PLACE THEORIES — ARGUMENTS FOR AND AGAINST

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Every audiologist knows the shape of the curve which connects the points of maximum displacement of the cochlear partition when it is activated by a sine wave. As von Békésy has measured, this curve shows a gradual rise up to a certain position on the partition, behind which it decreases rapidly and vanishes. The maximum and vanishing point move towards the basal side of the cochlea as frequency increases. This frequency-place relation has given rise to the so-called place-theories of hearing, which postulate that frequency analysis is made in our ear by place detection. Indeed, every sine wave has its own place of maximum amplitude on the cochlear partition, but that does not mean that all positions have their own frequency of maximum amplitude.

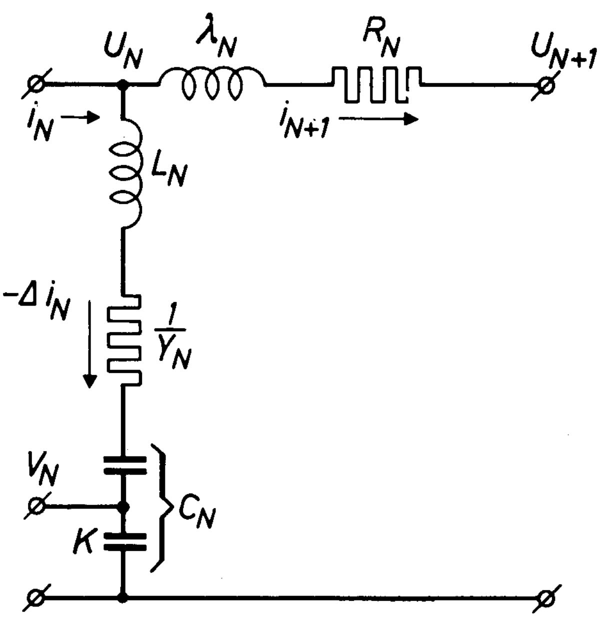

Fig. 1: The Nth segment of our cochlear model.

Many investigators have given a mathematical description of the mechanical behaviour of the cochlea and the agreement of their results with von Békésy's measurements depends on the values of the mechanical magnitudes with which they started. This agreement between theory and experiment enabled other investigators to build mechanical or electrical models of the cochlea. In most cases the latter exist of a number of parallel LCR-circuits coupled-by inductances, which means that the cochlear partition is thought to be split up into a number of small segments having their own mass, compliance and friction and being coupled to each other via the incompressible perilymphe. Fig. 1 shows such a segment together with its coupling element in an electrical model that we have built [1]). The tension across the capacitance K is a measure of the displacement of the part of the partition corresponding to this segment.

As the behaviour of the middle ear at higher frequencies is not exactly known, it is not yet possible to build a middle-ear model of which we can be sure that it is accurate. Anyhow, we may be certain that our middle ear cuts off high tones in the frequency range where it is mass-controlled. We built a middle-ear model which is based on a theory of Zwislocki [2]) with a cut-off frequency of 2500 c/s. Fig. 2 shows te amplitude as a function of frequency of different segments along the partition, indicated by the frequencies which have their maximum amplitude there, with a constant pressure at the eardrum

