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EFFECTS OF DIRECT CURRENTS ON THE ELECTRICAL ACTIVITY OF THE SPINAL CORD

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Scheminzky (see Scheminzky, 1940, 1947, and the papers quoted therein) has shown that constant currents flowing longitudinally along the vertebral column of frogs can evoke muscular inhibition (*Galvanonarkose*) if the cathode is situated caudally, and muscular spasm (*galvanischer Krampf*) if it is cephalic. Evidence exists that the phenomenon is of central origin (Köllensperger & Scheminzky, 1938), and the interpretation has been suggested (Scheminzky, 1940) that it is due to electrotonus of some 'functionally polarized' nervous elements situated in the spinal cord.

Bremer (1941) confirmed Scheminzky's results, observing that currents flowing between the upper regions of the spinal cord and a hindlimb (in mammals) reduce or increase, according to their direction, the slow potentials which can be recorded from the anterior horns of the spinal cord following excitation of a dorsal root.

Winterstein (1948) found that when the cathode was placed on the spinal cord of frogs, increased motor activity resulted, no matter where the anode was located upon the animal's body, and therefore he rejected the assumption of a functional polarization of spinal elements. Rowinski (1948) based a similar conclusion on theoretical considerations. Scheminzky (1948) argued, however, that the probable presence of curved lines of current renders Winterstein's results acceptable in the frame of his own original interpretations.

Quite recently, v. Baumgarten (1949) has shown that when current flows between two electrodes placed at the two opposite ends of the vertebral column of frogs, opposite motor effects can be obtained not only by reversing the polarity of the electrodes but also simply by displacing the trunk of the sciatic nerve. From these results he infers that Scheminzky's effect is conditioned by the electrotonic polarization of peripheral nerves.

In the present research, part of which has been previously reported (Ajmone Marsan, Fuortes & Marossero, 1949*b*), an approach to the interpretation of Scheminzky's phenomenon was attempted by studying the actions of galvanic currents on the rhythmical activity of the spinal grey matter of mammals.

METHOD

Decerebrated or anaesthetized cats and dogs were used for the experiments. The animals were deeply curarized, and artificial respiration was performed. The rhythmical potentials were led off from the anterior horns (histological control) by means of steel electrodes and recorded with a Grass ink-writing oscillograph which could follow frequencies of 5–70 cyc./sec. Other details of the recording technique have been described elsewhere (Ajmone Marsan *et al.* 1949*a*). As polarizing electrodes, chlorided silver wires or plates have been used. The intensity of the current could be smoothly increased up to 30 mA., but as a rule maximal values of 2–8 mA. have been used. The location of the polarizing electrodes was varied in different series of experiments, and is referred to in the following section.

RESULTS

When both polarizing electrodes are placed in or around, or are inserted into, the spinal cord, the electrical activity being recorded by means of electrodes placed between them, only minor changes, similar for both directions of the current, are observed (Fig. 1). If the cephalic electrode is placed upon or around

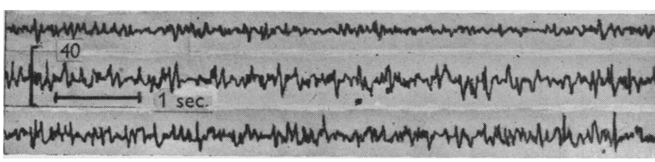

Fig. 1. Cat. One polarizing electrode on the cervical region of the cord, other just caudal to the lumbar enlargement. Recording electrodes inserted in the lumbar enlargement. 1st record: resting activity; 2nd: cervical polarizing electrode negative, current 10 mA.; 3rd: cervical polarizing electrode positive, current 10 mA.

the lumbar enlargement of the spinal cord and the distal one is on a peripheral nerve trunk of the sciatic plexus, or surrounds a group of both sensory and motor roots, increase of activity is sometimes observed when the cephalic electrode is negative, while, when the current flows in the opposite direction, no consistent change is induced, and in particular no appreciable flattening of the spinal waves is observed* (Fig. 2). Finally, if the dorsal roots are severed leaving the electrodes in the same position as above (as in Bremer's experiments), or if the caudal electrode is placed around a group of ventral roots, the flow of current is accompanied by tetanic hyperactivity when the cathode is cephalic (Fig. 3), and some depression can occasionally be noted when it is caudal.

In these conditions, electrical phenomena consistent with the motor effects studied by Scheminzky, Fuortes & Köllensperger (1939) are sometimes observed, i.e. effects opposite to those which are present during the flow of current may follow its interruption.

