Methods of analyzing dynamic responses of temperature-sensitive neurones[1]

R. Necker and G. Bicher

Arbeitsgruppe Temperaturregulation, Ruhr-Universität Bochum, Postfach 102148, D-4630 Bochum 1 (Federal Republic of Germany), 18 December 1978

Summary. Methods are described for analyzing the dynamic responses of temperature-sensitive neurones or receptors using a computer facility. The methods allow correlation of impulse frequency with temperature changes or with the rate of temperature changes independent of the time course of the temperature change. Different types of dynamic responses and different thermal sensitivities could be distinguished.

Temperature-sensitive receptors or neurones are usually characterized by the dependence of impulse frequency on temperature under static conditions, and by dynamic responses to rapid temperature changes[2]. In most cutaneous temperature-sensitive receptors the dynamic response, i.e. the response to a change in the stimulus intensity, consists of transient or phasic changes in impulse frequency such as excitatory overshoot or transient inhibition with a subsequent adaptation to a static level. In temperature-sensitive neurones in the central nervous system such transient responses are less common[3-5], i.e., the dynamic response consists of a proportional change in impulse frequency without an overshoot or transient inhibition.

Considering dependence on the rate of temperature changes, phasic responses (excitatory overshoot) have been quantified by assessing the maximal response to step-like temperature changes[6,7] or an average response during the period of temperature change[8]. No direct correlations between impulse frequency and rate of temperature change during one dynamic phase of the stimulation has been done as yet. Such a correlation is facilitated by computer evaluation, which is now generally available. Methods will be described for correlating impulse frequency with temperature and in a subsequent step with the rate of temperature change.

Methods and results. For computer analysis of temperature-sensitive receptors or neurones, recordings of temperature-sensitive slowly-adapting mechanoreceptors[9] and recordings of neurones in the spinal cord of pigeons[5] were selected. Both action potentials and stimulus temperatures were stored on magnetic tape in an analog manner. One stimulation period usually consisted of a rapid lowering of temperature by a thermode on the skin or on the spinal cord inside the vertebral canal and, after a period of adaptation, rewarming to the starting level. The analog data were fed into a computer[10] which sampled both impulse frequency and temperature at usually one second intervals (the sampling interval should be as short as possible because of the rapid changes during dynamic