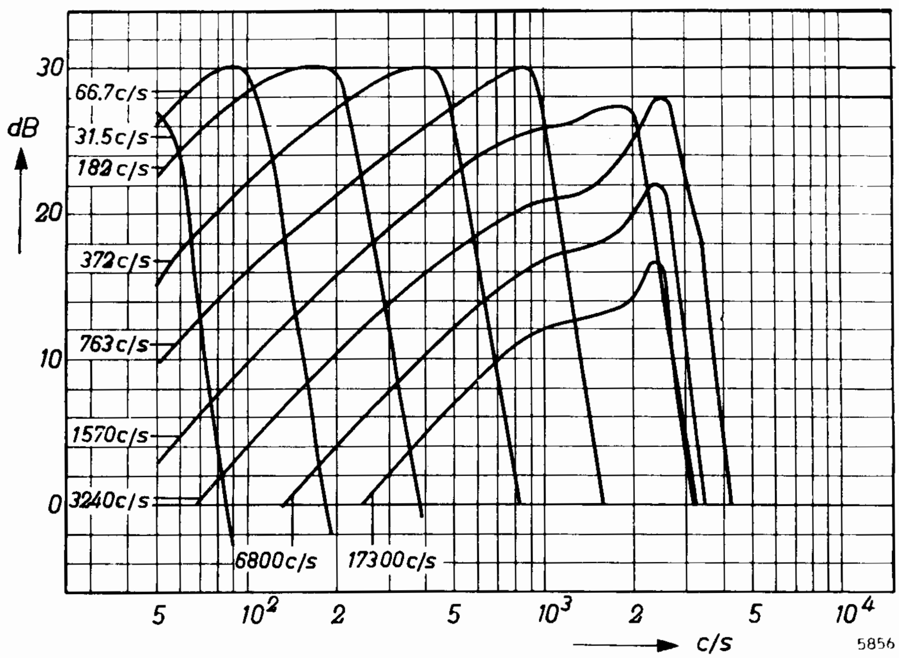

Fig. 2: The frequency characteristic of some segments, indicated by their peak frequency, measured with the combined middle-ear and inner-ear models with constant pressure at the eardrum.

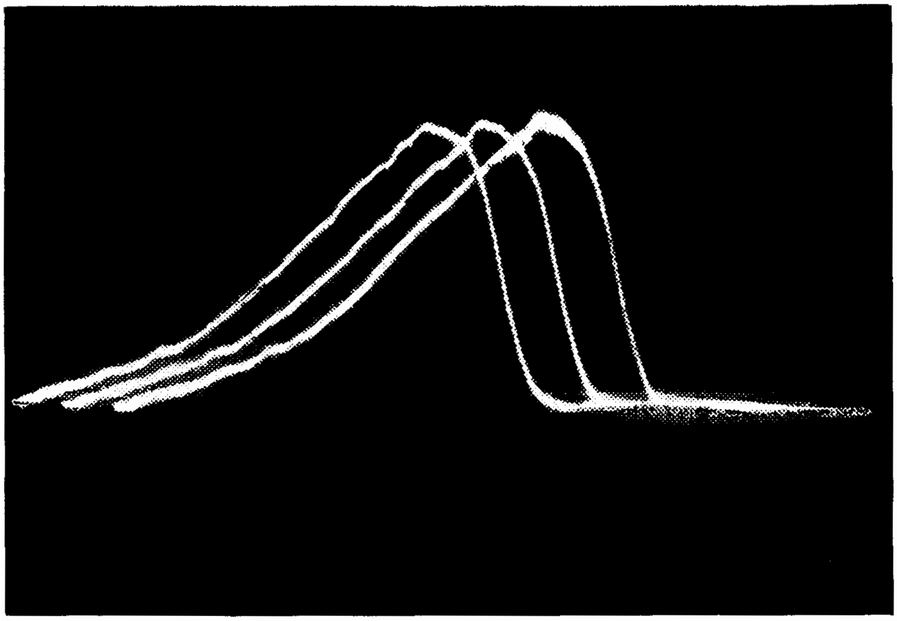

Fig. 3: From left to right: the envelope curve for a 1200 c/s tone, the same tone together with a just audible tone of 800 c/s and the same tone together with a just audible tone of 1600 c/s. The three curves are displaced with respect to each other so that they can be compared more easily.

of our combined middle-ear — inner ear model. We see that the low-frequency segments indeed have their own peak frequency, but for the high-frequency segments the peak is at 2500 c/s. This means that high-frequency information can be lost in the envelope curve of a complex signal.

The fact that place detection cannot give all information has already been proved by the residue phenomenon. The maximum in the envelope of the residue signal corresponds with a pitch which is not heard, whereas at the position corresponding to the heard pitch we find no signal.

