PHYSIOLOGICAL ASPECTS OF INFRARED RECEPTORS IN SNAKES.

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INTRODUCTION

Sensors that are sensitive to changes in temperature are present in nearly all animals. The means of processing the signals from these sensors to provide relevant information varies considerably. As a reflex circuit, the sensors are useful in avoiding damage through burning. In the *Crotalinae* and *Boidae* they serve, in combination with other sensory apparatus, to a clear impression of the environment. The way this sensory apparatus is useful depends upon a number of morphological aspects, in particular the storage and conduction of heat, as well as upon the properties of the surrounding tissue of the sensor. The switching of nerve impulses in the central nervous system finally decides the action or interaction which ensues.

MORPHOLOGY

The infrared sensitive organ of a snake is also called the 'pit'. It is a cavity in the cranium. The inner side is covered with nerve endings that are sensitive to changes in heat. The aperture is small - between 1 and 1½ mm in diameter. The inner area is expanded so that a mushroom shaped cavity is formed. The inner surface is covered with a membrane with a thickness of 0.015 mm and a surface area of 30 mm^2. The outer side is surrounded by an epithelial layer. In this membrane the branches of the dendrites of the Nervus trigeminus are located, so that one particular 'tree' serves one particular area of the membrane (see figure 1). The axons coming out of these areas (about 7000), form the nervous branches that leave the sensor. It is not difficult to understand that the way in which the surrounding tissue of the sensor is organised determines its sensitivity. If the sensor is located deep in the tissue, the outer layer has to change in temperature before the sensor will react. This introduces a delay and thus a weakening of the signal. So, heat conduction within and heat capacity of the surrounding tissue determines the usefulness of the sensor. In the rattlesnake the membrane is additionally surrounded by air from behind. The incoming radiant heat thus solely changes the temperature of the membrane; this increases the sensitivity of the system. In the *Boidae* this heat sensitive membrane is located directly next to the rear of the cavity. In this

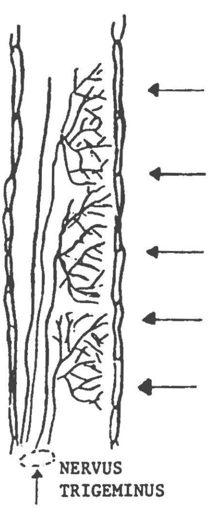

Fig. 1. Membrane of the pit. Dendrites of the Nervus trigeminus form the sensorical units in the membrane.

case a decreased sensitivity results when compared to the system evolved in the *Crotalidae*.
The way the sensors are illuminated by infrared radiation can be compared with the image projection in a camera with a not too small diaphragm. The aperture of the 'pit' determines the intensity of the transmitted radiation, but also governs the accuracy of the information which can be deduced.

PHYSIOLOGY

Several nerve fibres connect the pit with a central switching terminal. Neurophysiological research has shown that a series of nerve impulses can always be measured coming from the pit. In measuring temperature it is difficult to speak about a 'rest' situation and therefore the outcoming signal will be changed presumably in case of suddenly introduced changes in temperature. This change occurs within 100 milliseconds and shows a strong increase in the number of impulses per second and lasts for several tens of seconds. After this period, even if the radiation persists, the number of impulses decreases to the 'base' level at which the nerve impulses started. This is called adaptation. The pit organs are presumably useful in measuring differences in temperature, particularly in the case of dynamic situations (see figure 2). The disappearance of the stimulus induces a strong decrease of the number of impulses per second, and again, adaptation to the original level. Within this concept of sensitivity the pit can measure changes in temperature of the membrane of 0.003°C. Whether this degree of refinement is also achieved 'further down' the system depends highly upon the surrounding tissue, as pointed out above.
The gathered information, as a series of impulses, each travelling along its own nerve fibre, enters