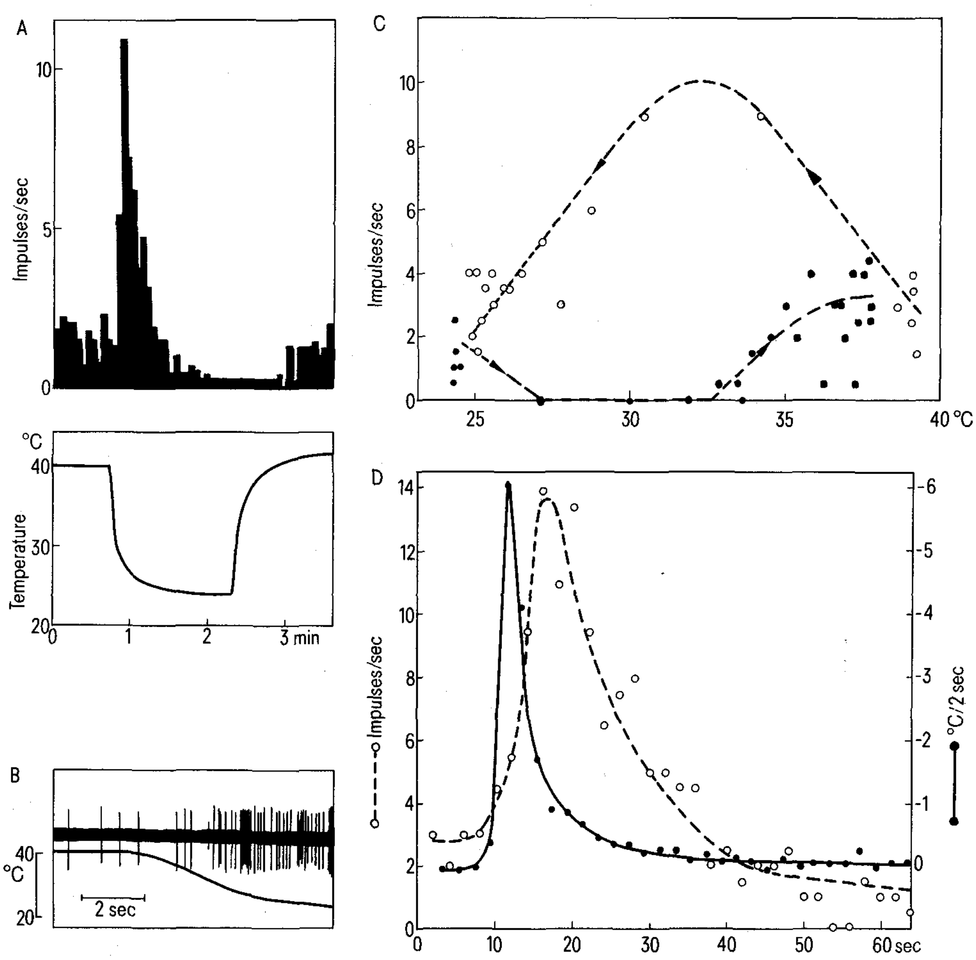

Fig. 1. A, B, C, D: Analysis of the dynamic response of a temperature-sensitive slowly-adapting mechanoreceptor in the skin of the wing of the pigeon. A: Time course of skin temperature (lower curve) and impulse frequency (means of 4-sec periods). B: Original registration of action potentials and skin temperature during cooling. C: Correlation of impulse frequency and skin temperature during cooling (open circles) and rewarming (closed circles). D: Comparison of impulse frequency and rate of temperature change (°C/2 sec) during cooling.

stimulations). In this way successive paired values were obtained and stored for further analysis.

At first the time course of both impulse frequency and temperature were plotted in a conventional manner as shown in figure 1A or figure 2. The next step consisted of a correlation of impulse frequency with temperature, i.e., the paired values were arranged in an increasing order with regard to temperature independent of the time course of the temperature change (figure 1C). There was a step in the computer program which could detect the inversion from negative to positive temperature changes; in this way the response to cooling could be distinguished from the response to warming by using different signs. In addition, if there was a time lag between the beginning of the tempera-

