the 1st straight segment the best discriminating feature is the correlation between T6 and O2 electrode and for the 2nd straight segment the F8-T6 coherence again.

To exclude the possibility the different EEG activity for the navigation in the horizontal and vertical direction we did the separate analysis just for the horizontal plane. We put into the analysis only the tunnels to the left and right direction and adopt the SOM maps as the clustering algorithm again. As you can see in the Tab. 3 the results were similar to the previous analysis, even thought there were some differences for the specific segment of the tunnel. The most frequent feature for all parts of tunnel was the coherence between the F8 and T4 electrode in the alpha band wave again

Turn (6s)	1-ego	6-ego	7-ego	11-allo	13-allo	Mean
F8-T4-coher.alpha	100	90	60	50	70	71,5
Cz-skewness	90	90	50	60	60	67,8
1st straight (10s)						Mean
P4-skewness	70	100	60	70	60	67,8
F8-T4-coher.alpha	100	80	70	60	60	66,2
C3-mean	60	90	90	60	90	64,6
2nd straight (10s)						Mean
Cz-skewness	90	60	60	50	80	66,2
F3-rel.delta	100	60	70	80	50	64,6
Tunel (26s)						Mean
F8-T4-coher.apha	100	100	90	70	70	72,1
P4-skewness	80	100	70	80	70	72,1
P4-mean	70	80	100	60	90	66,2
F7-wavelet.beta	90	90	60	80	70	65,4

Tab. 3. SOM results. Comparison of the SOM outputs to the preferred reference frame for the horizontal plane.

DISCUSSION

When we compare our results to the similar study (Gramann, 2006), there is only partial correspondence between them. Gramann (2006) identified the biggest difference between the activity of Broadmann areas 7 and 32. He employed the LORETA algorithm (Pasqual-Marqui and Biscai-Kirio, 1993) to reconstruct the information about the mean activity of cortical and sub cortical areas from the EEG signal. The result is the 3D map of the brain areas activation and the changes in this activity over time. There are some doubts about the possibility to reconstruct the sub cortical activity from the scalp measurement (Rieger et al., 2006), so we adopted just the classical 2D scalp mapping for the results visualization.

There are also some differences in the way of the activity decomposition. Gramann (2006) analyzed only the mean source activity, but we decomposed the signal from each electrode to 93 features, so there were mean values, deviations, skewness of signal, spectral activity in all band waves (alpha, beta, gamma, delta), correlations, coherences etc. Although both studies differ in the method of signal analysis, there should be similar results in the terms of the same brain areas involved in the processing of the egocentric and allocentric reference frame. The studies are graphically compared in Fig. 2.

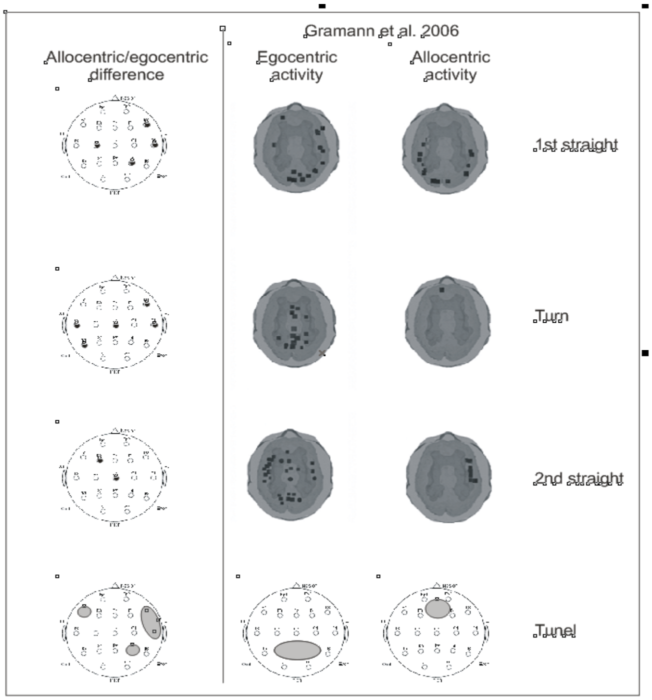

Fig. 2. The comparison of the presented study (left) to the similar (Gramann, 2006).

Gramann (2006) presents the results as the areas with the highest activity for the specific reference frame. In our study the results are represented as the areas with the biggest difference between two frames.

