

THEORY OF POTENTIAL PROFILES
LAYER-BY-LAYER ANALYSIS OF THE SURFACE-NEGATIVE WAVE OF
THE CORTICAL ANTIDROMIC EVOKED POTENTIAL IN CATS

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The depth profile of the cortical macropotentials may be either monotonic or nonmonotonic. The monotonic type is due to the purely dipole character of the source of the extracellular field, while the nonmonotonic type shows the influence of the contribution of the quadrupole component. Axo-somatic inhibitory synapses in the cat motor cortex evidently generate predominantly dipoles. A layer-by-layer analysis was made of the long surface-negative wave of the antidromically evoked response in the cat motor cortex. This wave is produced by axo-somatic inhibition of the pyramids. The potential profile was found to be monotonic in accordance with theoretical prediction. Not only the sign but also the character of the change in potential in the depth of the cortex can be used to interpret cortical macropotentials.

A theoretical investigation of extracellular fields [3] showed that their force in the cortex may be dipole or quadrupole in nature depending on the position of the active synapses on the postsynaptic membrane. A quadrupole is produced by synapses in the central part of the apical trunk and synapses on stellate cells, while axosomatic synapses on pyramidal cells generate predominantly a dipole moment, with a small quadrupole component. In the cat motor cortex this last component is evidently very small [2, 3]. If a large area of cortex is stimulated, the dipole moments create a field which varies with the depth of recording to give a monotonic profile, while quadrupole moments, on the other hand, create a field which falls away symmetrically towards the surface and toward the center [3]. Excitatory synapses, which terminate principally on dendrites [5, 6], create both dipoles and quadrupoles, and for this reason cortical potentials reflecting EPSPs must have a nonmonotonic profile; this conclusion is confirmed by the results of layer-by-layer analysis of the positive components of the evoked potential (EP0 [4, 12]).

Inhibition, which is probably produced by axo-somatic synapses [5, 6], generates principally dipoles and the corresponding cortical potentials ought therefore to have a monotonic profile. This is confirmed by layer-by-layer analysis of the negative wave of the EP [4,12]. The profile of the inhibitory surface-negative wave (SNW) of the antidromically evoked potential (AEP) of the cat motor cortex, according to the example shown by Kubata et al. [11], is approximately the same. However, according to Humphrey [8], it has a highly nonmonotonic profile. However, this problem has so far received little study, and this has usually been confined to the magnitude, the sign, and the point of inversion of the potential. For this reason, whether in an individual case the profile is monotonic or nonmonotonic does not necessarily represent the actual characteristics of the experiments performed by that investigator.

Since the inhibitory character of the SNP is not in question [9, 10, 13] and since the axo-somatic nature of this IPSP has also been confirmed experimentally [14], layer-by-layer analysis of the SNP of the AEP of the cat motor cortex can make an important contribution to the theory of potential profiles.

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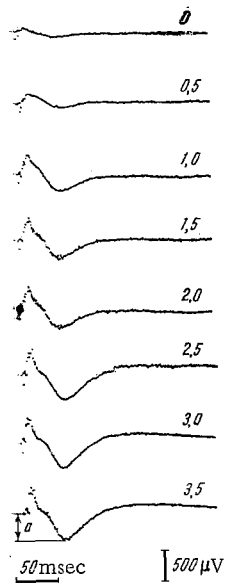


Fig. 1

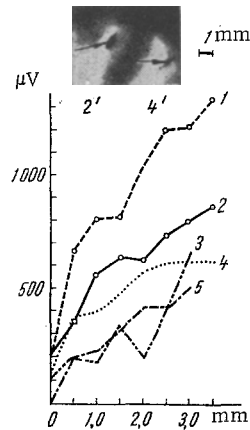


Fig. 2

Fig. 1. Depth distribution of SNWs. Each curve represents the mean of five stimuli. Numbers correspond approximately to depth of recording. Profile of this track is given in curve 4, Fig. 2. Bottom curve shows a method of measuring amplitude of SNW.

