Outline of a Cybernetic Working Hypothesis of Cochlea Based on Experiments

A review of theories of hearing available so far shows that they do not explain a considerable number of physical properties of the ear. Some of the important unanswered questions are: Logic of design of all parts of the cochlear partition and their performance, difference in relative elasticity of the parts of the cochlear partition, frequency selectivity, sensitivity to frequency shift, similarities in audiograms of related persons, diplacusis binauralis, intensity sensitivity as function of frequency, effects of a localized lesion of the basilar membrane, influence of age on upper frequency limit and on sensitivity, sufficiency of deflections to cause a sensation, masking, critical band of masking and of beats, quantization of auditory sensations, acoustic trauma regarding width of damaged band as well as transversal and longitudinal localization.

The knowledge and understanding of the exact design and performance of the hearing instrument is a precondition to a well founded theory of hearing. As, however, interaction and function of the many different parts of the inner ear, which instrument constitutes the most important and very complex portion of the hearing organ, is still rather obscure, detailed investigations on the inner ear of water buffalo were carried out. The inner ear of *Anoa bubalis* is very similar to that of man. The experiments established the exact interaction of all parts, and physical data which permit an explanation of the performance of the inner ear, as well as of the phenomena cited above and of further ones, without far-fetched arguments or postulation of obscure analizing mechanisms.

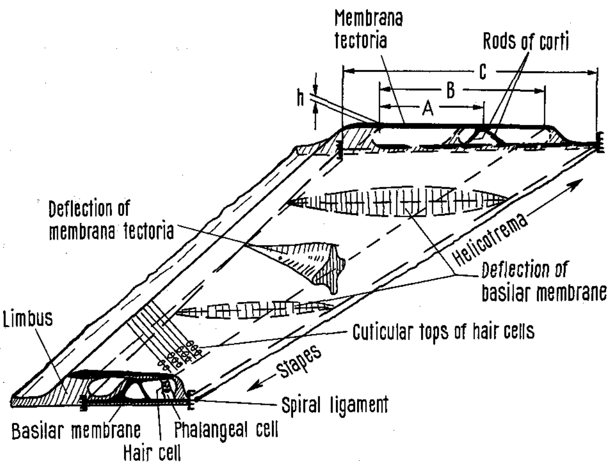

Fig. 1. Schematic drawing of a cybernetic model of the instrument in the cochlear partition of the inner ear (excluding Reissner's membrane), which has been developed with the help of the results of the experiments. Deflection of membrana tectoria has been shown, and follows the direction of the reinforcing fibers in the tectoria, which are inclined at about 20°, as well as the shifted arrangement of the transducers (cf. lower part of drawing). The foundation of the system (basilar membrane) has been drawn quasi clamped on the side of the limbus spiralis and at the spiral ligament on the other side. It is seen that the deflection of the basilar membrane, which has been shown in an exaggerated way, increases with the width of the basilar membrane. The span of the basilar membrane (C), and of the membrana tectoria from its place of attachment to the limbus spiralis to the point where the pillars meet (A) and its total span (B) increase continuously from stapes to helicotrema. Vice versa the thickness (h) of the tectoria decreases in the same direction (cf. also curves for A, B, C, h, and w in Figure 2).

The experiments show the inner ear, and in particular the cochlear partition as cybernetic model, the design and performance of which may be briefly described as follows (Figure 1).

The oscillations of the endolymph are picked up by those narrow, oblique segments of the tectorial membrane which possess corresponding natural frequencies. Due to the many oriented reinforcing fibrils, the tectoria has anisotropic mechanical properties and its segments behave similar to the reeds of a reed-type frequency meter. The natural frequencies of the narrow segments of the tectoria as derived from the experiments are in keeping with observations on the properties of the ear. An evaluation of the results of the experiments with the help of theory of oscillations explains inter alia phenomena, the origin of which was so far obscure.

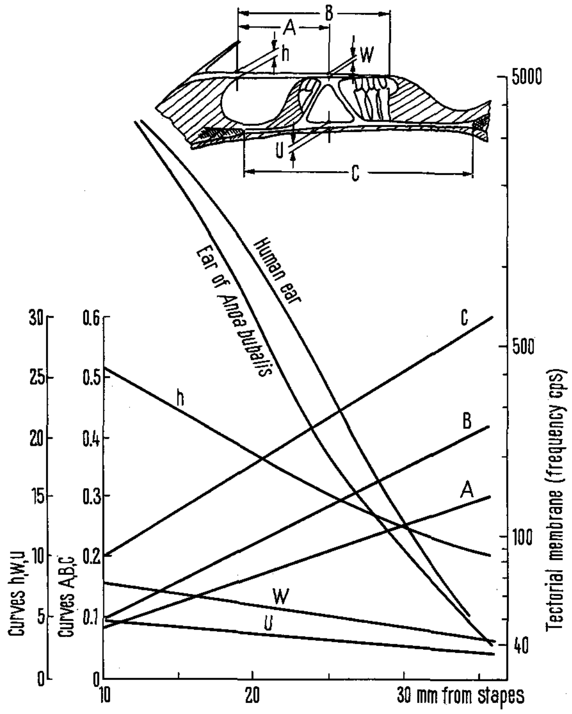

Fig. 2. Dimensional changes of some important parts of the instrument within the cochlear partition as a function of the distance of the place of measurement from the stapes.

