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Synchronization in the brain EEG-activity in modified Multiple Sleep Latency Test

To assess the degree of synchronization between different EEG channels, we propose a technique based on the use of wavelet bicoherence. Below we present a detailed description of the method to estimate wavelet bicoherence and describe an algorithm for numerical calculating the degree of synchronization.

On the first step we calculate the complex-valued coefficients $W_n(f,t)$ of continuous wavelet transformation (CWT) for each EEG channel $x_i(t)$ as

$$W_i(f,t) = \sqrt{f}\int_{t-4/f}^{t+4/f} x_i(t)\psi^*(f,t)dt,$$

where $i = 1,\dots,N$ is the number of considered EEG channel, and $N = 31$ is the total number of EEG channels, "*" denotes the complex conjugation, and $\psi(f,t)$ is the basic wavelet function. We are working with the Morlet wavelet as basic function, that is often applying for processing of biological signals

$$\psi(f,t) = \sqrt{f}\,\pi^{1/4} e^{j\omega_0 f(t-t_0)} e^{f(t-t_0)^2/2},$$

where ω_0 is the wavelet scaling parameter. Often in EEG studies, a parameter value $\omega_0 = 2\pi$ is used that provides the optimal frequency-time resolution in these biological signals [11]. To measure the coherence degree between two EEG signals $x_i(t)$ and $x_j(t)$, we calculate the corresponding complex-valued wavelet coefficients $W_i(f,t) = a_i + \mathrm{i}b_i$ and $W_j(f,t) = a_j + \mathrm{i}b_j$.

Wavelet bicoherence, WB, $\tau_{ij}(f,t)$ is estimated based on the mutual wavelet spectrum $W_{i,j}(f,t)$ of the signals $x_i(t)$ and $x_j(t)$. Similarly to [6] the coefficients $\mathrm{Re}[\tau_{ij}(f,t)]$ and $\mathrm{Im}[\tau_{ij}(f,t)]$ represented as real and imaginary parts of mutual wavelet spectrum can be calculated via Eqs. (3) and (4), respectively:

So, if signals $x_i(t)$ and $x_j(t)$ show completely coherent (or synchronized) dynamics, then $\tau_{ij}(f,t) = 1$. Conversely, if the WB-value becomes zero, $\tau_{ij}(f,t) = 0$, then these signals are fully desynchronized. In all other cases, the WB-value $\tau_{ij}(f,t)$ takes a value from 0 to 1, which characterizes the degree of synchronization of the studied signals at given time and frequency.

Note that in most studies to assess the degree of synchronization between the different EEG channels authors try to exclude from the equation (5) variable corresponding time [5, 6, 13], i.e. they use some kind of averaging in the certain time window. Obviously, this approach allows estimate the degree of synchronization of these signals in the certain time period, but it accompanies by a complete loss of information on the temporal dynamics of wavelet bicoherence.

To preserve the possibility of analyzing the time dynamics, we propose the following algorithm. Primarily, we carry out calculation WB for a certain frequency range Δf:

$$\tau_{ij}^{\Delta f}(t) = \frac{1}{\Delta f}\int_{\Delta f} \tau(f,t)\,df.$$

In this work, we use a five frequency ranges, traditional for modern neuroscience: Δf_1 [2–4] Hz, Δf_2 [4–8] Hz, Δf_3 [9–12] Hz, Δf_4 [12–20] Hz, Δf_5 [20–30] Hz [12]). Next, for each frequency range Δf, we divide the entire range of WB values into R intervals $\Delta\tau^{\Delta f}$ with fix width $\frac{1}{R}$.

Then for each interval $\Delta\tau^{\Delta f}$ we can estimate the discrete characteristic T_{ij} as

$$T_{ij}(\tau_{ij}^{\Delta f},t) = \begin{cases} 1, & if\ \tau_{ij}^{\Delta f}(t) \in \Delta\tau^{\Delta f}, \\ 0, & in\ other\ cases. \end{cases}$$

So, we can define the probability WB distribution $T_{ij}^{\Delta f}(\Delta\tau^{\Delta f},t)$, for frequency range Δf and synchronization measure interval $\Delta\tau^{\Delta f}$, as:

$$T_{ij}^{\Delta f}(\Delta\tau^{\Delta f},t) = \frac{1}{M}\sum_{\tau\in\Delta\tau} T_{ij}(\tau,t),$$

