from 38.9–42.2 °C, respectively. At lower ambient temperature there was no significant difference between control values. The metabolic effect of NA was lower than in the former ambient temperature or 36% in warm- and 41% in cold-acclimatized lemmings.

The Figure also shows the effect of Inderal. At higher ambient temperature neither warm- nor cold-acclimatized animals were affected. However, in warm-acclimatized animals the oxygen consumption was significantly lower ($P < 0.01$) after an injection of Inderal than in the cold-acclimatized animals. At lower ambient temperature the Inderal decreased metabolic rate in cold- and warm-acclimatized animals 67% and 78%, respectively. At the same time, body temperatures were decreased from 38.2–37.1 °C and from 38.0–36.7 °C, respectively. Shivering was seen, but its magnitude was not measured.

The basic value for FFA content in the blood of cold-acclimatized lemmings was 369 ± 10.9 µEg/L (S.E.M.) ($N = 7$) and in warm-acclimatized lemmings 283 ± 20.4 µEg/L (S.E.M.) ($N = 8$). The difference is significant at the level of $P < 0.01$. After the application of NA, the FFA content increased up to 1340 ± 61.1 µEg/L (S.E.M.) ($N = 8$) and to 1096 ± 76.3 µEg/L (S.E.M.) ($N = 8$) in cold- and warm-acclimatized lemmings, respectively. This difference is not significant.

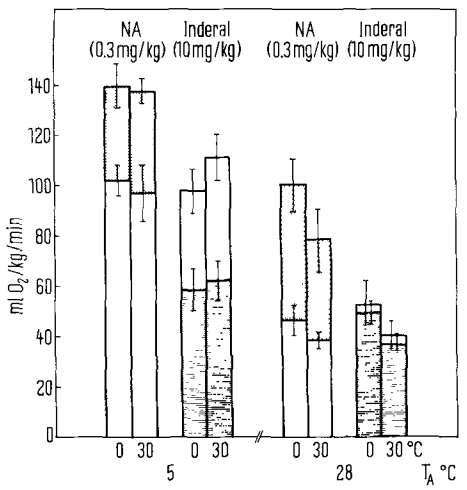
Conclusion. In the rat and the guinea-pig there is a positive correlation between the cold-induced non-shivering thermogenesis and the heat production after the injection of NA[13,14]. The present result is, however, in contrast to those observations. In spite of 30 ° difference in acclimatization temperature, the heat production after the dose of NA was as great in both acclimatizing groups both at 28 °C and at 5 °C. It may be that still lower ambient temperature would have been needed to uncover a possible difference between these groups. On the other hand, this result resembles those obtained in cold- and warm-acclimatized hedgehogs[13] and in hamsters[15]. The similarity in the magnitude of NA mediated heat production was confirmed with specific non-shivering thermogenesis blocking agent.

The FFA content in the blood plasma is in agreement with the results obtained in the cold- and warm-acclimatized rats by HANNON et al.[16]. Thus the result obtained does not support the observations that the effect of NA is secondary to its effect on the plasma FFA content. Although it was not studied, the turn-over rate of lipids may be higher in cold-acclimatized animals. In conclusion, the similarity in the magnitude of the non-shivering thermogenesis in both acclimatized groups suggests that its cold-induced elevation is not a general phenomenon in cold-acclimatized mammals.

Zusammenfassung. Der kalorigene Effekt des Noradrenalins wurde bei *Lemmus lemmus* L. untersucht. Die Hälfte der Tiere wurde bei Kälte (0 °C) und die andere Hälfte bei Wärme (30 °C) akklimatisiert. Beide Gruppen zeigten nach NA-Injektion Übereinstimmung auch hinsichtlich der freien Fettsäuren.

R. HISSA

University of Turku, Zoophysiological Laboratory, Turku 2 (Finland), 2 September 1969.



