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A Contact Thermal Stimulator for Neurobehavioral Research on Temperature Sensation

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MORROW, T. J. AND K. L. CASEY. *A contact thermal stimulator for neurobehavioral research on temperature sensation.* BRAIN RES. BULL. 6(3)281–284, 1981.—A thermal stimulation system is described which is suitable for use in psychophysical, behavioral and neurophysiological studies of temperature sensation. Skin temperature over a restricted area can be maintained at temperatures of 30 to 60°C. Heating from this initial temperature can be achieved at rates from 1.0°C to 30°C/second, up to a maximum temperature of 70°C. Stimulus duration can be varied from 1–15 sec. Safety features are employed to avoid accidental burning of subjects. The system can be used during electrophysiological recording with no electronic interference.

Thermal stimulator Thermode Temperature sensation Thermal pain

ANY experimental study involving the thermal stimulation of skin requires the use of precisely controlled stable temperatures. The critical parameters for temperature sensation include the final stimulus intensity, the adapted or initial skin temperature and the rate of change of skin temperature [1]. When conducting experiments on temperature sensibility it is therefore important to use a stimulator which will provide independent control over each of these variables. Such a device should be relatively easy and inexpensive to produce and adaptable to a variety of experimental testing conditions and animal species.

In other studies thermal stimulation of the skin has been accomplished by a variety of means: passing water at a preset temperature through a small probe in contact with the skin [2], radiant heating of the skin [3,4] and, more recently, using thermoelectric Peltier effect [5] or high energy laser emission devices [6]. The circulating water and radiant heat methods lack both versatility and flexible control over the rate at which the skin temperature can be changed. Peltier type stimulators, while affording good versatility in both construction and use, have a maximum rate of temperature change of only 2°C per second. Laser-based systems provide excellent control over all temperature parameters, but they are typically large, very expensive and difficult to implement, making them impractical for general use in many laboratories.

The thermal stimulator system described here, while originally developed to investigate neurobehavioral mechanisms of thermal pain in animals, is suitable for use in a broad spectrum of psychophysical, behavioral and neurophysiological studies of temperature sensation. With this device, temperature changes are conducted to the skin and underlying tissue by a thermal probe (thermode) that remains in contact with the skin throughout the period of stimulation. The thermode and electronic control system described here: (1) provide precise active regulation of skin surface temperature over an area of at least 1 cm^2, regardless of varying thermal load of the underlying tissues; (2) establish an adapting (resting) temperature which is continuously adjustable over a range from 30°C to 60°C; (3) provide thermal stimuli of up to 70°C; (4) allow the rate of temperature change and the stimulus duration to be continuously adjustable over the ranges of 1.0°C to 30°C per second and 1 to 15 seconds, respectively; (5) incorporate a protective fail-safe device to avoid accidental burning of the subject; (6) produce no electronic noise that would interfere with concurrent neurophysiological recording from the experimental subject.

SYSTEM OVERVIEW

The thermal stimulator system consists of two parts: (1) the thermal probe or thermode and (2) the electronic control

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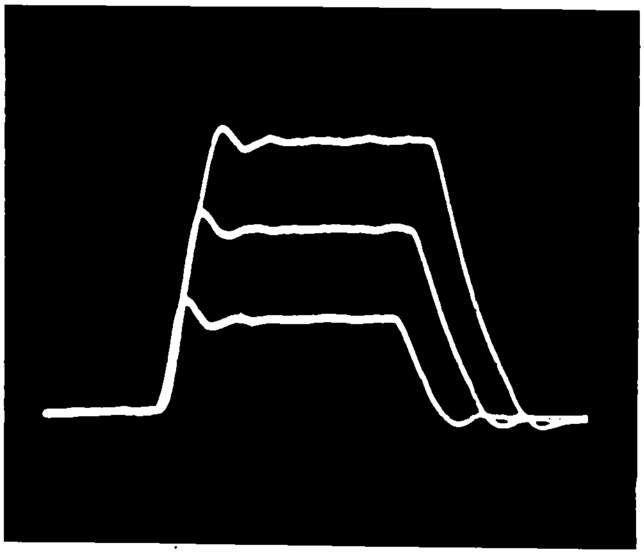

