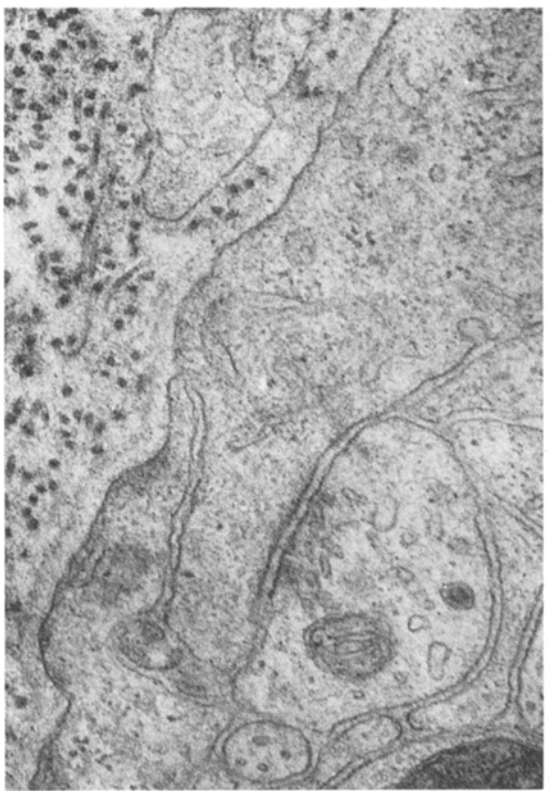

Fig. 2. Rat small intestine. Myenteric plexus. Synaptic junction between a nerve fibre and a dendrite of an intramural neuron. The nerve process contains agranular 'flattened' vesicles. × 57,000.

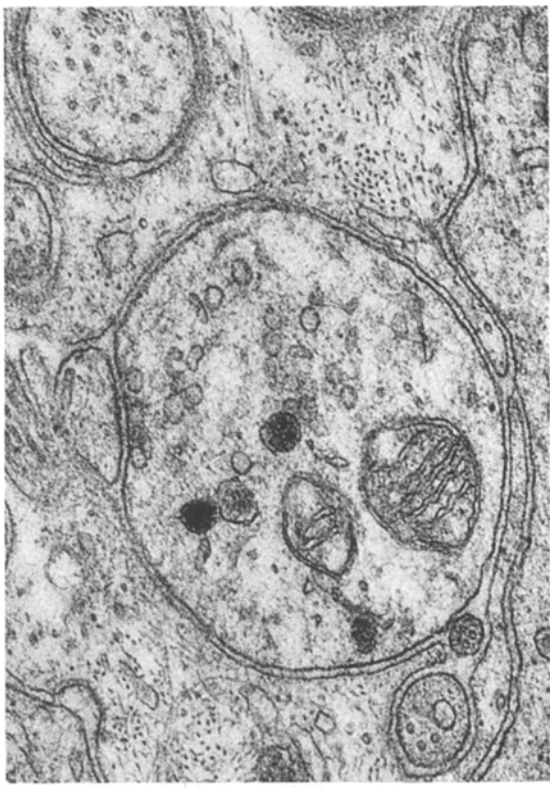

Fig. 3. Rat stomach. Myenteric plexus. A large nerve fibre makes a synaptic junction with a small nerve process, very probably a short dendrite stemming from an intramural neuron. × 50,000.

been reported both in the central nervous system[5,6] and in the intramural plexuses of the gut[7].

Morphological evidence suggests that in the small intestine relatively primitive transmission processes not only occur at the neuro-muscular junctions but also at junctions inside AUERBACH's plexus ganglia. Similar conclusions were reached by PATON and ZAR[8] through a pharmacological study of guinea-pig ileum. The higher number of synapses in stomach as compared to small intestine may be related to the richness of innervation from vagus nerve and to the high degree of extrinsic drive[9], which are typical of the stomach. Moreover, it has recently been shown that, following vagotomy, there is a dramatic fall in the number of synapses in the stomach[10].

In summary, both axo-somatic and axo-dendritic synapses were observed in the myenteric plexus of the rat stomach and small intestine. The relative number of typical (or conventional) synapses was significantly higher in the stomach[11].