Fig. 3 shows the envelope of a 1200 c/s masker tone together with an 800 c/s tone which is just not masked .The latter cannot be found in the picture. But at the 800 c/s segment we find indeed a superposition of a 1200 c/s tone and an 800 c/s tone.

As the haircells react only to one of the two excursions of the partition, they find there a periodicity in the signal of 400 c/s(which is the largest common divisor of the two). That we still hear an 800 c/s tone may be the result of the help of place analysis.

In the envelope curve of white noise together with a 1200 c/s tone which is just not masked we cannot find the latter. At first sight we do not even

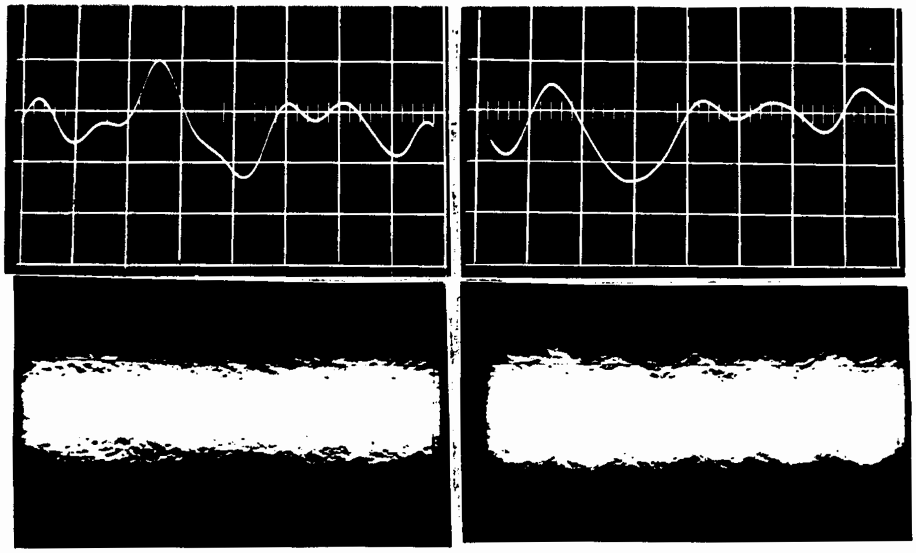

Fig. 4: The signal at the 1200 c/s segment for (left) white noise alone and (right) white noise together with a just audible tone of 1200 c/s. Above: oscilloscope triggered once; below: time exposure.

find a difference in the signal at the 1200 c/s segment if we have white noise alone or together with the 1200 c/s tone, as is shown in the upper part of fig. 4. A time-correlation measurement, for example a time exposure of the signal at the segment mentioned, reveals a clear difference between the two, as can be seen in the lower part of fig. 4.

The ability of the parrot to distinguish some human speech sounds with its very short cochlea may be another indication that the most important type of analysis of sounds lies in the time domain.

Above 4000 c/s synchronism between a sine wave and the pulse firing of a group of nerve fibres cannot exist and pitch recognition may be effected there by place detection. Moreover, the funnel action in the auditory nerve will not be accidental but will have its purpose. The intelligibility of speech sounds which are differentiated and clipped can best be explained by the conformity of their envelope curves with those of normal speech sounds, as can be seen in fig. 5.

There are reasons to believe that pitch recognition is a matter of analysis of the time function of a signal, and that timbre recognition has to do with place detection. This means that pure tones too will have a timbre, and indeed, low tones sound like "u" and high tones like "i".

