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Mini Review

The Action Potential Peak is Not Suitable for Computational Modelling and Coding in the Brain

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Abstract

Action potentials are highly plastic phenomena and vary greatly in trajectory from neuron to the next. The temporal positioning of the spike peak is very variable and modifiable by synaptic inputs. Consequently, it is inappropriately used in binary computational models of neuronal activity. Here we demonstrate that the action potential threshold has temporal constancy and should be used in ternary computational models, whose phases are: resting potential, threshold and the time dependent refractory period, which is an analogue variable. Thus, the action potential threshold is the most appropriate temporal fixed point for computational modelling, not the action potential peak.

Keywords: *Action Potentials; Resting Potential; Threshold; Computational Fixed Point*

Introduction

Action potentials play a number of roles in the nervous system, but are primarily thought of as the means by which cellular communication takes place between neurons and serve to trigger secretions from nerve terminals. Binary computational models of nervous systems usually use the peak of the spike to initiate activity, but this is an inaccurate method of computation, given the plasticity of action potentials not only in cell bodies[1,2], but also in nerve terminals [1,3,4] and axons [5]. Action potentials are generated by powerful ionic driving forces created by metabolic pumps such as the sodium-potassium pump, which instigate the membrane potential, but their properties vary substantially from one neuron to the next [6,7].

We have shown elsewhere that ternary phase computation is much more appropriate in modelling nervous activity where threshold is the instigator of the computational action potential (CAP): the three phases are thus: resting potential, threshold and the time-dependent refractory period, which is an analogue variable [8-10]. In particular the variable position of the action potential peak is well documented [3,7] and the maximum rates of depolarization ($\dot{V}_d$) and repolarization ($\dot{V}_r$) are highly variable phenomena and are clearly frequency dependent (Figure 1). This can be demonstrated using the phase plane technique (Figure 1C) [11], which is very useful for determining the threshold of action potentials [7,12-14]. Frequency changes result in a shift of the action potential peak and both $\dot{V}_d$ and $\dot{V}_r$ are modifiable by excitatory and inhibitory synaptic inputs [1,3,7].

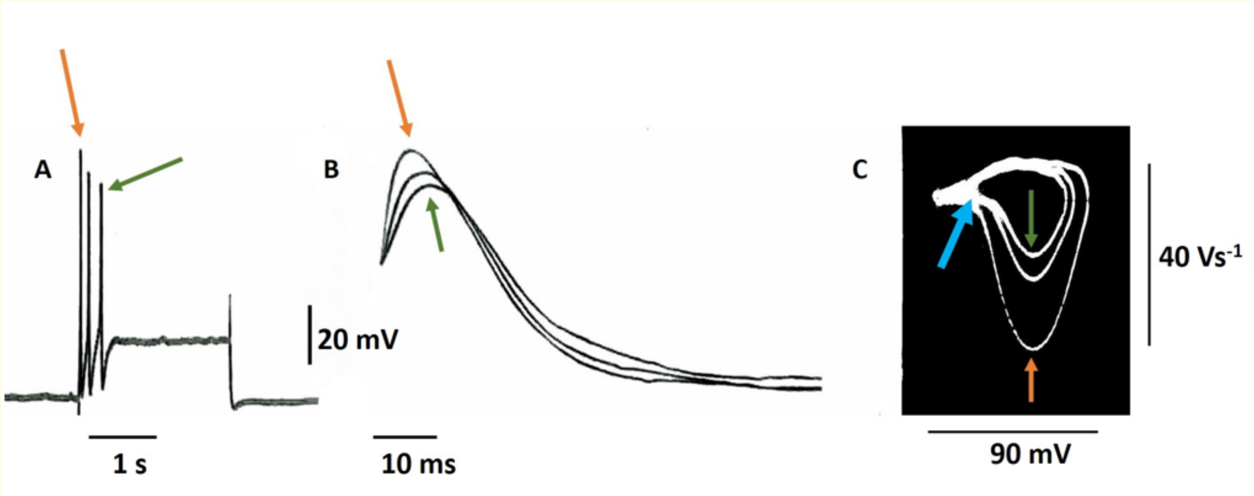

Figure 1: *Plasticity of action potential shape and action potential peak recorded from the soma of a fast adapting pedal I cluster neuron (for details see 15) in the intact brain of the mollusc Lymnaea stagnalis (L.). The cell was normally silent and activity was initiated by a 0.2 nA current pulse of 3s duration injected into the cell via a bridge balanced recording electrode. The same three spikes are represented in each case; a) on a slow time base, b) on a faster time base and c) as a phase plane portrait in which rate of change of voltage (dV/dt) is plotted against voltage itself and the inward depolarizing phase is displayed downward maintaining the voltage clamp convention (see 11 for details of the phase plane technique). In each trace the peak of the first action potential is indicated by an orange arrow, the second action potential peak is unlabelled the third action potential peak is indicated by a green arrow. The three successive spike peaks clearly vary temporally from one another, but the threshold point of initiation remains constant as indicated in c) by the blue arrow in the phase plane portrait (Data previously unpublished but provided from William Winlow's data bank).*

Figure 1 clearly indicates the temporal variability of the action potential peak ($\dot{V}$d) and the temporal constancy of the action potential threshold. This supports our opinion that threshold is the most appropriate temporal instigator of the computational action potential [8-10].

Conclusion

Future modelling of neural activity should use phase ternary computation, where the second phase of computation becomes the action potential threshold, the fixed point of action potential initiation.

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