* As the resting activity of the spinal cord was generally scarce, little effect could be expected as a consequence of the flow of 'descending' currents: moreover, it should be noted here that potential oscillations may be generated by iron electrodes in an ionic conductor, in the presence of polarizing current (B. H. C. Matthews, unpublished), and thus flattening of the waves could be obscured or increase of activity simulated, by purely physical factors.

The spinal hyperactivity evoked by 'ascending' currents is formally identical to the one induced by strychnine poisoning. Moreover, the action of the drug is additive with that of stimulating direct currents in the sense that both voltage and regularity of the strychnine waves are increased by 'ascending' current

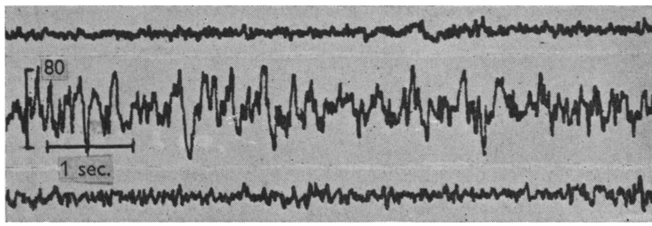

Fig. 2. Cat. Cephalic polarizing electrode on the cervica region, distal around a group of dorsal and ventral roots emerging from the lumbar enlargement. Recording electrodes inserted in the lumbar enlargement. 1st record: resting activity; 2nd: cervical polarizing electrode negative, current 2mA.; 3rd: cervical polarizing electrode positive, current 2 mA.

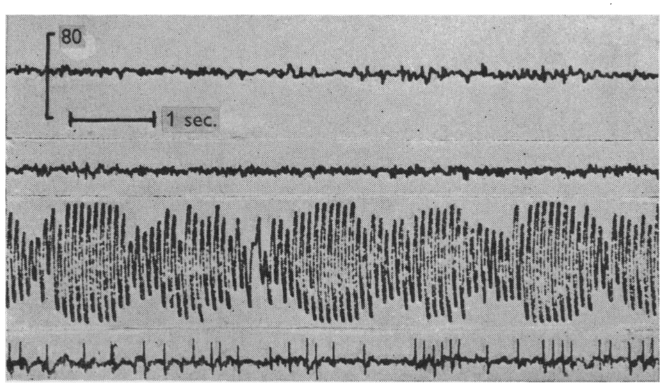

Fig. 3. Cat. Cephalic polarizing electrode around the cervical region, distal around a group of lumbar motor roots. One couple of recording electrodes inserted in the lumbar enlargement, another couple in one muscle of the hindlimb (all recording electrodes ipsilateral to distal polarizing electrode). 1st record: resting activity of spinal cord; 2nd: resting activity of muscle; 3rd: cephalic polarizing electrode negative, current 2 mA., spinal activity; 4th: same, muscular activity.

flow (Fig. 4) (see Bremer, 1941, p. 74), while 'descending' currents have a well-evident depressant effect on the tetanic activity induced by strychnine (Fig. 5). These findings are in agreement with what Köllensperger (1940) has observed with relationship to the motor activity.

DISCUSSION

The opposite effects of direct currents flowing in opposite directions on the electrical activity of the anterior horns are consistent with the motor effects observed by Scheminzky and co-workers in frogs: it is therefore assumed that the changes described above are the electrical correlates of Scheminzky's phenomenon. If this assumption is correct the present results confirm Scheminzky's original view that the locus of action of the current is situated within the spinal cord. Fuortes & Scheminzky (1939) have observed that the stimulating action of longitudinal direct currents is more marked and more easily

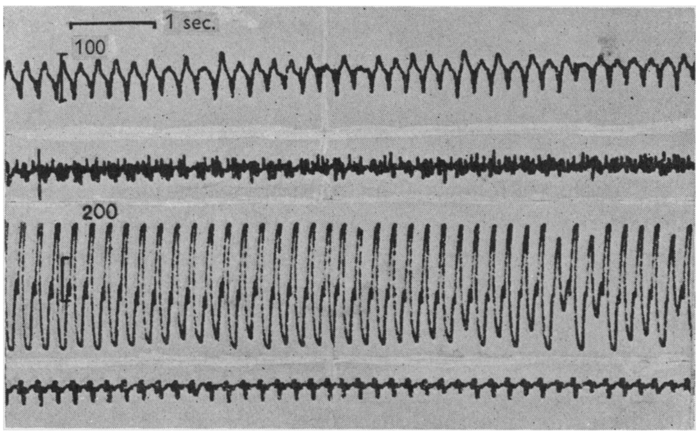

Fig. 4. Cat. Polarizing and spinal recording electrodes as in Fig. 3. 1st record: spinal activity during submaximal strychnine tetanus; 2nd: cephalic polarizing electrode negative, current 2 mA. Note different amplification.