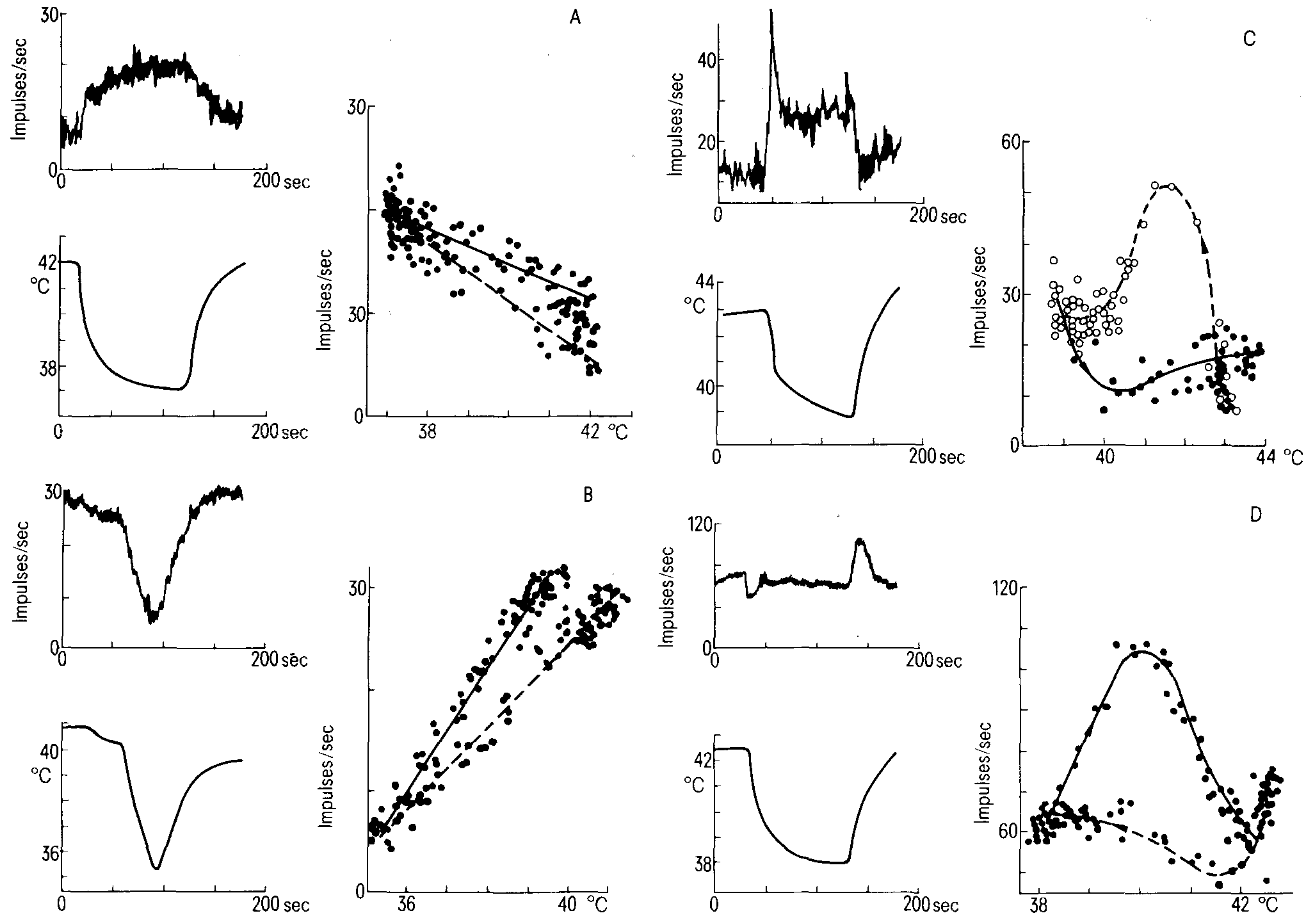

Fig. 2. A, B, C, D: Response of two cold-sensitive (A, C) and 2 warm-sensitive (B, D) neurones in the spinal cord of pigeons to cooling and rewarming. – On the left: time course of impulse frequency and spinal temperature; on the right: correlation between impulse frequency and temperature during cooling (open circles) and rewarming (closed circles).

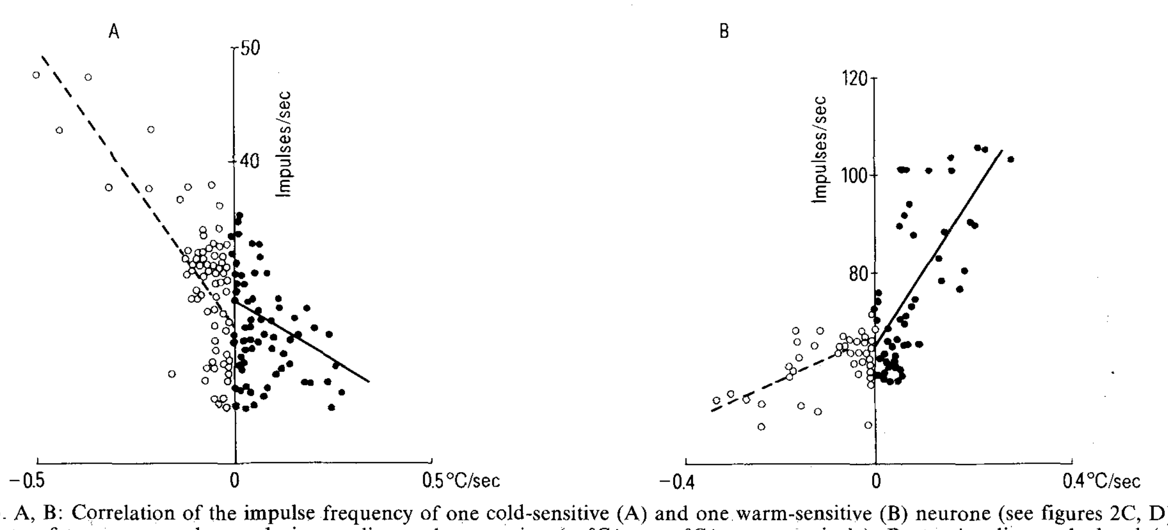

Fig. 3. A, B: Correlation of the impulse frequency of one cold-sensitive (A) and one warm-sensitive (B) neurone (see figures 2C, D) with the rate of temperature change during cooling and rewarming (– °C/sec, + °C/sec, respectively). Regression lines calculated (n = 40; r = −0.78/−0.48 in A, r = 0.71/0.54 in B).

ture change and the change in firing rate (see latency of the response in figure 1B) this could be compensated for by a shift of one of the time courses. As shown in figure 1C this procedure reveals a phasic response (which is not always as clear as in figure 1A) by a strong hysteresis (see also figure 2).

