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DOCTORAL THESES

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**SPATIAL AND TIME CHARACTERISTICS OF COGNITIVE
RELATED LINEAR AND NON-LINEAR SYNCHRONIZATION
MECHANISMS**

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1. Synchronization Likelihood

The activity of brain and the communication of neurons can be characterized by electrical phenomenon. The measurement of these electromagnetic fields offers a unique opportunity for investigating the brain function, since the EEG and MEG techniques are not invasive and their time-resolutions are better than the neuroimaging techniques will ever be. To keep these benefits, it is essential to apply analysis methods, which preserve and not lose the time dimension and resolution. The measuring of relation between different electrode sites gives the opportunity to follow the activity of neural networks. The activation of these networks or assemblies is essential to accomplish an elementary cognitive act (Valera et 2001).

A large number of different methods are developed for the measurement of the relationship between data series (Quiroga et al, 2002). One of the nonlinear interdependence measures is the Synchronization Likelihood (SL), introduced by Stam and van Dijk in 2002. The original SL was constructed to determine the statistical dependencies between two time series in time dependent way (Stam, van Dijk, 2002), but in neuroscience experiment it was almost exclusively used after averaging all of the coefficients (Stam et al, 2002; Stam, 2004; de Briun et al, 2004), loosing not only the time, but also the spatial resolution.

One of the goals of this dissertation is to investigate the time axis of SL method. Data sets, generated by mixing sin signal and noise with different range, were used for simulation tests. The conclusion of the simulation is the following: the SL method is not able to follow correctly the time changes of interdependencies. The methods produce artifacts even if the relationship of the time series is constant. Guidelines for correct parameter selection were drafted. Selective averaging is also recommended to exclude the section, where the appearance of artifacts is not avoidable.

The new recommendations are limiting the usage of the SL. Two alternative versions were constructed to improve the abilities of the original method. The time axes of the new versions were investigated with the same methods as than the SL's time dimension. The results show that the alternatives are more reliable versions; they follow the time changes of synchronization with less error. One of the new versions, the "Synchronization Likelihood Calculated with Correlation Index" is less sensitive to the choice of parameters, as well as it has better resolution in the signal-to-noise range of human EEG. On this basis, it can declare for robust version of the Synchronization Likelihood method.

2. Mental arithmetic

The mental arithmetic, the process of number's meaning and the mental representation of numbers were all intensively researched areas in the past decades. The Componential Model for Additions (Widaman et al, 198; Geary and Widaman, 1992) provides a concrete scheme for solving an addition task. According to this model, the addition begins with the selection of the two largest addends. The recalled sum of these addends is incremented with the value of the third largest addend (with unit-by-unit fashion), and so on, until the last addend, or until the counter reaches the stated sum. Predictions of the model are the followings: the addends will be reorder before the calculation; the new order will be the descending one.

Behavioral study was carried out to test these predictions, where subjects verified addition problems. Two conditions were applied, the addends (and the stated sum) appeared on the screen with delay (one after another), or simultaneously, without any delay. The subjects solved task containing the same addends in different orders.

The predictions of Wideman-Geary model were not fully supported by the results. The reaction times were longer, if the addends were presented in descending order. The analysis of reaction times showed that none of the investigated order was superior to the others, there are no unique order generally related to fastest answers. An optimal order can be found only for one given set of addends. The applying of addends rearranging strategy was confirmed by the data. The conclusion is the following: at least in certain cases the subjects used operand reordering strategy but this strategy is more complex and more flexible, than it was proposed by Wideman and Geary.

The effect of crossing the decade's border was also examined, significantly higher reaction time was measured after reaching the border. The responses were given slower after the ones in the sum become 1 again, not after the tens become a new value. E.g.: the reaction was faster if the sum was 21 than 20.

Several results show connection between calculation and egocentric mental rotation. In both task male subjects normally outperform females (e.g. Seurinck et al, 2004). Children (Karádi et al, 2001) and adolescents (Soltész, 2003) with dyscalculia are less accurate in egocentric mental rotation but not in allocentric mental rotation. Both acalculia and left-right disorientation are amongst the symptoms of Gertmann synfrome (Mayer et al, 1999). Young adults subject of the behavioral experiment carried out egocentric (task with computer rendered hand models) and allocentric mental rotation (task with item made of cubes) too.

The results did not clearly confirm the relationship between the performance indexes of the egocentric task and the calculation. The reaction times were independent in the whole group of subjects. However the subgroup of men was significantly faster than subgroup of women in the calculation as well as in the egocentric rotation task. The relationship was confirmed between the accuracy of rotation of hand and the accuracy of arithmetic tasks.

Subgroups of subjects, involved in the behavioral task, were identified according to the performance in the addition tasks. Two sub-groups were participated in the electrophysiological study, these two groups had the same effectiveness, but different efficiency during algebraic problems. The main aim of EEG experiment was to investigate the background and the electrophysical correlates of the (at least partially) task-specific higher efficiency. The more efficient (faster) group's EEG was characterized by a parietal alpha (10-12 Hz) event related spectral increasing between 500-1000 ms according to the appearance of stimuli. In the case of faster group a higher beta (20-25 Hz) power spectra decreasing was also found over the parietal area (with slightly left dominance), 200-500 ms before the response giving. According to the corresponding literature (Sauseng, 2005, Klimesch, Sauseng and Hanslmayr, 2007), the alpha-band activity increasing is attributed to task-specific inhibition (inhibition of irrelevant processes). It is presumed, the alpha activity is related to the manipulation of ongoing information, and it can be the electrophysical correlate of semantic elaboration strategies, for instance decomposing (Dehaene, Cohen, 1995). Beta activity is attributed to more activated parietal cortex. Source analyzing techniques could determine the exact psychological function of this activity.

3. Applying of alternative SL method

The newly developed, "Synchronization Likelihood Calculated with Correlation Index" method was applied for the analysis of alpha band activity. Through the time dimension, event-related synchronization can be investigated. In the more efficient group, significantly increased frontal-parietal synchronization was found. That synchronized activity completely lacked in the less efficient group. The cooperation of the frontal and parietal region can be interpreted as a sign of activation of fronto-parietal network. The previous hypothesis, about the alpha activity related to the elaboration strategy, is supported by this result. The frontal region can play a critical role during the strategy planning, supervising and controlling of execution.

The alternative SL method produced easily interpretable and consistent results on real data, too. On this basis, the development of alternative, robust Synchronization Likelihood method is judged successful; a further application is worth for consideration.

4. References

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