THE METHOD FOR DETECTING IMPULSES OF DIFFERENT DURATIONS IN THE CEREBELLAR PURKINJE CELLS

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Summary

An algorithm for detection of electrical potentials characteristic for simple (SS) and complex spikes (CS) of the cerebellar Purkinje cells (PC) is presented. The algorithm is based on determination of front of signals to be detected, forming of feature description of impulses taking into account their duration and amplitude dynamics in successive bins, and on comparing vectors describing a chosen template of impulse and the current signal. The results of algorithm testing on artificial sequences of impulses and neuronal activity recordings are described which demonstrate a high accuracy of impulse front detection and possibility of selective identification of SS and CS having similar polarity, amplitude and duration of initial components.

Introduction

A characteristic peculiarity of the PC (the basic structural element of the cerebellar cortex) electrical activity is a generation of SSs and CSs, which have different shapes and arise from inputs of different types [4, 5]. Up to now, the mechanisms of these inputs interactions at the PC level are one of fundamental problems of the cerebellar physiology. Besides, a selective automatic detection of SS and CS in PC activity is a complicated methodological problem [4].

A necessity for development of special methods for SS and CS detection (Fig. 1) follows from several reasons. First, the same cell may generate these electrical signals with both similar (amplitude, polarity and temporal parameters of initial components) and different features (total impulse duration and shape of later components). Second, both types of impulses have a significant variability of parameters during recording [4, 10]. Finally, while solving the problem of search for the PC-twins innervated by the same liana cell afferent [1, 2], a necessity for the development of method simultaneously providing a minimal error in measurement of moment of impulse generation and a possibility of low-amplitude potentials detection by averaging with respect to the referent impulse [3].

The known methods [7, 8, 9, 11] of neuron impulses detection for computer analysis are in the most cases directed to determination of moments of their appearing and may be tuned to various relatively constant spike parameters. However, they are sensitive to pronounced variability of impulse parameters (that is characteristic for the cerebellar PC activity especially for CSs) and may identify erroneous events or ignore signals to be detected in this case.

The present paper describes the method for detecting SS and CS of the cerebellar PCs that allows solving methodological problems described above.

The method for detection of simple and complex spikes.

The generation of neuronal impulses is connected with a brief variation of cell membrane permeability for sodium ions. This process duration does not exceed 300 µsec [6] and has the most stable parameters comparing with other impulse characteristics.

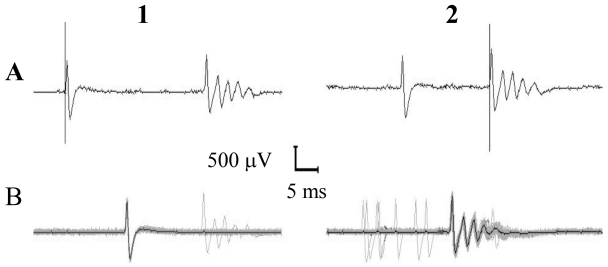

Fig. 1. Samples of selective detection of simple (**1**) and complex spikes (**2**) in activity of the cerebellar PC in original records (**A**) and their superpositions (**B**, *n*=50). In (**A**), the detected signals are marked by vertical lines.

Besides, the frequency of neuron spikes generation cannot exceed 500 Hz (for SS) [4].

Thus, the problem could be formulated as following: it is necessary to detect a signal and to determine a moment of its beginning if the signal has at least one stable feature, namely, a sharp changing of amplitude of potential (the front of increase or decrease) which is constantly reproduced in recording successive impulses of the same PC and can be considered as the moment of signal appearing.

The algorithm of signal detecting. In general case both for SS and CS the detection algorithm consist of three procedures: impulse front detection, formation of spike feature description encoding amplitude change in successive bins and comparing the descriptions of arbitrary and template impulses.