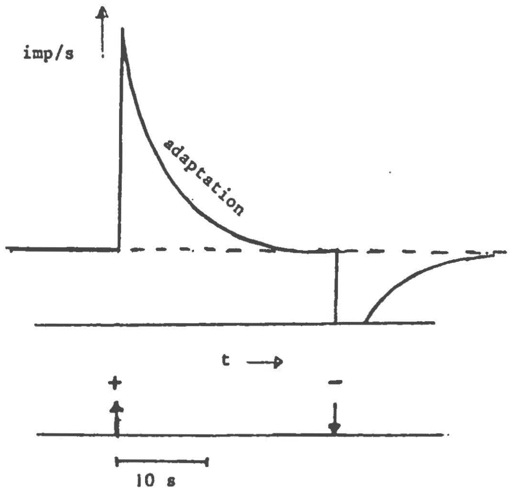

Fig. 2. Time course of the number of impulses per second in a nerve fibre: + in case of increased temperature, - in case of decreased temperature. The dashed level is the number of impulses per second in case of a static situation.

a switching centre in the lateral part of the mid-brain. The impulses coming from the left enter a centre located on the left and those from the right enter one located on the right side. From these centres they switch to nerves going to a more frontally located centre and subsequently switch to nerves that cross the midbrain. They all end within the left or right portion of the Tectum opticum. This part of the midbrain is also the target for information received from the eye. Thus information from visible wavelengths is combined with the information related to the infrared wave-lengths of the spectrum in the Tectum opticum.

INTEGRATION

How do these pictures fit together? Light coming

from the front will hit the eye on the rear surface of the retina. A similar situation exists in a pit for infrared radiation originating from that direction. Visible and infrared radiation originating from behind of the snake falls on the frontal part of the retina of the eye and the membrane of the pit.
The Nervus opticus (from the eye) and the Nervus trigeminus (from the pit) link the posterior part of their sensors to the anterior part of the optic tectum and the anterior part of their sensors to the posterior part of the optic tectum. The signals are not only crossed left to right, but also crossed front to back within each organ. The accuracy of the pit is such that in the case of a snake striking on the basis of information provided by the pit only, the snake may make an error of about 5^{0} in the angle of strike. By combining visual information with that provided by the pit this degree of error can be considerably reduced.

In the case of the python, the integration of information is rather more complicated. The complication arises because the snake has thirteen infrared sensitive pits instead of the two possessed by crotaline snakes. Figure 3 schematically shows the head of a python with only three pits (front, middle, back). The basic principle is that we can consider thirteen pits as components of one very big one. Each component will see a smaller part of the object. The anterior pits presumably see objects located in front of the snake and will project onto the anterior part of the tectum. The middle ones cover the middle part and the posterior ones project onto the posterior part of the tectum. However, each pit projects its picture crossed. In the scheme of figure 3 the area 2,3,4 with centre 3 (object) will stimulate maximum information. In combination with the visible information, relating to the object located at 3, a picture will be combined to show an object with a different temperature to that of its surroundings. Further integration with other parts of the brain will determine any subsequent action of the snake.

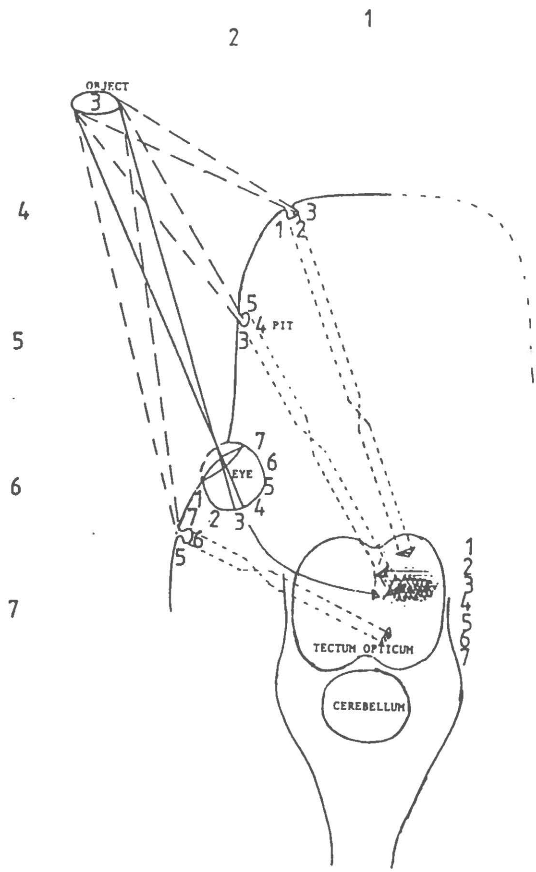

Fig. 3. Schematic representation of the pathes of information coming from the eye and pits in the python.

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