Renshaw Inhibition During Local Spinal Cord Cooling and Warming

Thermoregulatory reactions induced by direct temperature changes within either the hypothalamus or the spinal cord are identical in a qualitative way[1]. The segmental contributions to thermoregulatory reactions following local spinal temperature changes[2] are explained to a considerable degree by the temperature effects on the membrane properties of motoneurone cells, which have been elevated with the intracellular microelectrode technique[3]. Further it is suggested from these findings that the basic mechanisms constituting central nervous thermosensitivity are equal, in principle, in hypothalamic[4] and in spinal afferent[5,6] and efferent[7] neurones. Thus, a starting point is disclosed for a general analysis of this property of central nervous structures. Inhibitory processes which play an important role in central integration are known to be likewise temperature dependent[8]. The present investigation is concerned with the temperature effect on a special type of inhibitory influences on the motoneurone, the recurrent inhibition.

Method. The experiments were done in lumbar motoneurones and interneurones of anesthetized cats (30 mg/kg sodium pentobarbiturate i.p.) during continuous infusion of flaxedil (2 mg/kg/h) and artificial ventilation. Conventional microelectrode techniques (electrode filling: 2-mol K-citrate) were used. The ventral roots of L_7 and S_1 were prepared for antidromic stimulation. The temperatures of the body and of the paraffin pool covering the exposed lumbosacral spinal cord were kept constant between 37.5 °C and 39.0 °C with deviations not greater than ± 0.2 °C. The temperature of the spinal segments L_7–S_1 were changed by means of a 10 mm long metal thermode, circulated with water. Cooling and warming periods lasted 3–5 min and were repeated in one experiment not earlier than 20 min after the end of the forgoing period. The spinal temperatures were measured at the end of each experiment, with a thermocouple (⌀ 0.2 mm) inserted instead of the microelectrode, and the cooling and warming periods repeated.

Results. The antidromic inhibitory pathway to motoneurones includes special inhibitory neurones, the Renshaw cells. Their firing pattern and the principles of their function are well known[9], in contrast to other interneurones. In 5 Renshaw cells the recording conditions could be kept constant during 4 cooling and 3 warming periods such that the influence of temperature on the discharge pattern could be analyzed by extracellular recording.

The effects of spinal cord cooling and warming on the duration and the instantaneous spike intervals of single bursts of discharge recorded from two Renshaw cells are presented in Figure 1. During cooling the intervals between the spikes increased. For instance, the distance between the 7th and the 8th spike doubled from 0.9 msec at 37.8 to 1.8 msec at 33 °C. The intervals of the first 10 action potentials changed uniformly so that the interval curves were shifted approximately in parallel. Beyond the 10th spike, the interval became irregular and, on the whole, more prolonged. The total number of impulses decreased during cooling, in this cell to one half of the initial value by a drop in spinal temperature of 5 °C. It is obvious from the original recordings (upper left of Figure 1) that the changes in discharge pattern became manifest with a drop in spinal cord temperature of less than 1 °C.

While the number of impulses decreased considerably during cooling, the reduction was only slight during warming and occurred only at temperatures above 40 °C.

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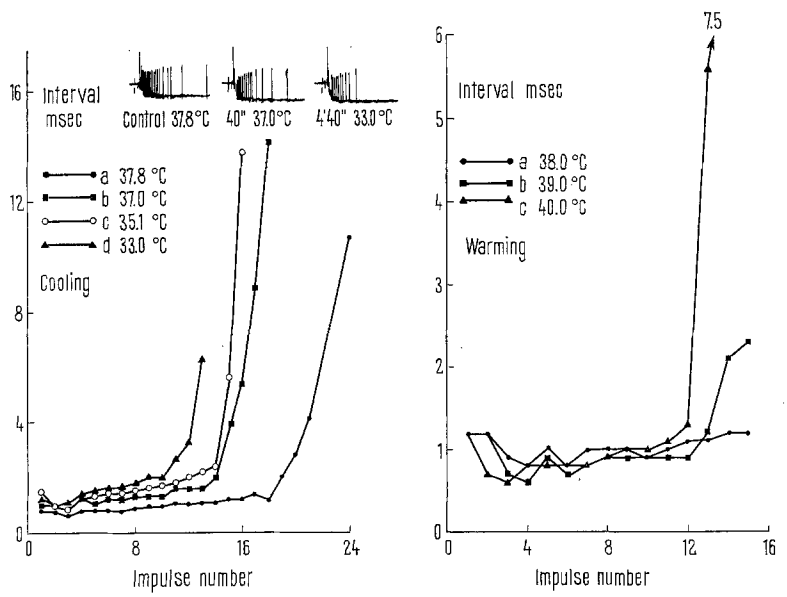

Fig. 1. Interspike interval and total number of impulses of single bursts of 2 Renshaw cells during local cooling and warming. Submaximal stimulation, frequency 1/sec. Ordinates: spike interval in msec. Abscissa: impulse number within the burst. Duration of temperature changes 5 min. Insets: original recordings of Renshaw cell firing bursts at control temperature and during local cooling. Temperatures in Figures 1 and 2 are intraspinal temperatures.

