THE INNERVATION OF THE BAT COCHLEA

by

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For different species of bats, fixed in 5 % formaldehyd, an estimation of the number of neurons in the spiral ganglion was made. The cochleae were decalcified in EDTA and embedded in paraffin. The complete series of sections were stained with hematoxylin. On the sections through the ganglion, the number of ganglion cell nuclei was determined, with the help of an eye-piece micrometer. A 200 times magnification was used. The figures obtained with this method were corrected, with the help of Floderus' formula: $N = n.\frac{T}{T+d-2k}$ (N = the corrected estimate of the number of nuclei centres within the section; n = the observed count; T = section thickness; d = diameter of nuclei; k = vertical thickness of the smallest visible fragment). This formula helps to avoid double counting of split nuclei. After this correction the following results were obtained (table I).

Table 1. *Number of nerve cells in the spiral ganglion*

Species	No. of specimens	No. of cells	Turns of the cochlea
Rhinolophus ferrumequinum	2	15,724	3½
Rhinolophus hipposideros	5	13,674	3½
Plecotus austriacus	1	15,236	2½
Cavia porcellus	5	19,323	4½
Felis silvestris		38,760	3
Homo sapiens		29,024	2½
Talpa europaea	3	5,444	2½

The numbers of *Cavia, Felis* and man are taken from Firbas, Wicke & Volavsek (in press), Schuknecht (1960), and Guild (1932). After comparing these numbers, it can be inferred, that the number of nerve cells in the spiral ganglion depends on the dimension of the cochlea, and on the range of perceived sounds. The neurons in the basal coil are responsible for the perception of high frequency sounds. It follows that in both the mole and the bat, the number of cells in this coil corresponds to the frequency range. The Talpidae are placed by Henson in the low frequency group. Our own investigation of the mole's cochlea also indicates the special sensitivity of this animal to low sounds. A study of the distribution of the nerve cells to the different coils revealed interesting details. It was seen, that in the Rhinolophidae the percentage of cells belonging to the basal turn is a little lower than in *Plecotus,* but nevertheless much higher than in the guinea pig. In *Rhinolophus* 38 % of the total number of cells belongs to the basal coil, in *Plecotus* 48 % and in *Cavia* 22 %. These percentages depend on the size of the basal coil, on the arrangement of cells, and on the number of turns. Nevertheless the highest absolute values are found in bats for cochlea of that size. As usual the spiral ganglion does not extend to the apex of the cochlea. Therefore in *Rhinolophus* the ganglion has three turns instead of three and a half in Corti's organ.

To get a better idea of the arrangement of cells, the density of cells in the different coils was determined. On photographs the nerve cells were counted on sections through the ganglion of a known area. This revealed an interesting difference between the Rhinolophidae and Vespertilionidae. The density increases in Rhinolophidae from basal to apical. In Vespertilionidae and in one species of Phyllostomatidae (*Phyllostomus hastatus*) the density is nearly equal in the basal and the upper coil. In table II the densities per 0.01 mm^2 of the ganglion in *Rhinolophus* and in *Cavia* are compared. The high density in *Rhinolophus* is obvious. The diameter of spiral ganglion cell nuclei is smaller in bats: 6 μ against 8.3 in *Cavia.*

Table II. *Density of ganglion cells in spiral ganglion.*

Species	Ganglion cells/0.01 mm² of section through spiral ganglion Basal	Middle	Apical
Rhinolophus ferrumequinum	62	75	87
Rhinolophus hipposideros	62	76	83
Cavia porcellus	32	33 30	31

Following the procedure of Balogh, the acetylcholinesterase activity was used to show up the efferent bundle in the cochlear nerve. The method of Karnovsky & Roots was applied to demonstrate the acetylcholinesterase in the efferent fibres of the Rasmussen's bundle. In *Rhinolophus hipposideros* a lot of efferent fibres were revealed by this technique. In the sections obtained, the efferent fibres were more diffusely arranged and seemingly more numerous than in the rat or the cat. But at present it is not certain wether there is a really large number of efferent fibres in the bats cochlea. In the guinea pig the number of efferent fibres is about 500. In the cat the distribution of these fibres in the cochlea is known (Ishii & Blogh, 1968). A similar investigation of the bat's cochlea is planned. Kimura could demonstrate efferent nerve endings on the hair cells of a bat.

A preliminary examination of hair cells in the organ of Corti was made. From two cochleae of *Rhinolophus ferrumequinum* surface preparations of Corti's organ were made with help of a microdissection. The cell nuclei were stained with gallocyanin-chromealum. An eye-piece micrometer was used to count the outer and inner hair cells per mm length of the organ of Corti. Because of the small number of countings a statistical analysis could not be made. The results obtained are listed in table III. Some comparisons from the available literature are also given. The number of outer and especially of inner hair cells per mm length of Corti's organ is largest in the basal turn. This corresponds with the data of Henson (1969), who finds dense nerve fibres in the basal coil of Rhinolophidae, Hipposideridae, and of Chilonycteris. It is probable, that the ratio of hair cells to spiral ganglion cells in the basal coil is higher for bats than for other species. That would give other possibilities in coding the acoustic signals. There is still controversy about the relation of inner and outer hair cells to spiral ganglion cells. According to Spoendlin (1969) most of the ganglion cells in the cat belong to the inner hair cells. The ratio total number of hair cells to total number of ganglion cells is approximately 1 : 2 in guinea pig and man, and 1 : 3 in cat. The ratio for bats is not yet known.

Table III

Number of hair cells per mm length of the organ of Corti in different mammals

Species	No. of outer hair cells	No. of inner hair cells
Rhinolophus ferrumequinum	454 basal	196 basal
	453 middle	163 middle
	370 apical	150 apical
Cavia porcellus	346 basal	106 basal
	365 2nd turn	101 2nd turn
	459 3rd turn	133 3rd turn
	257 apical	70 apical
Felis silvestris (cf. Schuknecht, 1960)	415	120
Man (cf. Bredberg, 1968)	290 basal	80 basal
	525 apical	115 apical

Finally the numbers of nerve cells in the spiral ganglion and in the cochlear nuclei are compared (table IV).

Table IV

Number of neurons in the spiral ganglion and in the cochlear nuclei

Species	No. of neurons in the spiral ganglion	No. of neurons in the cochlear nuclei
Plecotus	15,236	40,000 (Hall, 1969)
Macacus	31,247 (Gacek & Rasmussen, 1961)	88,000 (Chow, 1951)

The ratio of approximately 1 : 3 is the same in ultrasound sensitive and echolocating bat as in the monkey. According to Hall (1967) this ratio in whales is 1 : 5 to 1 : 8. As it is emphasized by Lütgemeier (1962) and Zvorykin (1959) the subcortical parts of the auditory pathway (like oliva superior and colliculus inferior) are extraordinary well developed in bats. Probably the neurophysiological correlation of the ability of echolocation can be seen in these central parts of the auditory system. On the other hand the ear apparatus and the peripherous parts of the auditory pathway are adapted for the perception of ultrasound.

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