Metabolic response of cold-acclimatized (0 °C) and warm-acclimatized (30 °C) lemmings measured at 5 ° and at 28 °C. (1) Open bars are the control values, (2) solid bars indicate metabolic rate after the injection of 0.3 mg/kg of NA, and (3) transverse-hatched bars indicate metabolic rate after blocking non-shivering thermogenesis with Inderal as measured 20 min after the application. Each bar gives the average of 7–8 measurements and standard deviations are indicated.

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Electrophysiological Evidence for the Action of Light on the Pineal Gland in the Rat

Environmental lighting exerts important effects on pituitary-gonadal functions which are in part mediated by the pineal gland, i.e. by the methoxy indoles synthesized and elaborated by the pineal[1]. Light reduces the ability of the rat pineal gland to synthetize melatonin, one of the methoxy indoles[1]. This inhibitory effect of light is mediated via a pathway involving the retina, the inferior accessory optic tracts and postganglionic sympathetic fibers from

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the superior cervical ganglia[2,3]. However, there has been no electrophysiological confirmation of the action of light on the mammalian pineal. We, therefore, set out to record the electrical activity of the postganglionic sympathetic fibers at their termination in the pineal of the rat.

Materials and methods. The experiments were carried out in 40 male Sprague-Dawley rats, 300–500 g, housed under normal lighting conditions. The rat was anesthetized with sodium pentobarbital and placed in a stereotaxic instrument. A bipolar concentric stainless-steel electrode (0.4 mm O.D., insulated, 0.4 mm interpolar distance) was inserted into the exposed pineal gland under direct visualization. The amplified electrical activity (bandpass 30–300 c/sec) was displayed on the oscilloscope screen and pen-recorded directly and after integration. Experiments were carried out in a darkened room. Photic stimuli were constant intensity (No. 4 or 8 setting of a Grass PS-2 photostimulator placed 30–50 cm directly in front of the animal's eyes), 40–50 flashes/sec for 30–60 sec. Turning on the overhead lights and the surgical lamp was also an effective stimulus which was presented for as long as 5 min. The position of the electrode tip was marked with anodal d-c current and a Prussian Blue reaction was obtained upon staining.

Results and discussion. The pineal of the rat in darkness displays a tonic level of spontaneous electrical activity ranging from 30–80 μV. Photic stimulation results in an immediate three- to four-fold depression in the level of electrical discharge (Figure 1). The duration of the response varied, outlasting the period of illumination in many cases (cf. B and C, Figure 1). The occurrence of this type of response depended upon an optimal combination of stimulus frequency and intensity. At lower frequencies (10–30 c/sec) there were flash-driven discharges during stimulation followed by a post-stimulatory inhibition of activity.

The inhibitory nature of the response to light is similar to the effects described by DODT and his collaborators while recording from frog pineal nerve or from teleost pineal organs[4–6]. However, in the rat the pineal is not itself the photoreceptor as in the lower vertebrates. We observed that the depression in electrical activity in response to illumination was prevented by covering the eyes with a strip of light-tight cloth in 7 rats. The inhibitory effect of light on pineal activity, therefore, originated in the retina and is similar to the effect of steady illumination on tonic retinal activity recorded in the optic chiasm by ARDUINI and PINNEO[7].

The role of the superior cervical ganglia in mediating the action of light on the pineal was tested preliminarily with a ganglionic blocking agent. In 9 experiments, after obtaining control records of responses to photic stimulation, hexamethonium chloride (10–20 mg/kg) was injected i.v. The immediate effect of the ganglionic blocker was a marked decrease in the level of spontaneous discharge recordable from the pineal which may have been related partially to the drop in blood pressure which also occurred. The level of spontaneous discharge increased in the 30–40 min following injection, the increases occurring step-wise with each increment triggered by the end of a period of photic stimulation (Figure 2, lower records). During this time the pineal response to light was abolished or