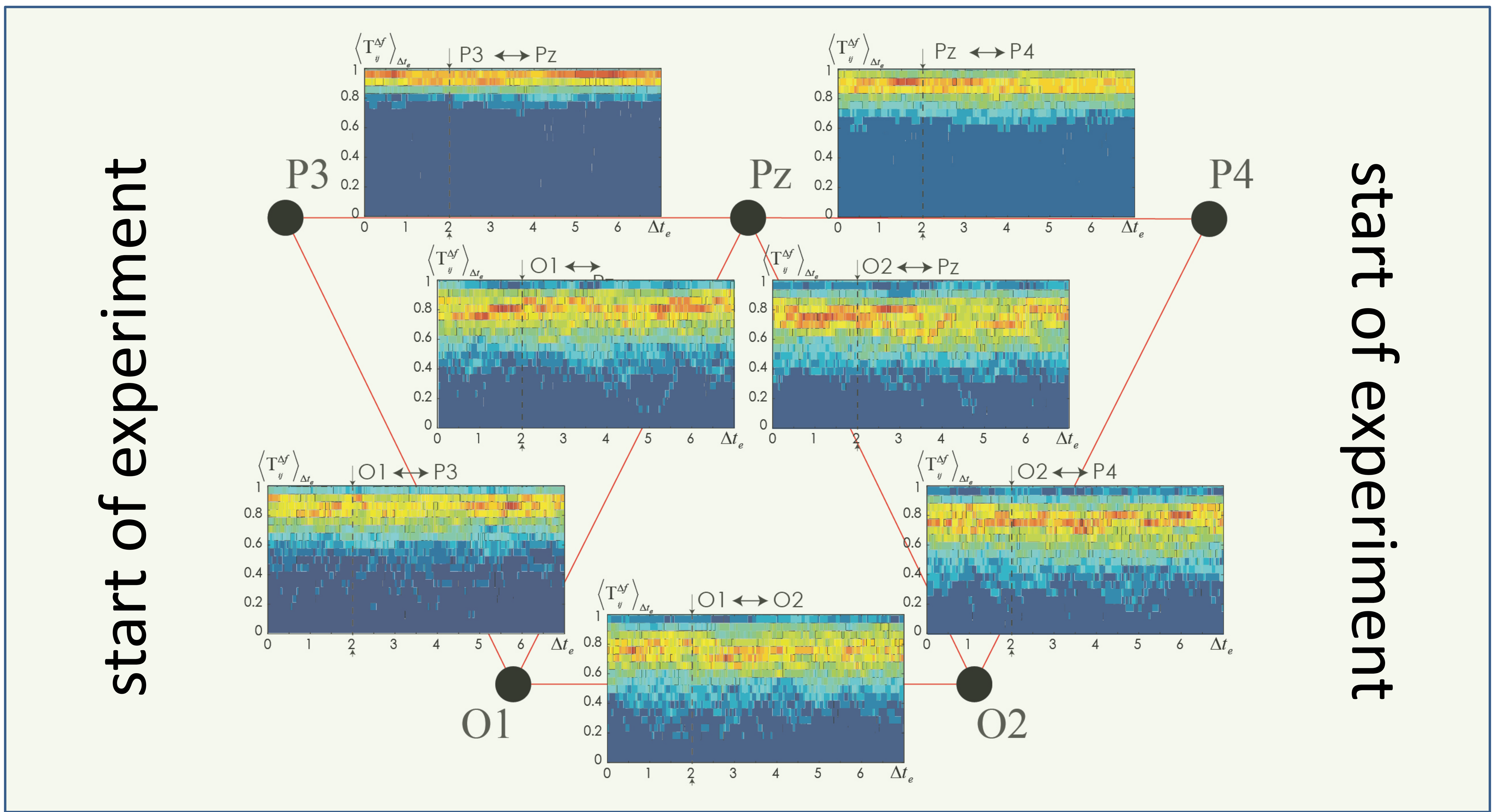
where M is the normalization coefficient, defined as the number of summed components in (8).