Let a signal be presented as the vector $\vec{\mathbf{a}} = \{a_i\}$ $i = 1..N$, where a_i is the amplitude of the signal at the moment t_i (Fig. 2). Let us transform the signal $\vec{\mathbf{a}}$ as follows:

$$\vec{\mathbf{a}} \rightarrow \vec{\boldsymbol{\Delta}} = \{\Delta_j\} \quad j = 1..N-1,$$

where $$\Delta_j = \begin{cases} \dfrac{\Delta a_j}{\theta} & \Delta a_j > \eta \\ 0 & \Delta a_j \le \eta \end{cases}, \qquad (1)$$

$\Delta a_j = a_{j+1} - a_j$,

θ - threshold,

η - noise level[1].

Then, the signal feature description $\vec{\mathbf{a}}$ can be presented as the vector $\vec{\mathbf{F}}$ of dimension n, each component of which encodes significant amplitude changing Δa of the original signal:

$$\vec{\mathbf{a}} \rightarrow \vec{\boldsymbol{\Delta}} \rightarrow \vec{\mathbf{F}} = \{\vec{\mathbf{f}}_k\} \quad k = 1..n,$$

where $\vec{\mathbf{f}}_k = \{\tau_k, \varsigma_k\}$,

τ_k - the number of successive vector $\vec{\boldsymbol{\Delta}}$ components of the same sign $\qquad (2)$

$$\varsigma_k = \sum^{\tau_k} \Delta_i$$

The template (impulse description characteristic for the given PC) and current

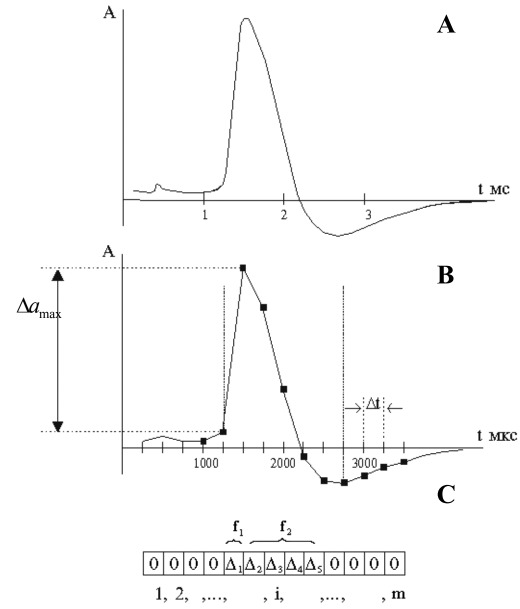

Fig. 2. The scheme of feature forming for the template signal for a simple spike:

A – a simple spike in an original record;

B – the same spike after analog-digital conversion (the bin Δt = 250 µsec);

C – the feature vector **F**={**f₁**,**f₂**} for the spike in (**A**).

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[1] On the basis of algorithm preliminary testing for the recorded PC activity the values of threshold and noise level were empirically chosen as $\theta = 0.4\Delta a_{\max}$ and $\eta = 0.1\theta$, correspondingly.

signal, $\vec{\mathbf{a}}$ and $\vec{\mathbf{a}}'$ correspondingly, are considered to be identical if dimensions n and n' and components of corresponding description vectors $\vec{\mathbf{F}}$ and $\vec{\mathbf{F}}'$ coincide. The components $\vec{\mathbf{f}}_k$ and $\vec{\mathbf{f}}_k'$ of vectors $\vec{\mathbf{F}}$ and $\vec{\mathbf{F}}'$ are considered to be equal if:

$$\begin{cases} \operatorname{sign}(\varsigma_k') = \operatorname{sign}(\varsigma_k)\,, \\ \tau_k' - \varepsilon_k \le \tau_k \le \tau_k' + \varepsilon_k\,, \\ \dfrac{\min(|\varsigma_k'|,|\varsigma_k|)}{\max(|\varsigma_k'|,|\varsigma_k|)} \ge w_k\,, \end{cases} \qquad (3)$$

where: ε_k is variability of duration τ_k of component $\vec{\mathbf{f}}_k$.