The curved segment of the tunnel is the most interesting part of the analysis, because the egocentric reference frame starts to rotate at this passage, but the allocentric frame does not change. Gramann concludes the highest activity of the left frontal anterior area for the allocentric frame and posterior parietal areas for the egocentric frame. We attribute the difference to the front temporal areas of the right hemisphere (alpha coherence between F8-T4 electrodes). The second most differentiating feature was the skewness at the Cz electrode, which is the place with increased activity for the egocentric frame in the Gramann's study (2006). We should also add the results of the hierarchical and classical clustering for this part of tunnel. We identified the differences in the left posterior temporal lobe, specifically the coherence in the gamma band (higher cognitive functions) between T3-T5 electrode and the activity in the beta band (active cognition) for the F8 electrode. The SOM analysis already proves the difference in the alpha band wave in this region. We should conclude that the results of the compared studies differ in this part of the tunnel. The only similarity is in the activity at the medial temporal areas.

The last part of analysis is focused on the tunnel as a whole. We processed 26 second of the tunnel traverse without specifying particular segments. There is no detailed analysis of processing in Gramann study (2006). He identified two Brodmann areas with the highest activity for the specific reference frame. The egocentric reference frame is tied with the activity in the area 7 and the allocentric frame with the area 32. Our results identified the biggest difference within the coherence between F8-T4 electrodes in the alpha band wave. There were also differences in the mean activity and skewness in P4 electrode. This electrode is situated in the Broadmann area 7, so the results are congruent with the Gramann study. The last salient feature for the reference frame differentiation was at the beta band wave around the electrode F7. Both areas (F7 and F8-T4) are situated in the frontal areas but they are situated more laterally than the Gramann specification of the Broadmann area 32.

CONCLUSIONS

We identify the differences in the processing of the allocentric and egocentric reference frame in the activity of the Broadmann area 7 in accordance to the similar study (Gramann, 2006). The question is, whether we should attribute the differences in the processing of mentioned frames to the area 32 (Gramann, 2006). The processing in the area 7 is consistent with the neuroanatomic finding, because this area is considered as the centre for spatial navigation and representation. For the specification of the results in the frontal areas we need to administrate this task for larger sample of participants.

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REFERENCES

1. S Breznen, B., Sabes, P.N., Andersen, R.A., (1999). Parietal coding of object-based saccades: reference frames. Abstr.-Soc. Neurosci. 25, 618.10.South J, Blass B (2001) The future of modern genomics. Blackwell, London
2. Colby, C.L., Goldberg, M.E. (1999). Space and attention in parietal cortex. Annual Review of Neuroscience, 22:319-49.
3. Friederici, A.D., Levelt, W.J.M. (1990). Spatial reference in weightlessness: Perceptual factors and mental representations. *Perception & Psychophysics,* 47:253-266.
4. Fink, G.R., Marshall, J.C.,Weiss, P.H., Stephan, T., Grefkes, C., Shah, N.J., Zilles, K., Dietrich, M., (2003). Performing allocentric visuospatial judgments with induced distortion of the geocentric reference frame: an fMRI study with clinical implications. NeuroImage 20, 1505–1517.
5. Galati, G., Lobel, E., Vallar, G., Berthoz, A., Pizzamiglio, L., Le Bihan, D., (2000). The neural basis of egocentric and allocentric coding of space in humans: a functional magnetic resonance study. Exp. Brain Res. 133, 156–164.
6. Gramann, K., Müller, H.J., Eick, E., Schönebeck, B., (2005). Empirical evidence for separable spatial representations in a virval navigation task. J Exp Psychol Hum Percept Perform 31,1199–1223.
7. Gramann, K., Müller, H., Schönebeck, B. & Debus, G. (2006). The neural basis of egocentric and allocentric reference frames in spatial navigation: Evidence from spatio-coupled current density reconstruction. Brain Research, 1118, 116-129.
8. Krajca, V., Petranek S., Pataková I., Varri, A.: Automatic identification of significant graphoelements in multi-channel EEG recordings by adaptive segmentation and fuzzy clustering, Int. J. Biomed. Comput., vol. 28 , (1991) 71-89
9. Pasqual-Marqui, R.D., Biscay-Lirio, R., (1993). Spatial resolution of neuronal generators based on EEG and MEG measurements. Int. J. Neurosci. 68, 93–105.
10. Rieger, J., Lhotská, L., Krajča, V. (2006). Forward and Inverse Problems in EEG. In 53. společný sjezd české a slovenské společnosti klinické neurofyziologie. Praha: MH Consulting, 29-30