The abscissa indicates the distance from the stapes. On the left ordinate dimensions are shown in micra for the thickness of the tectoria at its place of attachment (h), for its thickness above the junction of the pillars (w), and for the thickness of the basilar membrane between the feet of the pillars (u). The second ordinate on the left gives dimensions in millimeter for the span of the tectoria between limbus and junction of pillars (A), total span of the tectoria (B), and span of the basilar membrane (C). The continuous curves demonstrate the gradual change of dimensions between the stapes and the apex of the cochlea.

The ordinate on the right side gives the frequency in cps for natural frequencies of the tectorial membrane of the water buffalo, which have been determined during the investigation. For comparison the frequency curve for the human ear has been shown. It is seen that the curve agrees well with that of the human ear. It is noted that the ear of water buffalo favours frequency selectivity in the lower frequency range. This property of the inner ear of *Anoa bubalis* agrees well with findings during the experiments regarding its outer ear.

The tectoria is connected to the stereocilia which bridge the gap to the reticular lamina. These transmitter pins act on the cuticular plate which closes the upper side of the hair cells, and this diaphragm piston displaces the cytoplasm of the transducers and strains the fine nerve endings at their lower side.

The transducers are mounted in a lattice girder which consists of lower and upper rigid plate (basilar membrane and reticular lamina), the first one supporting the lower side of the transducers by means of the phalangeal cells, and the second one holding the upper rim of the transducers. These plates are connected by the rows of pillars towards their center, and at the edges by border cells and cells of Hensen. The 2 outermost transducer rows are shifted relative to the first and to the second transducer row, and this angle of shift corresponds to the oblique arrangement of the reinforcing fibers within the tectorial membrane. This contributes to the precision of the instrument. Tuning of first and of second order neurons and behaviour of synaptic connections further enhance the analising properties of the instrument described.

The experiments established 132 essential dimensions of parts as function of the distance of the place of measurement from the stapes, and some of the most important dimensional changes of the instrument along the cochlear partition, as well as natural frequencies of the tectoria of *Anoa bubalis* determined during the investigations and compared to the frequency function of the human ear, are shown in Figure 2.

Zusammenfassung. Basierend auf eingehenden Versuchs- und Messreihen am Hörorgan des Wasserbüffels (*Anoa bubalis*), dessen Innenohr dem menschlichen nahezu gleicht, wird ein kybernetisches Modell des Hörinstruments geschildert, das eine einfache und widerspruchslose Erklärung der Eigenschaften des Ohres gestattet.

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Changes in the Lumen of Coronary Vessels under Oligemic Hypotension

A number of papers describe the study of myocardial blood supply under oligemic hypotension[1–8]. Nevertheless data available are not sufficient to reveal whether active reactions of cardiac vessels contribute to changes of coronary blood flow in this case. Furthermore one cannot judge from these data of the shifts in the coronary vascular bed, arising immediately after start of hermorrhage, since coronary blood flow has not been recorded until the withdrawal of blood had been completed.

The present study was intended to reveal whether the active changes of coronary vessel lumen were possible under hypotension resulting from decrease in the circulating blood volume in cats.

Method. Experiments were carried out on cats (33) anaesthetized with urethane (1 g/kg), with the thorax open, under artificial breathing. Perfusion pressure in the left common coronary artery, into which blood was impelled by a constant blood flow perfusion pump from the same animal's femoral or carotid artery, revealed changes in the lumen of the coronary arteries. The catheter for perfusion was inserted via the left subclavian artery and the aortic arch into the left common coronary artery and fixed therein by ligature. Contractile force of the left ventricle was recorded with a miniature strain gauge similiar to one described elsewhere[9]. The strain gauge was sutured to the left ventricle surface. Pressure in the right atrium was recorded with a similiar strain gauge attached to the Marey tambour. Systemic blood pressure (in axillaris artery) and the coronary perfusion pressure were measured with mercury manometers. A decrease in the circulating blood volume was gained by withdrawal with a syringe of some blood from the animal through catheters inserted either into the inferior vena cava or left atrium, or femoral artery. After the systemic blood pressure had been reduced to 40–50 mm Hg (it would take 15 sec on the average) the blood removed was returned to the animal. The majority of experiments were performed on animals with denervated carotid sinuses.

Results. The decrease of circulating blood volume caused a fall of systemic blood pressure in all experiments, and in 19 experiments out of a total of 33 the increase of coronary perfusion pressure also occurred (Figure 1A), the latter having the latency of 4 sec on the average. Coronary vessel responses were accompanied with unaltered heart rate. The cardiac contractile force either increased or decreased, or did not change at all. The right atrial pressure fell in all animals.

The diminution of circulating blood volume in 7 other experiments out of a total of 33 brought about an increase of the coronary perfusion pressure with a latency of 45.3 sec on the average (Figure 1B). Coronary responses of this type were accompanied with unaltered heart rate and occurred with the shifts of systemic arterial and central venous pressure being very small or absent.

In 4 experiments out of a total of 33, the responses of both types were observed, one following the other (Figure 2).

The coronary responses of both types were observed in animals with bilateral cervical vagotomy. Atropinization did not exclude them.

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