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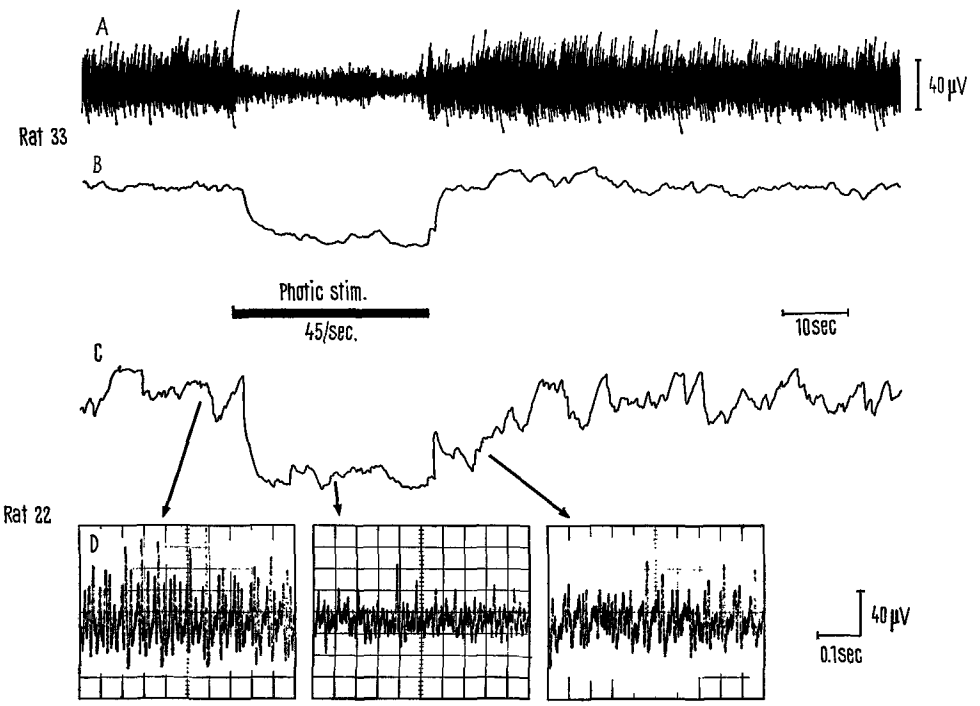

Fig. 1. Effect of illumination on the electrical activity recorded from the pineal gland of the rat. Trace A is the pen-recording of the amplified electrical activity in one rat and trace B, the corresponding integrated recording. Trace C is the integrated recording in another rat and trace D, the corresponding actual direct oscilloscope display of the amplified activity at 3 different times during the record in C: in the dark, when spontaneous activity is high; during illumination when spontaneous activity is inhibited; and after photic stimulation, as spontaneous activity returns to pre-illumination levels. Note the different response durations in the 2 rats.