FIG. 1. Oscilliscope traces of temperature pulses recorded from the monitor output. Temperatures are 40, 50 and 60°C, respectively, from a 30°C baseline. The slope is approximately 30°C per second and the pulse duration is 4 seconds.

circuitry. A convoluted length of nichrome wire, sandwiched between two square copper plates using a heat conducting epoxy, forms the basic heating element of the probe. This heater assembly is attached to the end of a plastic cylinder through which cold water is constantly circulated. The output of an iron-constantan (Type J) thermocouple, attached to the exposed surface of the outer plate, is used for feedback control of heater current, thereby regulating probe temperature. Temperatures can be controlled to within 0.5°C over the range between 30°C to 70°C.

The feedback controller permits the thermode to be switched from one temperature to another at selected rates, returning to a pre-set adapting or baseline temperature between thermal stimuli. The rate of temperature change (slope) can be controlled from less than 1.0°C per second to approximately 30°C per second in the warming direction from the adapting temperature. After a temperature pulse, cooling back to baseline is accomplished by the cold water circulating through the probe. During large, rapid changes in temperature, there may be a slight overshoot of the target temperature due to stored thermal energy in the heating element, copper plates and epoxy. With slower changes in temperature, the feedback electronics can better compensate for this stored energy and thus there is little or no overshoot. The maximum rate of temperature change, that can be achieved with good control, is a function of how well the probe heater assembly has been constructed. Several temperature pulses of different intensities are shown in Fig. 1. Fall time (to baseline) of a pulse is totally dependent on water temperature and its flow rate through the probe, the latter parameter being more critical. Typical fall times in our laboratory, using cool tap water, range from 2 to 3 seconds.

PROBE CONSTRUCTION (See Figure 2)

Two 13 mm square copper plates cut from 0.4 mm thick stock are cleaned with concentrated hydrochloric acid to remove any oxide deposits from the metal surface. The plates are then rinsed with water, followed by an additional rinse with acetone, to remove any surface oil and residual moisture. One side of each plate is given two thin coats of Epoxylite 6001-M lacquer (Epoxylite Corp., Columbus, OH) to provide electrical insulation from the heating element.

