Temperature Topography of the Brain Cortex: Thermoencephaloscopy

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Summary: Thermoencephaloscopy (TES) - a new method of functional imaging of the cerebral cortex by its infrared radiation was advanced and developed since 1984. Improved thermovision and image processing techniques allow 2D, contact-free, dynamic and non-invasive recording of background and evoked cortical activity through an unopened skull. Activated (heated) and deactivated (cooled) zones of the cerebral cortex are revealed. The temporal resolution of TES is 40 msec (25 maps/sec), the spatial resolution is up to 70 x 70 microns/pixel. The diameter of the smallest recordable active region of the cortex is 200-300 microns. The minimal time needed for a session used for averaging of 4-9 responses varied from 40 sec up to 18 min. TES allows to detect the position, size and sequence of operation of precisely located specific cortical zones, and to measure their dynamics before, during and after sensory and direct cortical stimulation, motor acts and conditioning (associative learning). TES-effects were recorded in rats, rabbits, cats, monkeys and humans. Waves were found spreading over the cortex with a speed of up to 30 mm/sec along trajectories specific for the sensory modality and the site of stimulation. Some pathological processes in the brain are detectable by TES: experimental tumours and epileptic foci. There are many sources for local heating: neural activity, local metabolism of units, local cerebral blood flow and thermoconductivity in the activated zones of the cortex. Thermoencephaloscopy is a dynamic, non-invasive, contact-free method with a relatively high temporal and spatial resolution and sensitivity. It can be a useful tool in basic neuroscience and medicine.

Key words: Neuroimaging; Mapping; Cortex; Temperature.

Introduction

In the past decades a set of new methods of neuroimaging was developed that permit the study of the spatial distribution of functional brain activity. All these methods have specific advantages but also inherent limitations: they may be invasive (isotopes, toxic dyes, strong light action, powerful magnetic fields, skull trepanation) or may have insufficient sensitivity, temporal and spatial resolution (for reviews see: Shevelev 1987; Shevelev et al. 1989a, 1992b). The main and the most common of these restrictions are invasiveness and, in most of the cases (except the optical imaging, MEG and EEG-mapping), the non-dynamic nature of the method not allowing to trace sufficiently fast (fractions of seconds) functional changes in the brain.

That is why we developed recently a new neuroimaging approach that is non-invasive, contact-free, sensitive and has sufficient spatial and temporal resolution. Since 1984 we are using the very weak infra-red (IR) radiation from an animal brain through an unopened skull, recorded by a thermovision technique. It must be noted that investigation of the production of heat by the brain has been recorded for many years invasively by thermistors inserted into the brain (Hayward and Baker 1969; Melzack and Casey 1967; McElliot and Melzack 1967; Kovalzon 1969; Tasaki and Nakaye 1985).

We present here a short description of the principles and characteristics of the new neuroimaging method - Thermoencephaloscopy (TES), as well as some illustrations of use to study brain functioning. These applications have been published previously mainly in Russian (Budko et al. 1984; Gulyaev et al. 1984; Gorbach et al. 1989; Shevelev 1987, 1992a,b; Shevelev et al. 1985a-c, 1986a-g, 1987, 1988, 1989a-c; 1990a,b; Tsicalov et al. 1984, 1987a,b; Volovick et al. 1989).

Methods

Principles

The living brain produces and emits heat (about 10mW/cm³). Due to thermoconduction about 25% of this heat spreads in all directions with the speed of sound in water. Some heat reaches the outer surface of the cortex and then the outer surface of the skull and scalp. Another 75% of the heat is taken from the brain to the pial...
surface by blood convection. The heat that reaches an 100 μm thick outer layer of the head is radiated into the environment in the IR range. In two wavelength bands, where the atmosphere is transparent for IR radiation (3-5 and 8-14 μm) it can be detected at various distances from the head. The intensity of the IR radiation is proportional to the temperature of the radiating object.

**Devices**

We used a commercial thermovision camera (AG-780M, AGEMA, Sweden) (Figure 1C) that has a Sb/In IR detector attached to the container with liquid nitrogen to reduce the thermal noise of the detector. From some distance (10 cm - 1 m) through a mirror, lens and 2-D optical-mechanical scanning system the IR image of the object was projected to the detector point by point, sequentially. Our thermovisor camera has 4 ms scanning time and a differential thermosensitivity of 0.2°C. To improve the sensitivity by relative suppression of noise (Gulyaev et al. 1984) digital image processing was performed (Figure 2). Through a custom fast interface (2.5 us ADC conversion time and 10 bit resolution) the digitized thermomap consisting of 128 x 85 pixels was transferred to a computer (Pericolor-2000E, Numelec, France).

Intervals between successive maps varied from 40 ms to 10 s depending on the duration of the recorded phenomena and their temporal pattern. Typically, 24 maps were used to record background thermoactivity, while 48-192 maps were used to record the stimulus induced thermoactivity.

**Processing**

To increase the differential thermosensitivity of our device we used: (1) phase sensitive averaging of 4-16 sets of maps (72 maps in each set), received by 4-16 repeated stimulations; (2) spatial digital filtering (sliding weighted mean for a pixel matrix of 3x3); (3) temporal digital filtering (weighted running window for 4-9 maps); (4) in some cases repeated use of (2) and (3) that is equivalent to n-step digital filtering; (5) in experiments that do not