Fig. 2. Profiles of SNW. Inset: electrode tracts corresponding to profiles 2 and 4. Fixation with formalin.

EXPERIMENTAL METHOD

Recordings were obtained at eight consecutive depths in both cerebral hemispheres of five cats anesthetized with Nembutal at the beginning of the experiment (50 mg/kg, intramuscularly) and with a further dose (10–20 mg/kg, intravenously) 6–8 h later. At the level of vertebra C1 a partial dorsal transection was made of the spinal cord, taking care not to injure the pyramidal tract into which the bipolar stimulating electrodes were inserted. The stimulus consisted of a series of 3 identical square pulses (about 0.4 mA, interelectrode distance about 1 mm, pulse duration 0.7 msec, interval between pulses 4 msec). The AEP was recorded in each layer by nonpolarizing electrodes inserted stereotaxically. The diameter of the deep electrode was 0.2–0.4 mm and of the surface electrode 2–3 mm. For monopolar recording (3 experiments) the reference electrode was inserted into the cavity between the frontal and nasal bones.

To avoid fatiguing the preparation during insertion of the electrode, the step between each successive depth was increased to 0.5 mm and the number of stimuli in each cluster was limited to 5; to avoid systematic error the AEP was recorded during both insertion and removal of the electrode. A Nihon Kohden type ATAC-401 storage device was used and the amplitude of the SNW was measured in accordance with Fig. 1. The blood pressure was sustained by intravenous infusion of physiological saline with 0.1% noradrenalin. The tracks of the deep electrode were verified histologically. The depth of insertion could not be determined accurately, but in order to determine whether the profile is monotonic or nonmonotonic it is only necessary to know that the electrode is inserted deeper into the cortex and that the last point of the track is in the white matter.

EXPERIMENTAL RESULTS AND DISCUSSION

In response to stimulation of the pyramidal tract with a series of 3 pulses a biphasic positive-negative EP was recorded in the motor cortex (Fig. 1). In the present experiments the medial lemniscus was probably stimulated as well as the pyramidal tract, and this would account for the nature of the positive phase [8] in which silence of the medial lemniscus was ensured. The position of the positive phase was

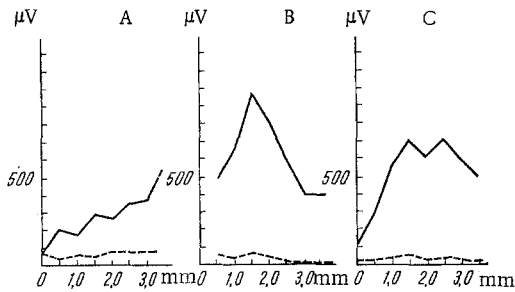


Fig. 3. Profiles of SNW obtained by simultaneous monopolar recording: A) stable monopolar response; B, C) unstable responses.

in the other it was produced on purpose: the blood pressure during the experiment began to be controlled only after it had fallen to 90 mm Hg. Instability of the SNWs can be also considered from the example given by Humphrey [8]; the amplitude of the transcortical SNW was about 0.15 mV, the monopolar surface potential was -0.35 mV, and the monopolar potential at a depth of 2 mm was $+0.2$ mV. A change in the depth of the barbiturate anesthesia is an important cause of changes in the SNW with time [1].

It follows from these results that the profile of the SNW is evidently monotonic provided that the conditions of recording remain unchanged at different depths.

Because of the monotonic character of the SNW profile the conclusions from Gutman's theoretical study [3] can be more definitely described.

1. Surface-negative, deep-positive macropotentials evoked by activity of deep inhibitory axo-somatic synapses, possess a monotonic profile. The potential gradient occurs at the layer of active synapses plus a higher layer with a thickness of the order of λ (the constant length of the apical dendritic trunk). The greater the area and thickness of this layer of pyramidal cells affected by inhibition, the more distinctly monotonic the profile. Long and thick basal dendrites, which are evidently absent in the cat motor cortex, "spoil" the monotonic character of the profile.