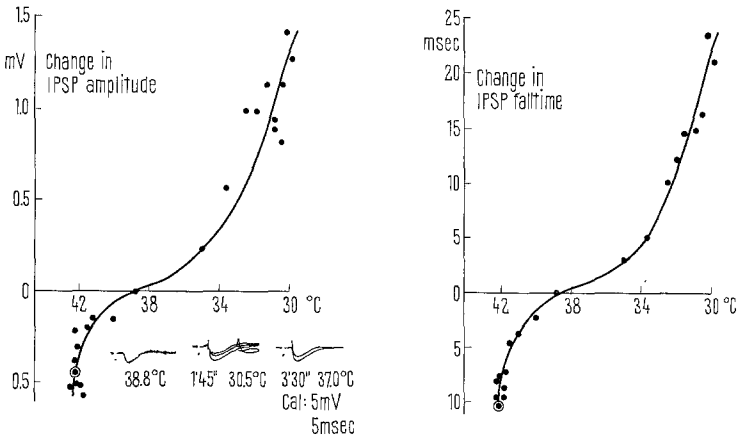

Fig. 2. Changes of amplitude and falltime of the antidromic IPSP of a lumbar motoneurone during local spinal cooling and warming as compared with the control data at 38.8 °C. Duration of temperature changes 3 min. Falltime represents the time of decay of the IPSP to 50% of maximal amplitude (max/2). Upward direction indicates increase. Insets: original recordings of IPSPs at 38.8 °C (control) and during cooling and rewarming. 8 traces are superimposed. Downward deflection indicates negativity. Note the spontaneous spike during cooling and the afterpotentials of antidromic spikes in the 2. and 3. recordings – the greater deflections. Note also the depolarisation of the resting membrane potential during cooling.

On the right side of Figure 1, showing the response of another Renshaw cell to warming, only the first 15 out of 18–20 spikes of each burst are plotted, since the last intervals were very irregular in this submaximally stimulated cell. During warming the intervals of the first spikes decreased by 0.1–0.3 msec but increased in the later phase of the burst (at 39 °C after the 12th and at 40 °C after the 8th spike). However, since the inhibitory effect of Renshaw cells upon the motoneurones is determined by the first part of the burst, warming seems to have increased the inhibitory power of the Renshaw cell. Both findings, the increase of discharge frequency in the first part of the burst during warming and the decrease during cooling were observed also in the other Renshaw cell investigated, in addition the decrease during cooling also in further 3 unidentified interneurones.

The decrease of the Renshaw cell discharge during cooling did not, however, result in a decrease of the antidromic inhibitory postsynaptic potential (IPSP). As demonstrated by the changes of amplitude and falltime in Figure 2, the IPSP instead became larger and longer during cooling and smaller and shorter during warming, the slope of the curves is more pronounced during the initial phase of warming. This seems to be consistent with the smaller range of thermoregulatory control above normal body temperature. With regard to the end points of the curves, an increase of temperature for almost 4 °C caused a reduction in amplitude by 0.6 mV, while cooling by 9 °C enlarged it by 1.4 mV. The corresponding changes of decaytime were -11 and $+24$ msec. In spite of the increased antidromic IPSPs during cooling, the original recordings at the left side of Figure 2 demonstrate that the motoneurones were nevertheless more readily excited by the antidromic stimulus. At a spinal cord temperature of 30.5 °C two spikes are generated by the antidromic stimulus, their afterhyperpolarizations are visible in the second inset. This means that the higher threshold of the antidromic action potential is overcome during cooling. The increased excitability of the recorded motoneurones during cooling is further demonstrated by the spontaneously occurring spikes. The third inset finally shows that during rewarming antidromic action potentials are evoked though the IPSP has already reached the initial value.

Discussion. In good agreement with the temperature-dependent changes of mono- and polysynaptic EPSPs[3] and orthodromic IPSPs[8], the alteration of the parameters of the antidromic IPSP can be explained by the temperature-dependent changes of the membrane resistance of the motoneurones. Furthermore, the alteration of the resting membrane potential has to be considered[3]. The augmented excitability of the motoneurones during rewarming (inset 3 of Figure 2) might be attributed to the delayed repolarization of the membrane. In analogy to the findings in motoneurones[7,10], recruitment of interneurones during cooling might contribute to the increase of inhibitory and excitatory postsynaptic potentials. On the other hand, an elevated firing rate of interneurones at lowered spinal cord temperature[11] could not be confirmed.

Some authors[7,10,11] have observed in spinal motoneurones that, inspite of the higher excitability during cooling, in many cases the firing rate decreased, the extent being apparently dependent on the cell size[7]. We suppose this depressant effect of cooling on the firing neurone is considerably caused by the presented increase of inhibitory neuronal processes, which was confirmed also by other methods[12], and by the prolonged afterhyperpolarization (unpublished observation). These two facts may have an important influence on the frequency coding during temperature changes in the spinal cord.

Zusammenfassung. Während lokaler Rückenmarkskühlung wurde die rekurrente Hemmung bei lumbalen Motoneuren narkotisierter Katzen verstärkt und bei Wärmung vermindert. Als wesentliche Ursache für diese Effekte wird die Änderung von Membranwiderstand und Ruhemembranpotential der Motoneuren angesehen. Die Änderungen von neuronalen Hemmprozessen und hyperpolarisierendem Nachpotential spielen offenbar bei der temperaturabhängigen Frequenzkodierung spinaler Efferenzen eine Rolle.

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