# The Neural Correlates of Spatial Reference Frames Processing

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## 1 Introduction

Spatial navigation is the important topics in the area of cognitive science. Neuropsychological studies focused on the processing of visual information uncovers separate visual (*what*) and spatial (*where*) subsystem (Milner, Goodale, 1995). The *where (dorsal) pathway* is responsible for spatial representation of object location and for motor execution. From the neuroanatomic point of view there is parietal lobe involved in the processing, mainly medial temporal, medial superior temporal, posterior parietal ventral and lateral areas.

In the area of spatial navigation the reference frame is considered as orthogonal system with the origin (deixis center) in retina, head, body or other points, objects, or array in space (Colby a Goldberg, 1999; McCloskey, 2001). In the series of experiment (Carlson-Radvansky, Irwin, 1993) researchers identified differences in the using of reference frames. They concluded that reference frames are simultaneously activated (Carlson-Radvansky, Irwin, 1993), and automatic (Carlson-Radvansky, Logan, 1997). In the later studies they identified modulation of neural activity (EEG signal) for the specific reference frames (Carlson, West, Taylor, Hendon, 2002).

The further research on neural correlates confirmed the differences between the adoption of egocentric (relative frame and the center of deixis is identical with observer) and allocentric (fixed absolute system) reference frame (Fink et al., 2003). Researchers identified brain areas involved in processing of egocentric reference frames. These are frontal parietal areas including posterior parietal cortex and premotor cortex in the right hemisphere. There is only part of these area activated for the allocentric reference frame processing (Galati et al., 2000). But there is the methodological problem, because of static stimuli presented to the participants. It should decrease ecological validity of the results as people used to perceive space in the dynamic 3D environment. There are some recent studies that improve this problem by presenting virtual environment as a stimuli (Gramann et al., 2005, 2006).

## 2 Method

The goal of the study is to administrate modified version of the Gramann study, with the extension to the vertical plane. Gramann et al. (2006) presented only the tunnels in the horizontal plane, so we added upward and downward turned tunnels to the stimuli set, to differentiate between horizontal and vertical navigation. We recorded the EEG signal during the traversing the tunnel to uncover the mechanisms of the different reference frames processing and specify the brain areas involved in this task.

Experiment design consists of 20 traverses through the virtual tunnel. Subject has to choose after each traverse one of the two arrows pointing to the origin of the tunnel. The choice is the answer to the question, what reference frame he/she adopted as the navigation system. The differences between the separate reference frames are explained in Fig. 1.

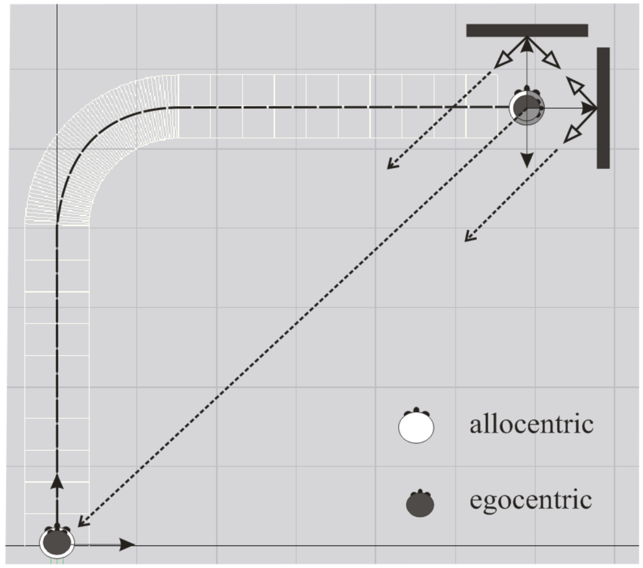


**Fig. 1.** The difference between egocentric and allocentric reference frame. At the beginning of the tunnel both frames are identical. At the end of the tunnel the egocentric frame is rotated the same angle as the head turns during the curved segment of the tunnel. The allocentric frame is fixed. The difference between these two angles is the same as the angle between the two arrows presented on the screen (dark bar) after the tunnel traverse.