A 12 to 13 cm length of 0.406 mm diameter enamel insu-

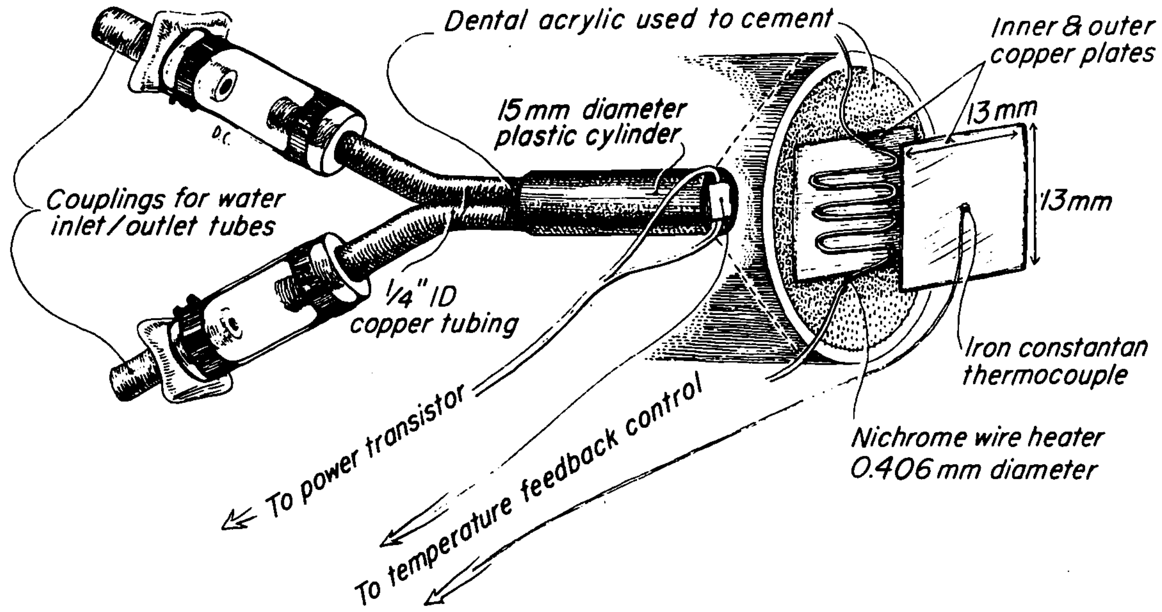

FIG. 2. Thermode construction Exploded view illustrates the shape and placement of the heating element between the copper plates.

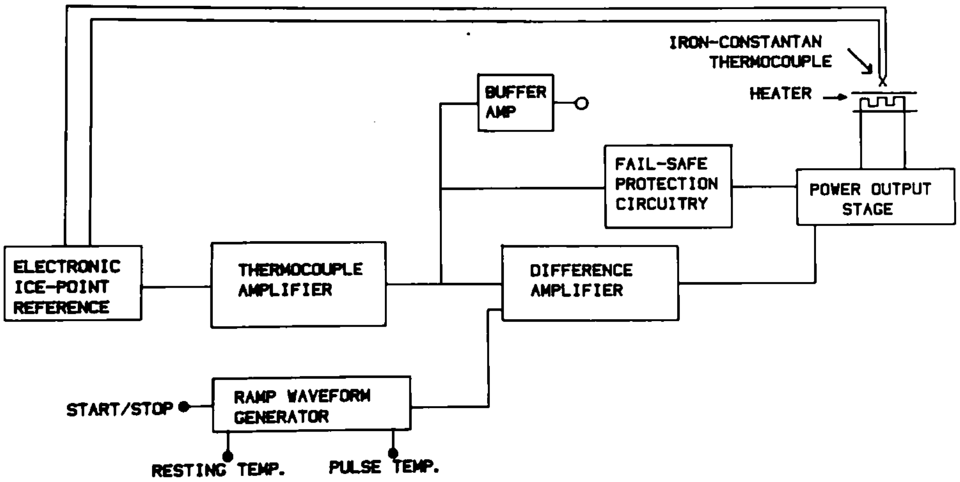

FIG. 3. Block diagram of the electronic temperature control system.

lated nichrome wire (0.12 ohms/cm) is bent to form a "zig-zag" heater grid (see Fig. 2) and is further insulated by dipping once in Epoxylite. This heating element is fixed between the insulated surfaces of the two copper plates using Omega Bond 201 heat conductive epoxy compound (Omega Engineering, Stamford, CT). The epoxy is then thoroughly cured at an elevated temperature according to the manufacturer's recommendations. Extreme care must be taken in this step to avoid any electrical contact between the heater wire and the edges of the copper plates.

As an alternative method of heater construction, bare uninsulated copper plates can be used. A thin sheet of mica punched with numerous 2 mm diameter holes, and cut slightly larger than the copper stock, is sandwiched between the outer plate and the heater wire. With this method the mica sheet provides the necessary electrical insulation between the outer plate and heater. The mica, wire and plates are held together with heat conductive epoxy as in the previous description. This method has the advantage of providing better heat conduction from the nichrome element to the copper plates, since the conductive epoxy is in intimate contact with both. Overall construction, however, is more difficult with this technique.