2. Surface-positive, deep-negative macropotentials evoked by activity of deep excitatory dendritic synapses, possess a nonmonotonic profile. The maximum of deep negativity must occur deeper than the center of the active layer, and the potential gradient extends above and below the active layer for a depth λ . If inhibitory synapses are present on the apical trunk, the corresponding profile will be the same except for the sign.

3. Potentials evoked by activity of synapses on the apical dendrites satisfy the usual dipole requirements and their gradient disappears at a depth greater by an amount λ than the position of the active synapses.

Several combined variants can also be observed in practice. For example, the IPSPs not only create their own field, but they also "block" the field of spontaneously active cells. To give another example: a nonmonotonic profile, negative at all depths [7], is found at a focus of paroxysmal activity. In this case EPSPs are evidently created both in the depth of the cortex and on its surface, and the experimental result can be explained by superposition of profiles of types 2 and 3.

The concepts described above can be useful in connection with the interpretation of the synaptic nature of the potentials. In particular, dendritic EPSPs may sometimes differ from IPSPs in the localization of the gradient. For example, it seems preferable to regard the negative wave of the primary potential as deep-negative in nature [11]. The alternative hypothesis that it arises through excitation of apical dendrites does not agree with the absence of a potential gradient in the uppermost layers of the cortex. Conversely, the negative component of the EP, as the work of Sasaki et al. [14] has shown, is most probably dendritic in origin.

not studied. The SNW had a latent period of 15–25 msec and a duration of 50–80 msec, in good agreement with the observations of Humphrey [8] who specially demonstrated that the SNW does not depend on stimulation of the medial lemniscus.

In 4 of 5 profiles of the SNW without monopolar control, in 4 it was monotonic and 1 curve was unstable in character. The complete transcortical potential was always maximal (Fig. 2).

The reason for the instability of the profile could be instability of the evoked potential itself. To test this hypothesis 3 insertions of the electrode into the successive layers were made with simultaneous monopolar recording of the SNW (Fig. 3). Temporal stability of the monopolar SNW was accompanied by a steady change of potential with increasing depth, and vice versa. Instability of one curve was due to unknown causes, while

LITERATURE CITED

1. M. Veselyunene, A. Gutman, and V. Lesene, *Farmakol. i Toksikol.*, No. 5, 520 (1971).
2. A. Gutman, *Biofizika*, 14, 891 (1969).
3. A. Gutman, *Biofizika*, 15, 888 (1970).
4. V. N. Kazakov, *Fiziol. Zh. SSSR*, 55, 1070 (1969).
5. M. I. Colonier, in: *Brain and Conscious Experience*, New York (1966), p. 1.
6. J. C. Eccles, in: *Brain and Conscious Experience*, New York (1966), p. 24.
7. R. J. Gumnit, H. Matsumoto, and C. Vasconetto, *Electroenceph. Clin. Neurophysiol.* 28, 333 (1970).
8. D. R. Humphrey, *Electroenceph. Clin. Neurophysiol.*, 24, 116 (1968).
9. D. R. Humphrey, *Electroenceph. Clin. Neurophysiol.*, 25, 421 (1969).
10. R. Nagel and V. B. Brooks, *J. Neurophysiol.*, 32, 540 (1969).
11. K. Kubata, H. Sakata, K. Takahashi, et al., *Proc. Japan. Acad.*, 41, 195 (1965).
12. C. I. Li, L. Cullen, and H. H. Jasper, *J. Neurophysiol.* 19, 111 (1966).
13. C. G. Phillips, *Quart. J. Exp. Physiol.*, 41, 58 (1956); *ibid.*, 44, 1 (1959).
14. D. A. Pollen and H. D. Lux, *J. Neurophysiol.*, 29, 369 (1966).
15. K. Sasaki, H. P. Staunton, and G. Dieckmann, *Exp. Neurol.*, 26, 369 (1970).