We record the EEG activity within the tunnel traverse (19 electrodes). Every tunnel is composed of 3 segments: the 1st straight, the turned and the 2nd straight segment. The period of traversing was the same for each tunnel a constant for each segment. The curvature of the turned passage varied. The tunnels were randomly presented. The answers were evaluated to decide what type of reference frame subject prefers. The criterion was the percentage of answer consistent with one type of reference frame. If the subjects chose the same frame above the 85 percent level, he/she was considered as the representative user of the particular reference frame.

## 3 Results

At the first stage we process the raw signal by the adaptive segmentation method. The algorithm divides the signal to the segments of variable length. Then we decomposed segments from each electrode to the signal features. There are 103 features for every electrode, inter-hemispheric and intra-hemisperic coherences of electrode pairs. Then we selected the best features discriminating between allocentric and egocentric reference frame adoption.

### 3.1 Hierarchic clustering

The first method is based on hierarchical clustering. The criterion for the analysis is the ability to divide subjects to groups according the reference frame they preferred. We analyzed separate segments of the tunnel and also tunnel as a whole and identified differences mainly in the right temporal and left frontal areas. The best features are the F4 and F8 electrode at the beta band wave (frontal lateral lobe at the right hemisphere) and the T3/T5 coherence in the gamma band wave (posterior temporal lobe at the left hemisphere).

### 3.2 Clustering

We did similar type of analysis based on the classical clustering. It is possible to define number of target groups and the algorithm divides the data according to this parameter. The results were similar to the hierarchical clustering. We identified differences in the right temporal lobe, left frontal lobe but also at the occipital lobes (bilaterally). The best features are T3-T5 coherence in the gamma band wave, O1 at alpha band wave, F4 electrode at gamma band wave and F4-C4 coherence at alpha bad wave. For the detail analysis of all tunnel segments we adopted the self-organizing networks (SOM).

### 3.3 SOM

SOM architecture categorizes input data to selected number of clusters and the learning process improves the categorization results comparing to the classical clustering. We adopted 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. The output layer consists of two neurons representing separate reference frames.
Then we compare the network output to the ideal values (preferred reference frame based on the answer after the tunnel traverse) and calculate the accuracy of every feature. You can see the results for the separate parts of the tunnel and the tunnel as a whole in the Tab.1.

| 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 |

| 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. 1.** The SOM results. Comparison of the network results for both planes (left) and for separate horizontal plane (right). At the first row there are subjects and their preferred frames, then the results (percents of correct classification) for the separate parts of the tunnel traverse. There are mean values for whole sample.

The classification accuracy was 65 percent in average. The most frequent feature for the 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 $1^{st}$ straight segment the best discriminating feature is the correlation between T6 and O2 electrode and for the $2^{nd}$ straight segment the F8-T6 coherence again.
To distinguish the navigation in the horizontal and vertical direction we did the separate analysis just for the horizontal plane. There were some differences in both straight segments of the tunnel and the whole tunnel (see Tab.1). The curved passage resulted in the same areas for the reference frame differentiation. The most frequent feature for all parts of tunnel was the coherence between the F8 and T4 electrode in the alpha band wave again.

## 4 Discussion

We adopted several methods for the signal classification and feature extraction to find the best features and brain areas involved in the egocentric and allocentric reference frames processing. When we compare our results to the similar study (Gramann et al., 2006), there is only partial correspondence between them. Gramann et al. (2006) identified the biggest difference between the activity of Broadmann areas 7 and 32. They employed the LORETA algorithm (Pasqual-Marqui and Biscai-Kirio, 1993) to reconstruct the information about the activity of cortical and sub cortical areas from the EEG signal. The result is the 3D map of brain areas activation. There are also some differences in the way of signal decomposition. They analyzed just the mean source activity. We decomposed signal from each electrode to the 103 features, so the description of the signal is much more detailed and should identify more precisely the differences between the reference frame adoption. Although the both studies differs in the method of signal analysis, there should be similar results in terms of same brain areas involved in processing of egocentric and allocentric reference frame.

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 et al., 2006). The processing in the area 7 is consistent with the neuroanatomic finding, because this area is considered as the center for spatial navigation and representation. The question is, whether we should attribute the differences in the processing of mentioned frames to the area 32 (Gramann at al., 2006). Moreover the distinction between results in horizontal plane and the both planes leads us to the conclusion there are special brain areas involved in the vertical navigation. We need to analyze these findings in more detail in the further research.

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