The heater assembly is then cemented over the end of a 10 cm plastic cylinder (1.5 cm diameter) using a cold cure dental acrylic (Grip Cement, L. D. Caulk Co., Milford, DE). Inlet and outlet tubes (8 cm lengths of 6.35 mm, 1/4 inch O.D. copper tubing) are cemented into the open end of the cylinder opposite the heater using dental acrylic, permitting the circulation of water beneath the copper plate sandwich. At this point in construction, a thermocouple, made from Teflon insulated 36 ga iron and constantan wires (Omega Engineering, Stamford, CT), is carefully soldered to the uninsulated surface of the outer copper plate. The nichrome heater wires protruding from the probe head are connected to 18 gauge copper wire and are led to the power output stage of the heater control circuitry. Again care must be taken to insure that no electrical contact is made between the heater wires and the outer copper plate.

ELECTRONIC TEMPERATURE CONTROLLER

The control electronics consist of five sections: the digital waveform generator (slope generator), the thermocouple amplifier/ ice point reference, the difference amplifier, the power output stage and the fail-safe circuitry. An electronic ice point reference (Omega Engineering, Stamford, CT) is employed to provide stability in the thermocouple temperature feedback system. When a temperature pulse is initiated, the waveform generator digitally synthesizes a negative going ramp voltage which falls to a predetermined value dependent on the selected pulse temperature. This voltage level is maintained for a preset time (the selected pulse duration) and then returns to its initial value. The starting (initial) voltage of the ramp determines the resting or adaptation temperature of the thermode.

During a temperature pulse, the ramp waveform is used to initially imbalance the inputs to the difference amplifier, which also receives the temperature feedback signal from the thermocouple amplifier. The voltage difference between the falling ramp and thermocouple output is amplified and used to drive (turn on) a high-current pass transistor (the power output stage), regulating the flow of current through the heating element. This current passing through the nichrome wire element (approximately 1.3 ohms resistance) heats the probe. As the temperature increases, the thermocouple error signal to the difference amplifier approaches the ramp voltage, balancing the inputs and reducing amplifier output. The system, stabilized by this constant temperature feedback, controls the level of heater current so that the probe reaches a steady state at a new temperature. Pulse temperature is maintained until the ramp returns to its initial resting value. At this time the difference amplifier is again imbalanced, but in the opposite direction, reducing current to the thermode and permitting the probe to return to the adapting temperature.

The output of the thermocouple amplifier is also fed to the failsafe protection circuitry. This circuit consists of a pair of analog comparators which act to turn off the input to the power amplifier stage, preventing current flow to the proble. This circuitry protects the subject from accidental burning if the probe becomes too hot or if sensor leads break or become disconnected. This level of protection has been found sufficient to avoid accidents in our laboratory, since the prime source of problems has typically been broken or accidentally disconnected sensor leads. A block diagram of the control circuitry is shown in Fig. 3.

This thermal stimulator system is easy to use and reasonably inexpensive to construct, making it ideal for use in most laboratories. Since many approaches can be undertaken in the construction of the control electronics, only the essential building blocks and their function have been discussed.

REFERENCES

1. Kenshalo, D. R. Psychophysical studies of temperature sensitivity. In: *Contributions to Sensory Physiology*, edited by W. Neff. New York: Academic Press, 1970, pp. 19–74.
2. Hensel, H. and Y. Zotterman. Action potentials of cold fibers and intracutaneous temperature gradient. *J. Neurophysiol.* **36:** 377–385, 1951.
3. Hardy, J. D., H. Goodell and H. G. Wolff. The influence of skin temperature upon the pain threshold as evoked by thermal radiation. *Science* **14:** 149–150, 1951.
4. Green, L. C. and J. D. Hardy. Adaptation of thermal pain in skin. *J. appl. Physiol.* **17:** 693–696, 1962.
5. Kenshalo, D. R. and D. C. Bergen. A device to measure cutaneous temperature sensitivity in humans and subhuman species. *J. appl. Physiol.* **39:** 1038–1040, 1975.
6. LaMotte, R. H. and J. N. Campbell. Comparison of responses of warm and nociceptive C-fiber afferents in monkey with human judgments of thermal pain. *J. Neurophysiol.* **41:** 509–528, 1978.