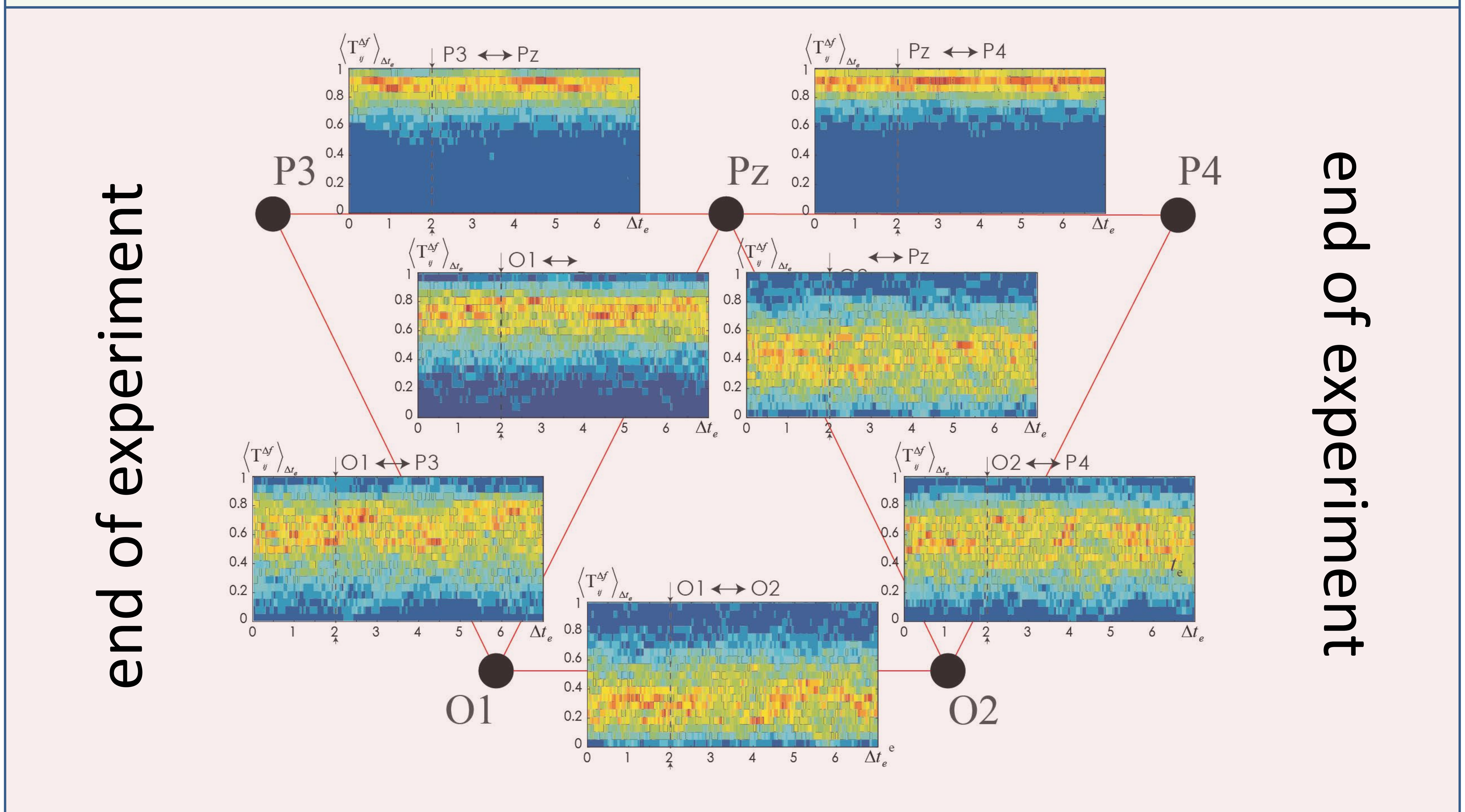
After estimate the probability distribution of WB (8), we can average characteristic $T_{ij}^{\Delta f}(\Delta\tau^{\Delta f},t)$ over same type events, based on the logic principles of calculating the evoked potentials. Let during the experiment amount E events of the identical type occur with the same time duration Δt_e. In this case, we can calculate the average WB as follows:

