Method for the automatic diagnosis of states of wakefulness, sleep, and epileptic activity by rats invasive ECoG signals

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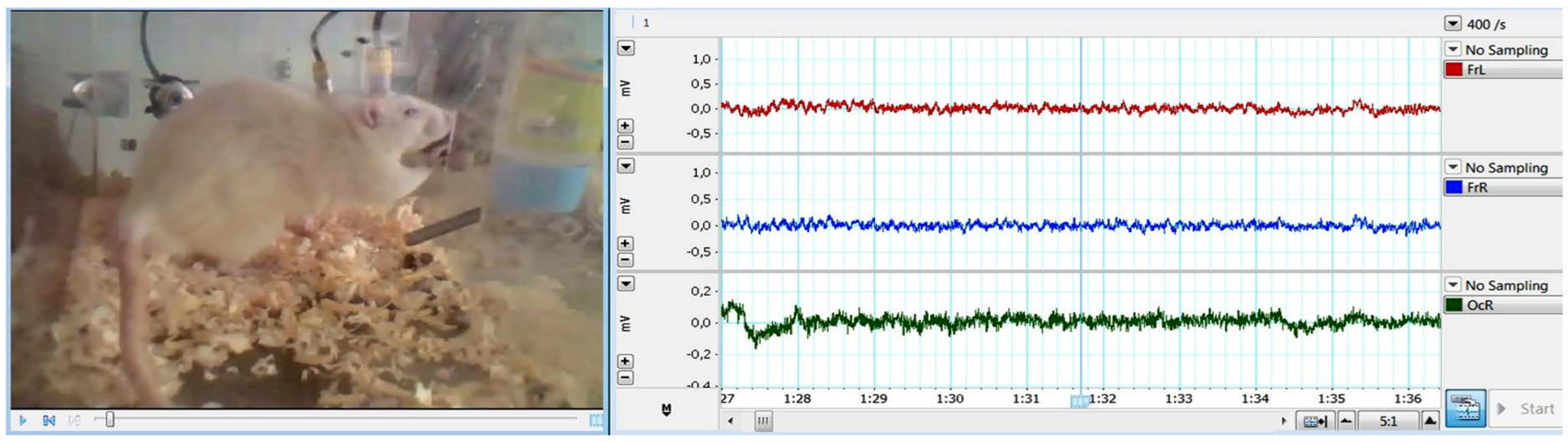
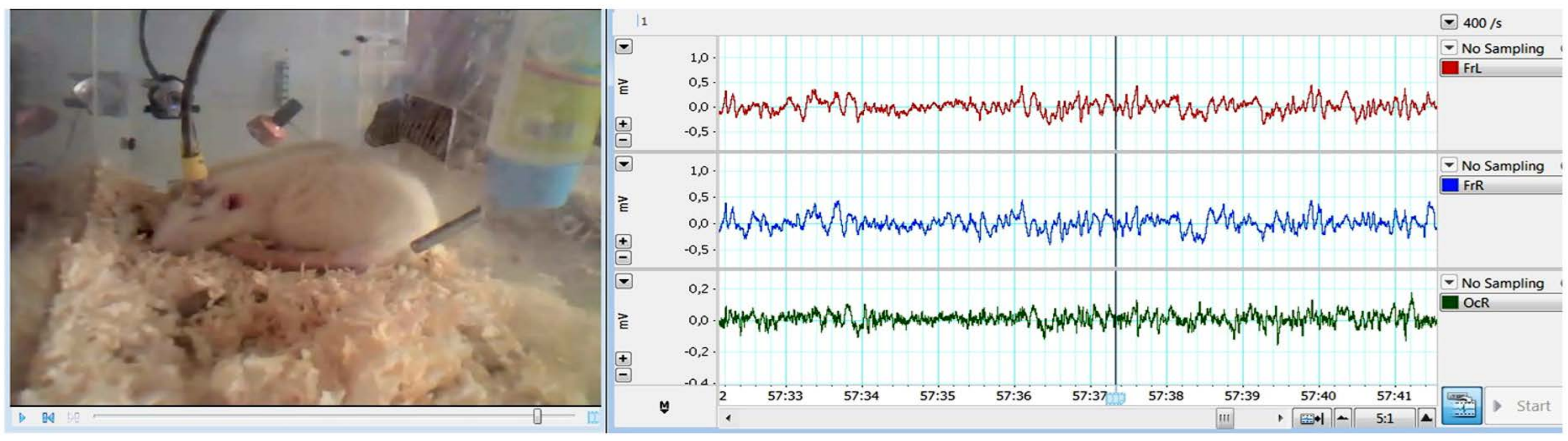
From the surface of the cerebral cortex, a temporary signal of the electrocorticogram $x(t)$ with a duration of T and a sampling rate $(\frac{1}{N})$ is recorded. A continuous wavelet transform $W(x,t)$ is calculated for each signal $x(t)$ using the Morlet wavelet with the parameter $\Omega_0 = 2\pi$ that makes it possible to use the classical Fourier transform in the analysis of the frequency f. The total instantaneous energy of the continuous wavelet transform $E_{\Delta f}(t) = \sum_{f\in\Delta f} E(f,t) = \sum_{f\in\Delta f} W(f,t)^2$ is calculated at each time point t for each frequency range $\Delta f_1[2.5; 4.5]$, $\Delta f_2[5; 10]$, $\Delta f_3[10.5; 12.5]$, $\Delta f_4[15; 18]$. The integral value of the total instantaneous energies takes the form is $\varepsilon_{\Delta f}(t_0) = N * \Delta t * \sum_{t_1}^{t_2} E_{\Delta f}(t)$ for every moment $t_0, \Delta t = 0.5sec, t_1 = t_0 - 0.5\Delta t, t_2 = t_0 + 0.5\Delta t$. Detection of physiological states of sleep and wakefulness is carried out on the basis of dependence analysis $\varepsilon_{\Delta f_4}(t_0)$. When it registers M EEG signals $\varepsilon_{\Delta f_4}(t_0)$ becomes replaced with $\tilde{\varepsilon}_{\Delta f_4}(t_0) = \frac{\sum_1^M \varepsilon^i_{\Delta f_4}(t_0)}{M}$. The integral value of dependence is $\langle \varepsilon_{\Delta f_4}(t_0) \rangle = N * \Delta t * \sum_{t_1}^{t_2} \varepsilon_{\Delta f_4}(t)$ for every moment $t_0, \Delta t = 10sec, t_1 = t_0 - 0.5\Delta t, t_2 = t_0 + 0.5\Delta t$. Accordingly, the threshold values $\varepsilon_1 = 1.3 * N * T * \sum_0^T \varepsilon_{\Delta f_4}(t)$ and $\varepsilon_2 = 0.45 * N * T * \sum_0^T \varepsilon_{\Delta f_4}(t)$ are individual for each living being. If $\langle \varepsilon_{\Delta f_4}(t_z) \rangle$ has become more than ε_1, it's necessary to find a moment $t_s < t_z$, when $\langle \varepsilon_{\Delta f_4}(t_s) \rangle$ had become more than ε_2, then the moment t_s is the beginning of the animal's wakefulness interval. If the interval is less than 10 seconds, it is diagnosed incorrectly.