Riassunto. Nel plesso mienterico dello stomaco e dell'intestino tenue di ratto si osservano tipiche giunzioni sinaptiche sia axo-somatiche sia axo-dendritiche. Il numero di contatti sinaptici per unità di superficie di sezione o per cellula nervosa è piú di sei volte maggiore nello stomaco che nell'intestino tenue.

G. GABELLA[12]

Department of Anatomy, University of Torino, I-10126 Torino (Italy), 5 November 1969.

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[12] Author's present address: Department of Anatomy, University College London, Gower Street, W.C. 1.

Ascending Neurons of the Spinal Cord Activated by Cold

The observation that cooling and heating the spinal cord may influence the ascending reticular activating system and thermoregulatory effectors requiring supraspinal control[1,2], is indirect evidence for the afferent conduction of the spinal thermal stimulus. Activation of ascending units of the medial lemniscal pathway during spinal cord heating[3] has confirmed this assumption for the spinal warmth stimulus. The increased discharge of spinal neurones at the segmental level during spinal cooling[4] further suggests that ascending units might be

activated also by the spinal cold stimulus. The discovery of central afferents activated by cold would be of special importance for the conception of central thermosensitivity, since direct evidence for central cold sensors in the hypothalamus is still tentative[5].

Method. In nembutalized cats, breathing spontaneously or – in the case of spinal transection at C_1 – being artificially ventilated, spinal cord temperature was changed by means of a perfused thermode which was located extradurally, extending from the sacral to the upper thoracic vertebral canal. The experiments were carried out at room temperature, while the animals were placed on a heating-pad to control body temperature. 6 degrees of spinal cord cooling or heating could be established: strong (C III), moderate (C II), and slight (C I) cooling, neutral temperature, and slight (W I) and strong (W II) heating, which corresponded to perfusion temperatures of 20, 26, 32, 38.5, 43.5 and 47 °C, as a rule, at a perfusion flow of 30 ml/min. Cooling and heating periods of mostly 4 min duration were performed. – The upper cervical vertebral column was immobilized in a stereotaxic apparatus (Baltimore Instruments) by means of ear bars and vertebrae clamps. The upper cervical spinal cord was exposed by removing the arcs of the 1st to 3rd vertebrae. For unit recording steel microelectrodes sharpened to less than 5 μ and coated with Insul-X (impedance at 800 Hz a.c. >1 megohm) were inserted by a microdrive into the spinal cord at the level of C_2–C_3. The potentials were fed into a Tektronix 2A61 plug-in amplifier and were displayed on a Tektronix 565 oscilloscope. Records were taken with a Tönnies camera. Rectal temperature and vertebral canal temperature close to the thermode were measured by thermocouples and were recorded on a Philips 12-channel servo recorder. The position of the electrode tips during recording was controlled by determining the stereotaxic coordinates of the electrode position in relation to the spinal cord dimensions. Eventually micromarking of the tip position was performed after recording by applying weak anodic currents to the electrodes and subsequent histological control by the ferrocyanide method in frozen transverse sections.

Results. In 17 animals 25 recordings, mostly single unit recordings, were obtained in which neuronal activity was found to change significantly with spinal cord temperature. Among these, 18 recordings in 13 animals showed an increase of activity by spinal cord heating above and/or a decrease of activity by cooling below the neutral temperature level. This finding agrees with observations on spinal thermosensitivity in guinea-pigs[3]. Especially, however, on 7 occasions in 5 animals unit activity was observed which increased during spinal cord cooling. Figure 1 demonstrates the discharge frequency of one of these cold activated units during various cooling and heating periods. The discharge rate increased definitely during cooling and seemed to follow the course of peridural temperature. Maximum activity was obtained during strong cooling. Slight heating seemed not to alter the unit discharge, while strong heating had a moderate activating effect. 4 more units showed this type of response to cooling. Another type of cold activated unit is demonstrated in Figure 2. Here, a definite dynamic component of the frequency response was apparent during the transient phases of the cooling and rewarming periods. On the whole, the response of this unit showed some similarity to the discharge pattern of peripheral cold fibres[6]. In a 2nd unit showing a similar dynamic cold response, the steady discharges during the cooling periods could not be properly evaluated. The discharges at the ends of one or more cooling periods of different intensities could be measured in 6 cold activated units. At moderate cooling (perfusion temperature 26 °C), the discharge frequency rose, on the average, from 1.9/sec at 38.1 °C to 13.3/sec at 34.1 °C peridural temperature. In a further 4 animals, 4 units were recorded which responded to spinal temperature changes in a manner that could not definitely be classified as either heat or cold activation.