Following the evolution of the ear we can conclude that sounds are recognized by analysis of the time function of the signal to which the remarkable mechanical properties of the cochlea have added the means of refinement. It may be possible that there are people in whom one of the two mechanisms

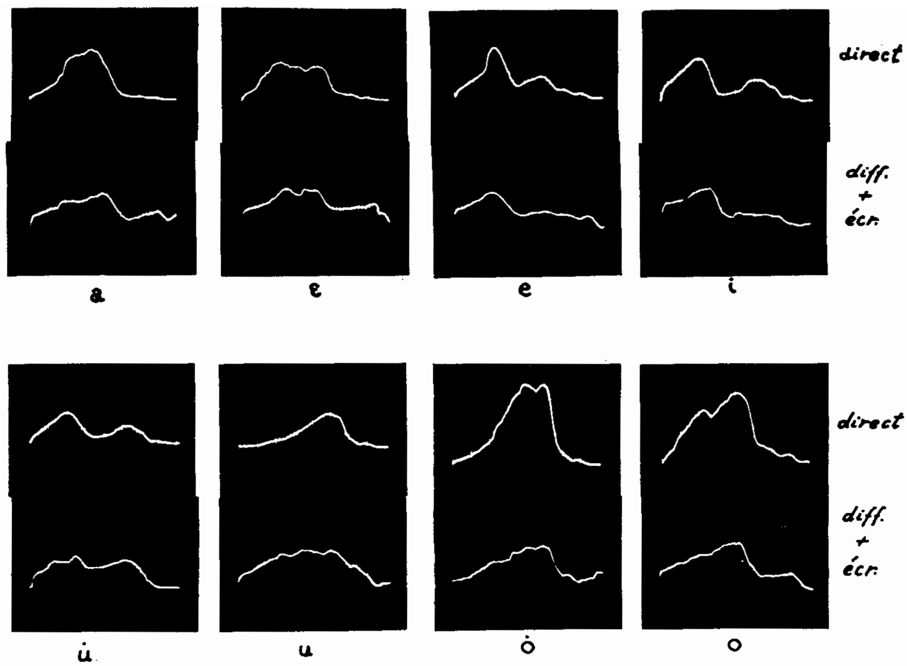

Fig. 5: Envelope curves of some Dutch vowels (above :direct; below: differentiated and clipped) measured on our inner-ear model.

is dominant, which is suggested by Enkel's [3]) distinction between linear and polar ears.

THEORIES DE LA LOCALISATION: ARGUMENTS POUR ET CONTRE

Au moyen d'un modèle électrique de l'oreille humaine nous étudions la courbe enveloppante de la déviation de la membrane cochléaire dans le cas des signaux composés, ainsi que les déviations elles-mêmes telles qu'elles se perçoivent en certaines endroits le long de la membrane. Quelques exemples sont donnés, et nous pouvons en conclure que le mécanisme dit de localisation n'a qu'une importance d'ordre secondaire pour l'analyse du son.

Literature :

1) C. Wansdronk, Philips Res. Reps. Suppl. 1, 1962.
2) J. Zwislocki, J. Acoust. Soc. Amer. **29,** 1312—1317, 1957.
3) F. Enkel, Nachrichtentechn. Fachber., **3,** 3—6 1956/57.

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DISCUSSION:

De Boer:

Dr Wansdronk showed how the progressive cutt-off of the middle ear beyond 2.500 c/s eliminates the maxima of excition found at any given **place** for a certain frequency.

In my opinion this is not an argument against the place theory, as I may have understood Dr Wansdronk meant it to be. For any given **frequency** a characteristic pattern is set up in the cochlea that may only show a decreased over-all amplitude as a result of the cutting-off.

Wansdronk:

Perhaps Dr De Boer did not understand me. I mean this:

Let us suppose that we have a complex sound having three components. Without the middle-ear cut-off we would have found the situation from fig. a, which represents the three components together with the total envelope curve. With middle-ear cut-off we would have found the situation of fig. b. That was what I meant by supposing that some high-frequency information can be lost.

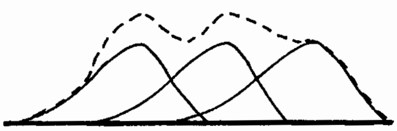

fig. a

fig. b