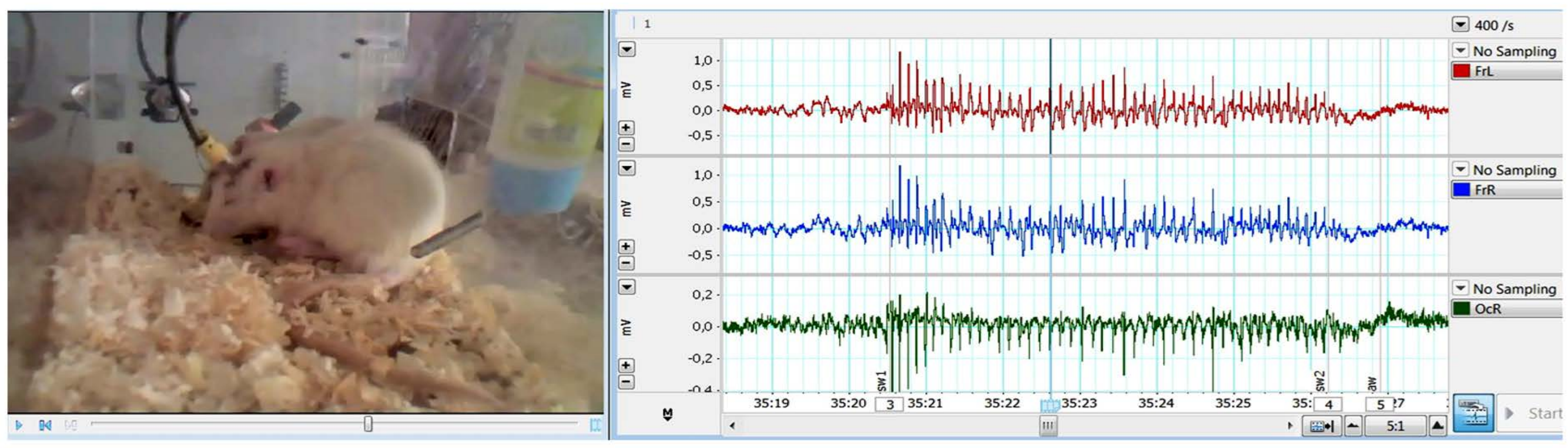
To detect the physiological state of peak-wave activity, determine the parameter $\varepsilon_{sw}(t_0)$ according to the following relationship $\varepsilon_{sw}(t_0) = \frac{\varepsilon_{\Delta f_3}(t_0)}{\varepsilon_{\Delta f_1}(t_0)+\varepsilon_{\Delta f_2}(t_0)}$.
If M EEG signals are recorded, the dependence $\varepsilon_{sw}(t_0)$ is replaced by a similar one $\tilde{\varepsilon}_{sw}(t_0)$.We estimate the values $\varepsilon^1_{sw}(t_0), \dots, \varepsilon^M_{sw}(t_0)$ for each signal $x_1(t), \dots, x_M(t)$. The dependence $\tilde{\varepsilon}_{sw}(t_0)$ is calculated according to the following formula $\tilde{\varepsilon}_{sw}(t_0) = (\varepsilon^1_{sw}(t_0) + \dots + \varepsilon^M_{sw}(t_0))/M$.
For each moment t_0, we calculate the integral dependence $\varepsilon_{sw}(t_0)$ using the following formula $\langle \varepsilon_{sw}(t_0) \rangle = N * \Delta t * \sum_{t_1}^{t_2} \varepsilon_{sw}(t_0)$, $\Delta t = 3sec, t_1 = t_0 - 1.5\Delta t, t_2 = t_0 + 1.5\Delta t$.
Then we introduce the threshold values $\varepsilon^1_{sw}, \varepsilon^2_{sw}$ according to the following relations, calculated for the entire duration T of the time series $x(t)$ of the electrocorticogram $\varepsilon^1_{sw} = 1.75 * N * T * \sum_0^T \langle \varepsilon_{sw}(t_0) \rangle$, $\varepsilon^2_{sw} = 1.55 * N * T * \sum_0^T \langle \varepsilon_{sw}(t_0) \rangle$.
Threshold values are individual for each animal.
The moment of the onset of the physiological state of epileptic activity is detected at the moment of time t^1_{sw}, for which the relation $\langle \varepsilon_{sw}(t^1_{sw}) \rangle > \varepsilon^1_{sw}$ is satisfied. The end of the state of epileptic activity is detected at the time t^2_{sw}, for which the relation $\langle \varepsilon_{sw}(t^2_{sw}) \rangle < \varepsilon^2_{sw}$ is satisfied. Time interval $[t^1_{sw}; t^2_{sw}]$ corresponds to the physiological state of epileptic activity.