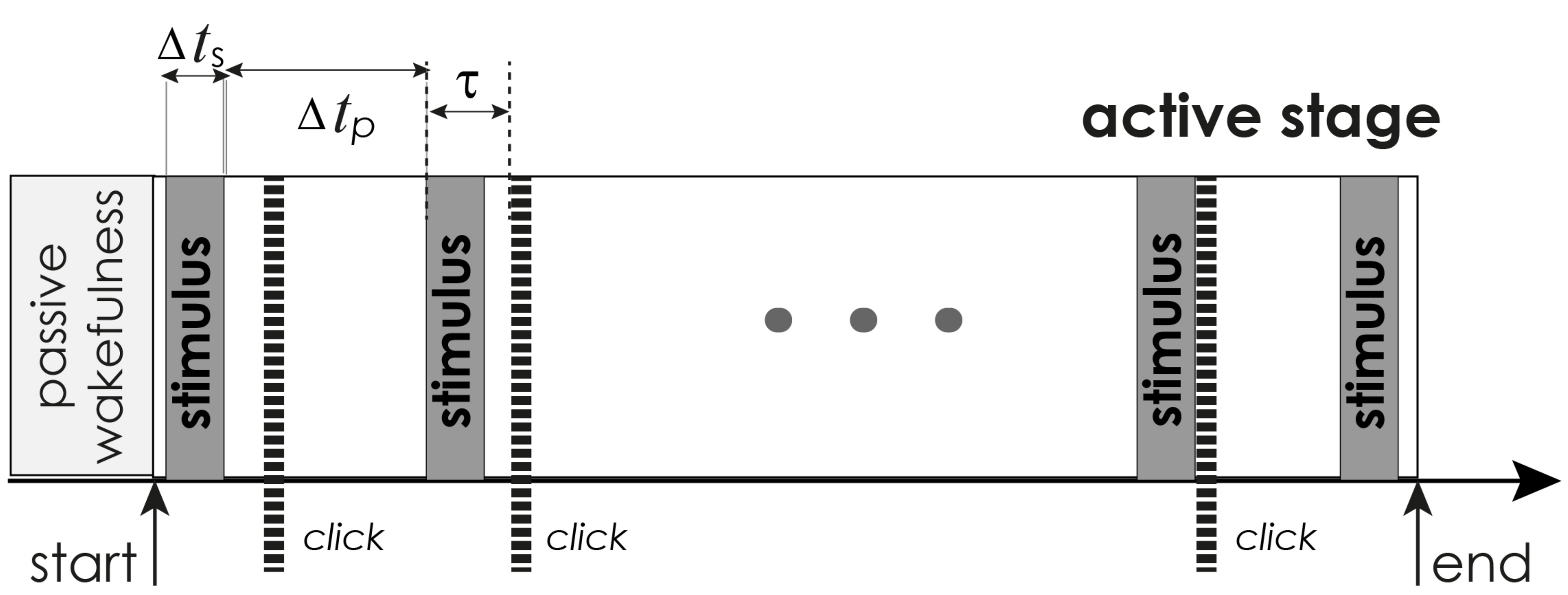
$$\langle T_{ij}^{\Delta f}(\Delta\tau^{\Delta f},t)\rangle_{\Delta t_e} = \frac{1}{E}\sum_E T_{ij}^{\Delta f}(\Delta\tau^{\Delta f},t_e),$$

where $t_e \in \Delta t_e$. Thus, for two EEG signals $x_i(t)$ and $x_j(t)$ in each analyzed frequency range $\Delta f_{1,\dots,5}$, we can define the only one WB probability distribution function $\langle T_{ij}^{\Delta f}\rangle_{\Delta t_e}$, described the average dynamics of the synchronization degree for these signals during events of the same type.

So, further we demonstrate the possibilities of the presented method for estimating the dynamics of the synchronization between different experimental EEG signals.

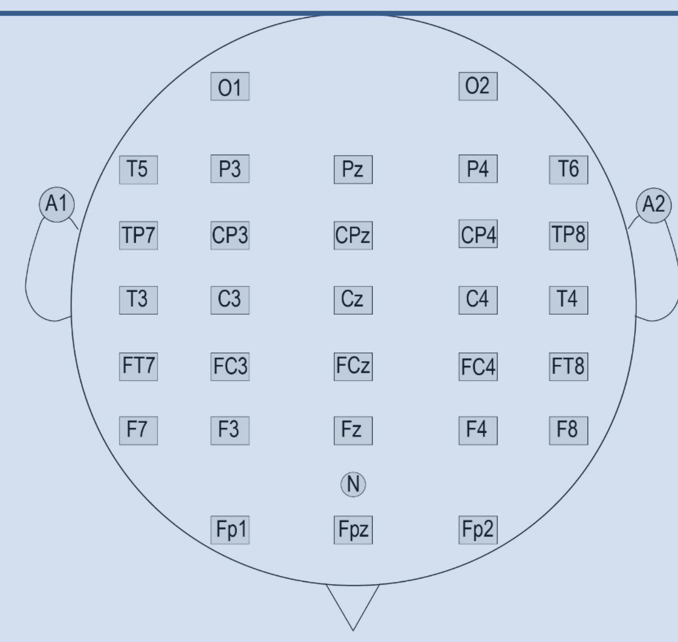






Electroencephalographrecorder Encephalan-EEGR-19/26 (Medicom MTD). This electroencephalography system in designing, development, manufacturing, realization and technical service of electronic medical equipment complies with the requirements of international standards ISO 9001 and ISO 13485

The quality of medical devices complies with the requirements of Council Directive 93/42/EEC. This system is produced under European standards EN 60601, EN ISO 14971, EN 62304 and certified by British Standards Institution (BSI).



Standard scheme 10-10 for EEG measurements
the frequency range 0.016 - 70 Hz
notch filter 50 Hz
the sampling frequency of the data of 250 Hz
additional channels: EOG, EKG, EMG
video signal for control