Both heat and cold activated units were detected in an area between 0.6 and 1.6 mm apart from the lateral margin of the spinal cord and 2.3 to 4.5 mm below its dorsal surface at the respective points of electrode insertion. These coordinates, though allowing only a coarse estimation of the recording sites, indicated that the units were located in the antero-lateral quadrants. The positions of the heat and cold activated units seemed not to be grossly different. The more exact determination by micromarking in 6 cases shown in Figure 3 (2 cold and 4 heat activated units) confirmed the conclusion drawn from the stereotaxic estimations, thus indicating that afferent activity was recorded. The afferent nature of these units shown in Figure 3 is further ensured by the fact that they were detected in animals spinalized at C_1.

Discussion. Since unit activity was recorded at C_2–C_3, while the thermode extended only to the upper thoracic region, the responses observed cannot be due to a direct

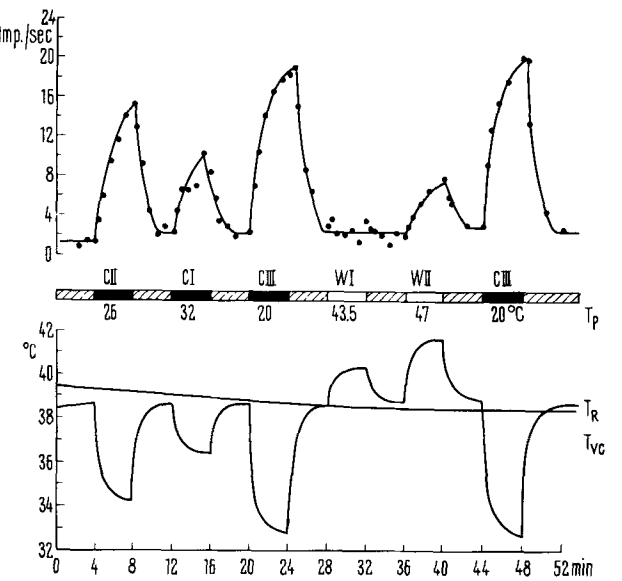

Fig. 1. Discharge rate (Imp./sec) of a cold activated ascending spinal unit during spinal cord cooling and heating; black bars, cooling; hatched bars, neutral temperature; white bars, heating; perfusion (T_P), rectal (T_R), and peridural (T_{VC}) temperatures.

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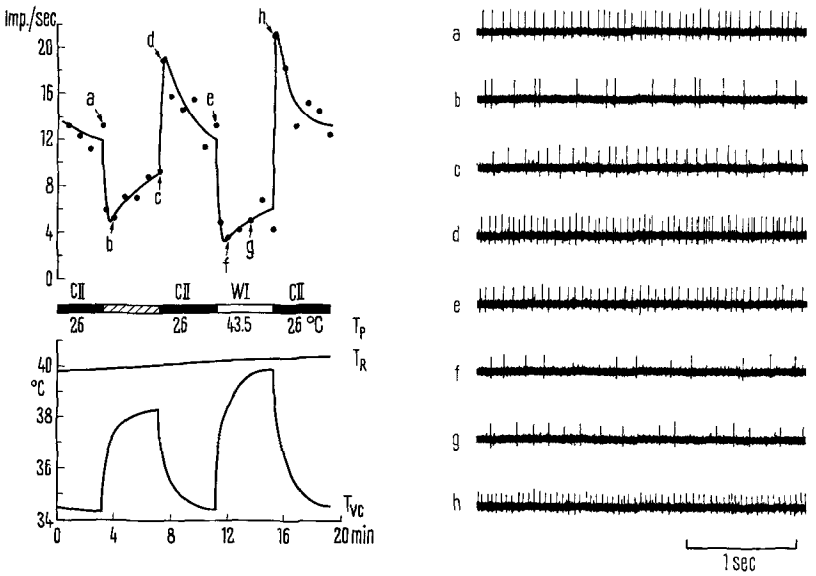

