An electrothermal stimulator for sensory tests

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In a previous investigation of cutaneous thermal thresholds it was found that although thresholds to contact warmth and cold stimuli in terms of a fixed temperature scale were extremely labile, they were consistently related to the skin temperature at the site under test (Lele, 1954). Thus thresholds measured in terms of degrees above or below the skin temperature at the test site remain more or less constant over a wide range of skin temperatures. A subsequent study of the reaction times to cutaneous thermal stimuli led to the conclusion that for thermal stimuli it is essential to express stimulus intensities by measuring them from and in terms of the threshold intensities and not from an absolute zero since only then can legitimate comparisons between different areas, different sessions, and different subjects be made (Lele and Sinclair, 1955). Little attention has been paid to these facts in the past and perhaps some of the numerous discrepancies in work on skin sensation stem from this cause. Moreover, convenient instruments for conducting thermosensory examinations in this manner are not readily available. The electrothermal stimulator described below was designed to fulfil this need and provide an instrument which would enable the application of warm or cool stimuli of different sizes and shapes and of desired (physiological) intensity to the skin, irrespective of the differences in the surface temperature of the skin at different sites.

DESCRIPTION OF THE INSTRUMENT

The instrument essentially consists of a thermojunction of two different (*p* and *n* forms) semiconductors, a low-voltage, high-current power supply, and a current reversing switch. On passing a current through the two semiconductors in contact with each other a marked Peltier effect develops, one end of the junction becoming warmer and the other cooler than initially (Joffe, 1958). The electrical conductivity of these semi-conductors is better than their thermal conductivity and thus a stable temperature gradient proportional to the current flow becomes established between the two ends of the thermojunction and the ambient temperature. Reversal of the direction of the current reverses the thermal effects.

Thus, either end of the thermojunction can be used for warming or cooling an object (of low thermal capacity) placed in contact with it. In practice, one end is used for stimulation, the other being kept in contact with metal fins to aid thermal dissipation.

The skin temperature at various test sites varies between 18° and 35° C. even when the subjects are in thermal equilibrium with the ambient temperature (Lele, 1954). Thus the range of stimulus temperatures needed for an adequate sensory examination extends from about 10° to 45° C. This range of 35° and the rapidity with which the stimulus temperature needs to be changed determine the size of the thermojunction and the power supply needed. In practice, a thermojunction with a thermal pumping capacity of about 5 watts is found to be adequate. The power requirements for maintaining the temperature of the stimulator at a selected level during its application is determined by the thermal capacity and conductivity of the skin, the maximum temperature gradient, and the duration of stimulation. Under normal conditions of use, 0.5 to 1.0 watt of power is needed.

Based on these considerations the instrument shown in Fig. 1 was constructed. The mains-operated power supply is capable of delivering up to about 15 amperes of partially filtered direct current at 6 volts maximum and thus could be used with larger thermojunctions. A variable autotransformer (Variac) allows of continuous variation in the input voltage to the power supply and thus in its output voltage. The current flowing through the thermojunction is kept well under the safe maximum limit by series and shunt resistances so that unsafe monitor operating conditions or damage are precluded.

A power level switch switches the two main current-limiting resistors from a series connexion (low-power position) to a parallel connexion (high-power) giving a 4 : 1 resistance ratio. The high-power position is used to bring the stimulus temperature rapidly to the desired value; the low-power position is then used to maintain it at this temperature. A D.C. ammeter is used to monitor the current continuously in the circuit.

The direction of the current through the thermojunction is controlled by a current reversing switch. In addition, this switch also inserts another resistor in the circuit when the direction of the current is such that the stimulus temperature is rising, since the efficiency of the thermojunction for heating and cooling is not equal. A commercially available bismuth and antimony telluride thermojunction with a thermal pumping capacity of 5 watts (maximum current 15 amperes; the figure of

FIG. 1. Schematic diagram of the stimulator.

A = D.C. ammeter 0.25 amp

M = temperature meter

T₁, T₂ = s.w.g. 40 copper-constantan thermocouples to measure stimulus and skin temperatures respectively

S = interchangeable stimulator tip

n, p = two forms of semiconductors

FIG. 2. Photograph of the stimulus tip assembly. Two s.w.g. 18 flexible cables are connected to each of the two terminals of the thermojunction which are left bare for accessibility. The potential difference between the two terminals does not exceed 1.5 volts and accidental short circuiting is harmless both to the experimenter and the equipment. The thermocouple lead is seen anchored to the power cable. Calibration mark = 2.0 cm.

merit ($Z = 2 \times 10^{-3}$ and $\Delta T = 60^\circ \text{C.}$) is used. For maximum flexibility consistent with the required current carrying capacity 8 feet of s.w.g. 18 flexible cable is used for the connexion, two conductors in parallel with each other forming one lead. One surface of the thermojunction is in intimate contact with the stimulator tip and the other with aluminium strips (fins) which are painted black and act as a 'heat sink' (Fig. 2). The thermojunction is kept covered with a thin film of silicone compound to ensure good thermal contact. The assembly is held together in a screw clamp thus enabling stimulus tips of many sizes and shapes to be interchanged quickly. Interchangeable stimulator tips of from 1 mm.² to 200 mm.² contact area have been used. Each stimulator tip carries a copper-constantan (s.w.g. 40) thermocouple which records its temperature correct to $\pm 0.25^\circ \text{C.}$ A similar freely suspended thermocouple is used to measure the surface temperature of the skin without altering it by measurable amounts. Both the thermocouples are connected to a short period temperature meter calibrated to read $1^\circ \text{C./scale division}$. A galvanometer is used when greater sensitivity is desired.

The power supply and the current control devices are mounted on a chassis together with a d.p.s.t. mains-switch, fuses, and colour-coded pilot lights. The stimulator

measures $30 \times 30 \times 45$ cm. and its layout is such that when in use the subject cannot see the control panel.

This electrothermal stimulator has been found to be entirely satisfactory in studies of sensation in patients with lesions of the spinal cord and in those recovering from spinal anaesthesia (unpublished data) and in a study of the fluctuation of skin sensitivity to thermal stimuli (Melzack, Rose, and McGinty, 1962). However, for routine clinical use a similar electrothermal stimulator incorporating a current control device which will automatically change the stimulus temperature to any desired pre-

set value above or below the skin temperature is being developed.

I wish to thank the U.S. Public Health Service for a grant (B-3222) which made the development of this instrument possible. Thanks are also due to Mr. P. Lefferts of Electro-Audio Research of Princeton, New Jersey, U.S.A. for much help in its design.

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