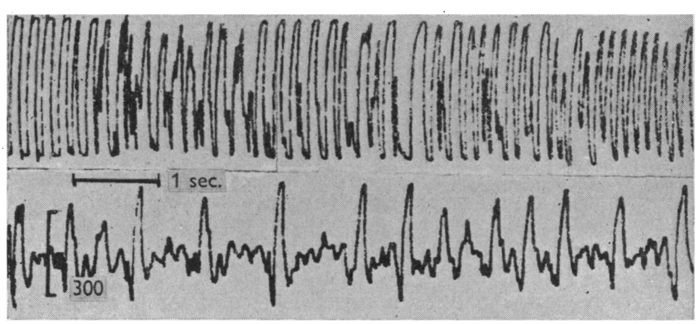

Fig. 5. Cat. Electrodes as in Fig. 4, but muscular records omitted. 1st record: spinal activity during strychnine tetanus; 2nd: cephalic polarizing electrode positive, current 2 mA.

obtained in the hind- than in the fore-limbs of frogs: considering that the lumbar roots lie in the same axis of the cord while the higher roots have a more divergent course when they leave the upper spinal regions, the present experiments seem to agree with this latter finding as well as with all other experimental results, to show that the effects of direct currents on the spinal structures are most easily obtained when the current follows a path including the spinal cord cephalically and the motor roots caudally.

It is known (Barron & Matthews, 1938) that currents flowing with appropriate direction along a similar path evoke repetitive discharge of the motor neurons, caused by the depolarization of the neuronal body, while currents of opposite direction cause inhibition of the reflex discharge of impulses. It seems therefore likely that Barron & Matthews's direct-current excitation and inhibition of the motor neurons constitutes the basis of Scheminzky's phenomenon. In this latter phenomenon, however, other factors may also play a role, due to the fact that spinal structures other than the motor neurons are included in the current path.

As the pattern of the electrical activity of the anterior horns evoked by the flow of stimulating current displays typical signs of synchronization of the individual potential oscillations, it follows from the above-mentioned suggestions that synchronized rhythmicity of pools of neurons can be obtained through the depolarization of the active units, possibly as a consequence of a uniform increase of their activity. As far as most of the arguments raised by Winterstein (1948), Rowinski (1948) and v. Baumgarten (1949) are directed to challenge Scheminzky's suggestion of 'functional polarization' of spinal elements, it might be stated here that, in the view of the present authors, the concept of 'functional polarization', in the broad sense in which Scheminzky (1940) has defined it, is not contradictory with the interpretation suggested above. The morphological organization of the spinal cells, as Levi (1948) has pointed out with reference to this problem, is not ordered in a prevailing direction, but it is clear that a preferential direction exists in the orientation of the axons of the motor cells, and it is suggested here that these axons constitute a channel through which applied direct currents can easily act upon the motor neurons. Indeed, Scheminzky's concept of 'functional polarization' makes it easy to conceive how a current flowing along the whole vertebral column may act mainly upon the motor neurons, as it is probable that the neurons of the anterior horns (somata and axons) are the only systematically oriented units of the cord.

The present suggestion seems to be well consistent with Scheminzky's results and interpretations, and to offer a possible explanation of apparently contradictory results of other authors.

SUMMARY

1. Direct currents flowing (in mammals) along a path including the spinal cord cephalically and the motor roots caudally evoke changes in the rhythmical activity of the anterior horns, which are opposite for opposite directions of the current: if the cephalic electrode is negative, increase of the activity (up to synchronized tetanic hyperactivity) may follow, while flattening of the waves is observed if the cathode is caudal.

2. These effects are similar and additive to those evoked by strychnine. The actions of the current fail or are less evident when the current is made to flow longitudinally along the cord, or to follow other pathways including other spinal and peripheral structures.

3. It is suggested that Scheminzky's *Galvanonarkose* and *galvanischer Krampf* are fundamentally due to the direct-current excitation and inhibition of the spinal motor neurons, demonstrated by Barron & Matthews.

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