Fig. 2. Left: Discharge rate of a cold activated ascending spinal unit with dynamic response; symbols as in Figure 1. Right: Recordings of unit activity at the points of the response curve indicated by the letters.

temperature influence on nerve cells at the recording level. The location of the units in the antero-lateral column and the consistent results in intact and spinalized animals indicate that warm and cold activated units were ascending fibres. That the afferent activation by cold might have arisen from muscle receptors stimulated by shivering seems unlikely, especially with respect to the peculiar response of the unit shown in Figure 2. Further, in the case of Figure 1, no shivering was observed during the 1st period of severe cooling, while during the last cooling period definite shivering occurred with no additional effect on unit activity. Finally, the ventral and dorsal spinocerebellar tracts carrying muscle receptor afferents are located in the dorsolateral quadrants of the spinal cord at the level of C_3[7]. The sensitivities of the cold activated units, as related to the decrease of peridural temperatures during cooling, ranged between 2 and 4 Imp./sec/°C with an average value of 2.9 Imp./sec/°C. The true sensitivities of these units may have been somewhat lower or higher, since the positions of the thermoceptive sites in relation to the thermode, and hence their precise temperatures, were unknown. With respect to long-term temperature changes adaptation might further modify the fibre responses. The different responses demonstrated in Figures 1 and 2 suggest that at least 2 types of spinal cold activated units might exist. However, different time courses of the temperature changes at the thermoceptive sites might also account for this observation.

Conclusion. The results indicate that activation of ascending spinal neurons occurs during spinal cord cooling. The temperature sensitive sites inducing this activation are located within the vertebral canal, probably within the spinal cord. The cold activated units seem to have the property of 'measuring' the degree of spinal cord hypothermia and might serve, therefore, as central cold sensors participating in the evocation of thermoregulatory responses observed during spinal and general body cooling.

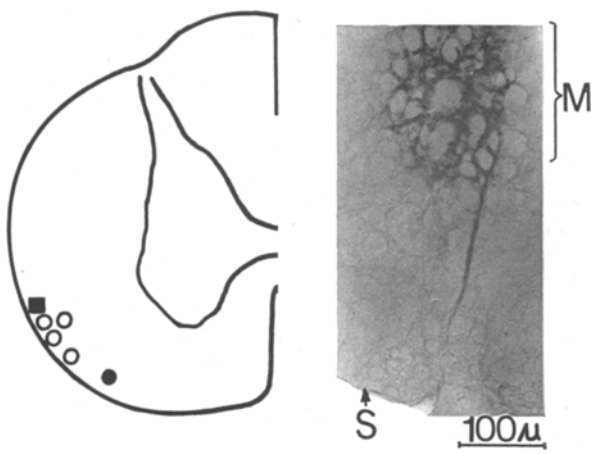

Fig. 3. Left: Recording points of 2 cold activated units (filled symbols) and 4 heat activated units (circles) obtained from spinalized animals as determined by micromarking. Right: Transverse section of the spinal cord (S, spinal cord surface) showing the micromark (M) for a cold activated unit (dot in the left side figure).

Zusammenfassung. Bei narkotisierten, intakten und bei C_1 spinalisierten Katzen wurden Mikroableitungen aus dem 2.–3. Zervikalsegment des Rückenmarks während Temperaturänderung des thorakalen und lumbosakralen Rückenmarks durchgeführt. Im Vorderseitenstrang konnten neben wärme-aktivierten Einheiten kälte-aktivierte aszendierende Neurone nachgewiesen werden.

E. SIMON and M. IRIKI

W.-G.-Kerckhoff-Institut der Max-Planck-Gesellschaft, D-6350 Bad Nauheim (Germany), 10 December 1969.

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