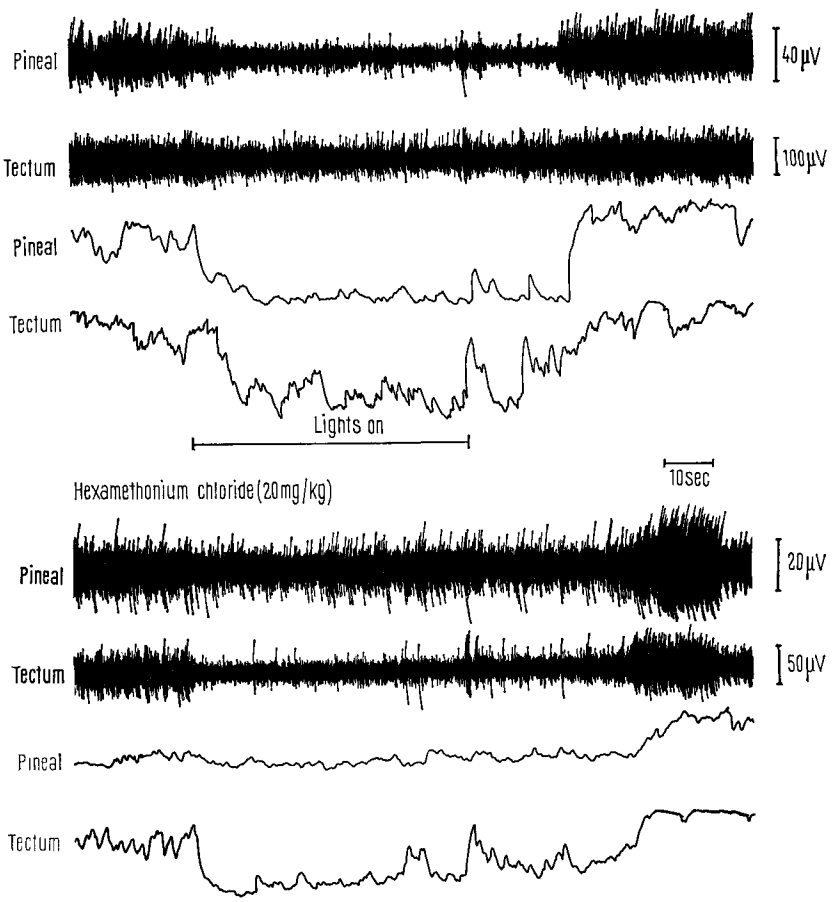

Fig. 2. Effect of illumination on the direct and integrated electrical activity recorded simultaneously from the pineal and the adjacent tectum in the same rat, before and after hexamethonium chloride. The 'lights on' and '10 sec' bars refer to all tracings. Note the differential effects of the ganglionic blocking agent on both activities: the abolition of the pineal response and the persistence of the tectal response.

markedly diminished (Figure 2). The response to light was, however, reversible, and at times it returned before the blood pressure had returned to normal levels.

Since the pineal lies so close to the visual tectum it was of interest to see if this response to light could be localized to the pineal. In 6 experiments, 2 recording electrodes were used; one was inserted into the pineal and the other was lowered stereotaxically into the tectum. Tectal discharge was also inhibited by photic stimulation (Figure 2), an effect which was only obtainable within a radius of 2.3 mm from the pineal electrode. However, the tectal and pineal effects differed, since at a time when the pineal response was abolished by the ganglionic blocking agent, the tectal response persisted (Figure 2). This difference in responses of the visual system and the pineal lends support to an action of the ganglionic blocker on transmission in the multisynaptic pathway from the retina to the pineal. Other differences between these two systems which further support the action of the blocker appeared in their respective responses to photic stimulation when the level of spontaneous discharge in darkness was low[7], as occurred with the blocking agent.

In conclusion, we have been able to demonstrate, by electrical recording from the rat pineal, a high tonic level of spontaneous activity in darkness which is inhibited by periods of illumination, thus confirming the anatomical and functional evidence for the action of light on the pineal. The inhibitory effect of light on pineal electrical activity was found to be mediated by the retina. Additionally, using a ganglionic blocking agent, we have presented preliminary supportive evidence that the pathway from the retina to the pineal involves postganglionic sympathetic fibers from the superior cervical ganglia. These results must be confirmed in ganglionectomized or decentralized preparations. Further application of the electrophysiological approach should provide useful information concerning the central neural components and their mechanism of action in mediating the response of the pineal to light[8].

Résumé. La lumière a un effet inhibiteur sur l'activité électrique tonique spontanée de l'épiphyse du rat, enregistrée dans l'obscurité. Les éléments photosensibles se trouvent au niveau des yeux. Le fait que la réponse a été bloquée par le chlorure de hexamethonium suggère qu'elle est transmise à l'épiphyse par les nerfs sympathiques postganglionnaires.

A. Newman Taylor and R. W. Wilson

Department of Anatomy and Brain Research Institute, University of California School of Medicine, Los Angeles (California, USA), 15 September 1969.

[8] Aided by NIH research grants No. NB 07884 and No. AM 08468 and a Ford Foundation Summer Fellowship to R.W.W. An abstract appeared in Anat. Rec. *163*, 327 (1969).