(*a*)

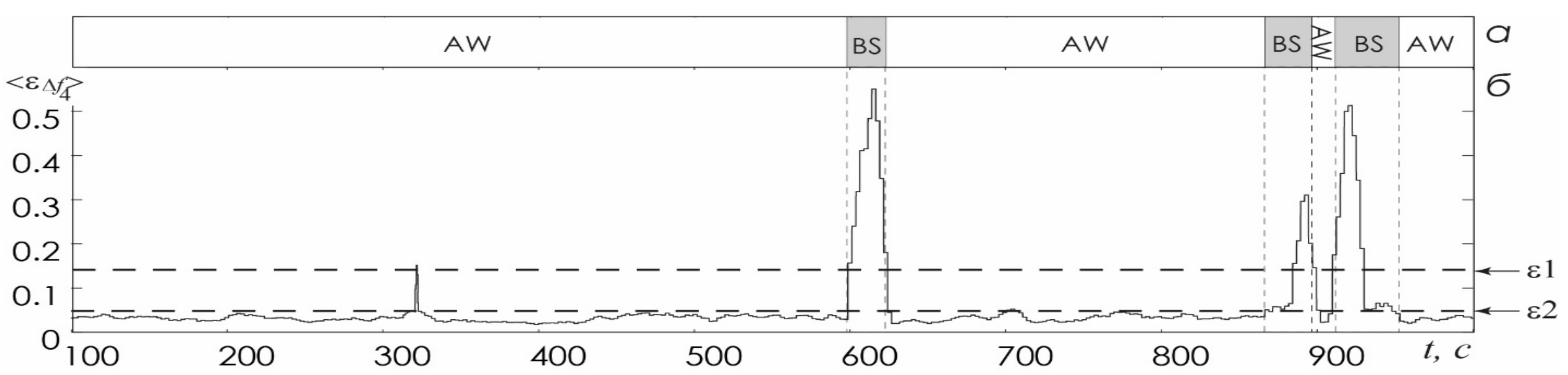


(*b*)