Peculiarities of detection of simple and complex spikes. Taking into account the known differences in SS and CS properties [4] (see, for example, Fig. 1) the algorithms described above have several peculiarities while detecting impulses of different types. In particular, a dimension of a vector describing CS was significantly larger then that of SS. Besides, while forming a feature description of SS the zero components of vector $\vec{\mathbf{\Delta}}$ in (2) were excluded. Finally, while detecting SS an additional analysis of refractoriness (prohibition time of next impulse generation) was made. In this case, after vector feature description for the next fragment of record $\vec{\mathbf{E}}' = \{\vec{\mathbf{e}}_l'\}$ was obtained according to (1) and (2) the potential amplitude changing comparable with the threshold θ during period τ_R of about 2 ms was prohibited. In other words, if $\tau' \le \tau_R$ and $|\varsigma'| > \theta$ for any component of vector $\vec{\mathbf{E}}'$ the signal $\vec{\mathbf{F}}'$ was considered as irrelevant to SS. While detecting CS, taking into account the presence of several high-amplitude components the refractoriness analysis was not considered.

Estimation of effectiveness of signal detection algorithm. The algorithm described above was implemented as software and tested in processing of artificial sequences of noisy signals similar to activity of SS of PCs. The results of the testing are presented in Fig. 3. It can be seen that if signal to noise ratio exceeds six, 97% of impulses, which parameters correspond to the given template, can be correctly identified, and there are no falsely detected events.

While processing recordings of real electrical activity of the cerebellar PCs (Fig. 1) with the same range of signal/noise relation the number of correctly detected SS was a bit less (about 90% in average) than while processing artificial sequences[2]. The detection accuracy depended on parameters of an impulse that was chosen as template description, details of impulse shape for the given cell and their temporal distribution. In processing of real recordings, the errors of two types happened: first type (non-identified impulses) and second type (false events). In the second error type group CS of short duration (less than 5 ms) were included most often, while slow waves of potentials including those of high amplitude, having a slower front, and high frequency bursts (similar to stimulation artifacts) were excluded.

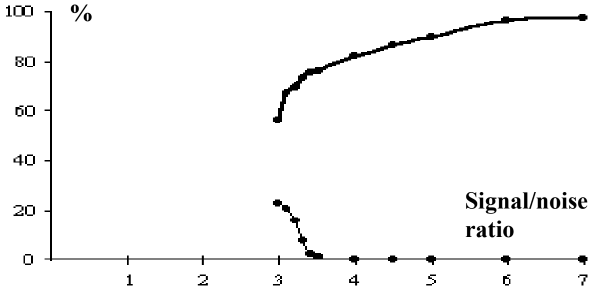

Fig. 3. Dependence of the number of correctly identified simple spikes (▬) and falsely identified events (—) on signal/noise relation.

To improve accuracy we developed an algorithm for correction of impulse template description in accordance with impulse form dynamics while recording. The algorithm is based on averaging of parameters of impulses to be detected in the current fragment of record and on optimization of coefficients ε_k and w_k in (3). This allowed increasing the number of correctly identified impulses with variable parameters.

The accuracy of CS detection (as the case of

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[2] While processing of recordings of neuronal activity of the cerebellar PCs the bin Δt was equal 100μsec.

SS) depended on several factors but was less (in average about 60% without corrections of algorithm initial conditions). However, if SSand CS durations in the PC to be analyzed

were significantly different, the accuracy of detection of impulses of two types was comparable (up to 95%).

Conclusion

The developed algorithms and software are used in neurophysiological and model studies while processing impulse activity of neurons in the cerebellar and the visual cortices [2, 10]. They simultaneously provide possibility of analysis of temporal impulse sequences and potential dynamics with acceptable accuracy and high temporal resolution (about two bins of analog-digital conversion of original records). In addition to high-amplitude impulse analysis this method allowed identifying low-amplitude potentials [2], comparable with a noise level in original record in vicinity of the referent impulse while potentials averaging.

The proposed methods enable an on-line quantitative analysis of experimental data and visualization of results, which yield options of on-line control of the experimental procedures.

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