A further method consisted in the calculation of the rate of temperature change (°C/sec) from successively sampled temperature values and to relate it with the impulse frequency. In figure 1D the time courses of both the rate of temperature change and impulse frequency during the cooling phase of the stimulus are plotted in the same graph. There is a striking similarity between both time courses although the time course of the impulse frequency obviously is lengthened (a multiplication of the time course of the rate of temperature change by a factor of about 3 would yield a curve which would be nearly identical with the impulse frequency curve). This analysis reveals that there is a relationship between firing rate and rate of temperature change but that this relationship is not a linear one.

Figure 2 shows four examples of different dynamic responses of spinal temperature-sensitive neurones. The examples of figures 2A and B represent one type which did not show phasic responses. The impulse frequency changed linearly with temperature both in the cold-sensitive neurone (negative correlation in figure 2A) and in the warm-sensitive neurone (positive correlation in figure 2B). The slopes during cooling and rewarming are different which results in a divergency of both curves. In the long run the impulse frequency returned to its initial level (not included in the evaluation period). As for the different slopes, there is obviously not a dependence on the direction of temperature change but a dependence in that a stimulus which results in an increase of impulse frequency is related to a steeper slope.

The examples of figures 2C and D show one warm-sensitive and one cold-sensitive spinal neurone with phasic responses as shown in figure 1. Again a strong hysteresis can be seen with nonlinear changes in impulse frequency which is in contrast to the response of the neurones in figures 2A and B. Although there is obviously no linear dependence of the firing rate on the rate of temperature change (see figure 1D), in figure 3 correlations of both parameters (imp./sec ~ °C/sec) were done with the neurones shown in figures 2C and D. Despite considerable variations the regression lines calculated both for the rate of cooling (− °C/sec) and the rate of warming (+ °C/sec) reveal a similar behaviour as with the nonphasic neurones in figures 2A and B, namely a steeper slope of the curve during that temperature change that results in an increase in firing rate.

Conclusions. The methods described above make it possible to discriminate clearly between different types of response to dynamic thermal stimulation of temperature-sensitive receptors or neurones. Appropriate correlation techniques revealed functional properties like the relationship between the rate of temperature change and the firing rate during one stimulation period and like the different slopes of the response to cooling or warming, respectively, which otherwise cannot be seen. In this way a more detailed characterization of different types of temperature-sensitive receptors or neurones can be given, which is helpful for a better understanding of the mechanisms underlying the temperature sensitivity of excitable membranes.

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Automatic recognition of squirrel monkey vocalisations by means of a filterbank

M. Meier, U. Steppuhn and W. Rück

Max-Planck-Institute for Psychiatry, Department of Primate Behavior, Kraepelinstr. 2, D-8000 München 40 (Federal Republic of Germany), 24 November 1978

Summary. Up to now the problem of classifying squirrel monkey vocalizations has not been solved satisfactorily. The problem is now approached by a method, which consists of 2 phases. At first the monkey vocalizations are compared with the aid of physical criteria and classified by types. According to the classification of types, the membership of the individual vocalizations is tested.

The social behavior of squirrel monkeys *(Saimiri sciureus)* can be described - among other things - by their visually recognizable behavior, and their vocalizations[1]. We here present a method to recognize squirrel monkey vocalizations. In the 1st phase of the process of recognition, several types of vocalization are defined, while in the 2nd phase individual vocalizations are classified according to these types.

A vocalization is physically depicted through a frequency-time-diagram and thereby characterized. Up to now the vocalization types have been differentiated on the basis of similarities in their physical components (e.g. basic frequency)[2]. In the program presented, the following criteria of similarities will be quantified in such a way that the vocalizations can be objectively defined and automatically recognized.

By a telemetrical system, it was possible to transfer acoustic signals from the transmitter located on the head of the monkey to the tape recorder[3]. From there, the vocalizations were conveyed by means of a filterbank into a digital frequency-time-matrix[4]. This information is then sent through a databreak directly into the memory of a PDP12 computer, where it is held available for further analysis[5].

The frequency-time-matrix embodies the necessary information to classify the vocalizations[6]. It turned out that the following parameters play an essential role in differentiat-