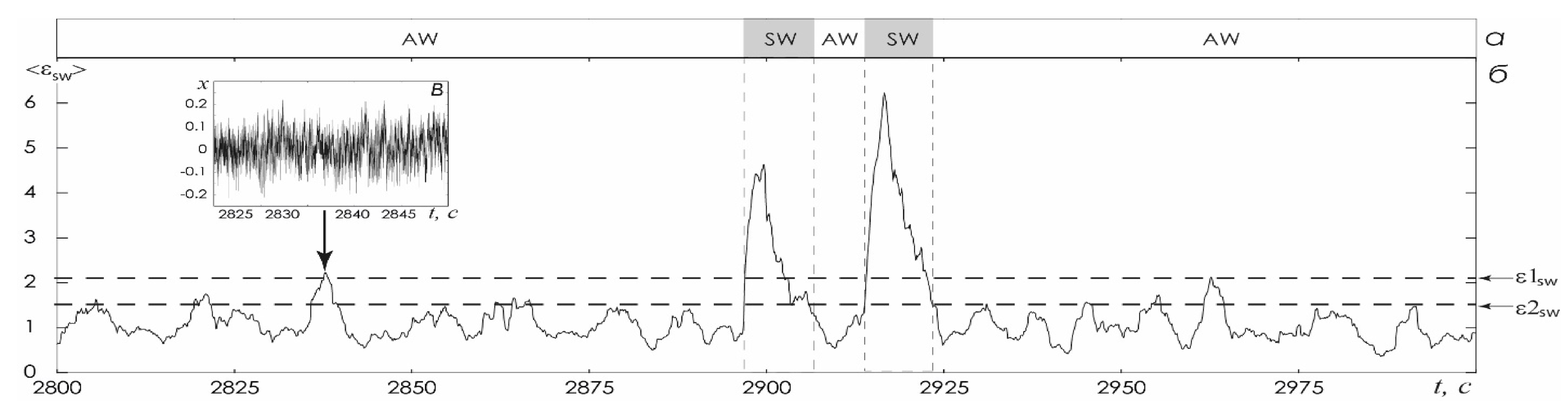


(*c*)

(***a, b, c***) The signals were recorded using the standard EEG method in rats. Experimental work was carried out on male WAG / Rij rats at the age of 9 months. The electrodes were implanted into the skull bone epidurally (that is, over the surface of the dura mater) over the right and left of the frontal cortex (AP = 2, L = + / - 2) and the occipital cortex (AP-5; L 4). All coordinates are in mm relative to the bregma. A reference electrode was placed over the surface of the cerebellum to provide monopolar recording from the surface electrodes.
PowerLab 4/35 was used for recording an electrocorticogram with *M* = 3 channels. Duration *T* was from 1 hour up to 2 hours in frequency band 0.5 – 200Hz with sampling frequency *N* = 400 for each channel. At the same time, video recording wasmade in LabChart 7 with camera Genius eFace 1325R.



You can observe the artifact of a short random increase in values $\langle \varepsilon_{\Delta f_4}(t) \rangle$. Taking into account the additional limitation of the minimum duration of the stages of sleep and wakefulness excludes the possibility of false detection of such events.



The characteristic exceeds the threshold values. However, the analysis of the dynamics of the signal $x(t)$ of the electrocorticogram eliminates false detection of this event as epileptic activity.

Taking into account the additional limitation of the minimum duration of the stages of sleep and wakefulness excludes the possibility of false detection of such events. A comparative statistical assessment of the success of detecting various physiological states in animals was carried out on the basis of manual processing of video recording and EEG by a neurophysiologist and the claimed method. The accuracy of automatic diagnostics in assessing the duration of time intervals of physiological states reaches 96.53% in determining the intervals of wakefulness, 94.70% of sleep, and 99.34% of spontaneous epileptic activity.