Dear Randy and List, Rijswijk, August 14, 2012

Randy, in your message about dichotic stimulation of the basilar membrane [BM] you formulated your remarks and asked for answers and/or comments on the following topic:

** Do the BM's in a dichotic experiment using two harmonically related tones (e.g. 200/300 hz) have the same vibration profile or are they different? **

And you apologized in the following way:

** I don't know if this is beyond the scope of this forum in which case I apologize. However, if this topic is not too crazy, I would welcome any answers, guesses or speculations. **

To my opinion your remarks are to the highest level relevant for everybody who is involved in the research of our hearing sense, so also for members of this List.
And in my view it is far from crazy.

At the risk of fluttering the dovecote I want to give you my answers and comments you asked for.
However for a better understanding of my comments I can only do this in two steps.

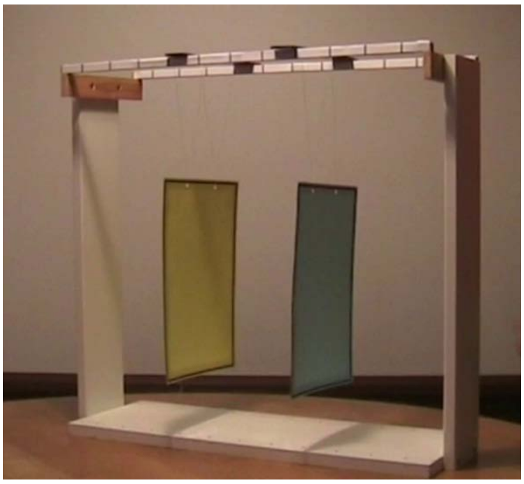
Please let me first reopen as shortly as possible that other topic issue, because it is directly related with the setup of my present answer to you.

In November/December last year we have had the discussion whether a traveling wave exists inside the cochlea or on the BM that transfers the sound pressure stimulus of a pure tone to the point where, for the corresponding frequency, the BM can resonate. Also the model that makes use of the transmission line concept was discussed then.

I on my turn presented in that discussion session in a PDF the solution of the non-stationary Bernoulli equation, that is perfectly well valid in the case of the push-pull movements of the perilymph inside the scala tympani [ST] and scala vestibuli [SV], while the in between embedded scala media [SM], filled with endolymph at rest, has substantial – and therefore not negligible – dimensions.
According to hydrodynamic rules these dimensional conditions make that the hypothesis in which both the influence of the Reissner membrane and the content of the SM can be ignored and the cochlear duct can be considered as a folded tube with only the BM as an interface in between is definitely invalid.

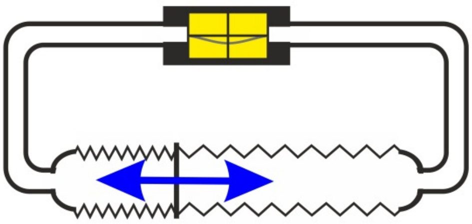
At the end of that discussion Dick Lion stated that in his opinion the local frequency dependent flexibility or compliance of the BM makes it possible that this membrane is bending outwards – a local movement of the BM towards the SV – and that this bending is the cause of evoking sound related stimuli in the BM, organ of Corti and finally via the auditory nerve to the auditory cortex.
He therefore firmly disagreed with my point of view and my theoretical work couldn't convince him (and others on this List) that the functional mechanism in the cochlear partition might be completely different from what is assumed at the moment.

Well like the well-known promoter of physics, MIT professor Walter Lewin, does in his magnificent physics courses, I have built my own demonstration equipment for clearly showing what happens on the walls of a duct in which an alternating flow in core direction is evoked.



The one experimental set-up is extremely simple, but therefore also highly convincing.
As can be seen in the right figure, to mimic utmost compliance in the ‘walls’ in one of the experiments I have hanged on thin wires in an open frame two sheets of paper that can move freely.

Between the two I can evoke an alternating flow parallel to the surfaces of the sheets of paper with by moving up and down a spatula.



And like it is shown in the left figure I have constructed a closed loop with a tube and a bellow, the latter centrally subdivided by a plate, with which I can create a push-pull flow in the tube, while in the upper branch of the tube locally a flexible yellow membrane is mounted in the wall, which registers what happens on the wall of the tube.

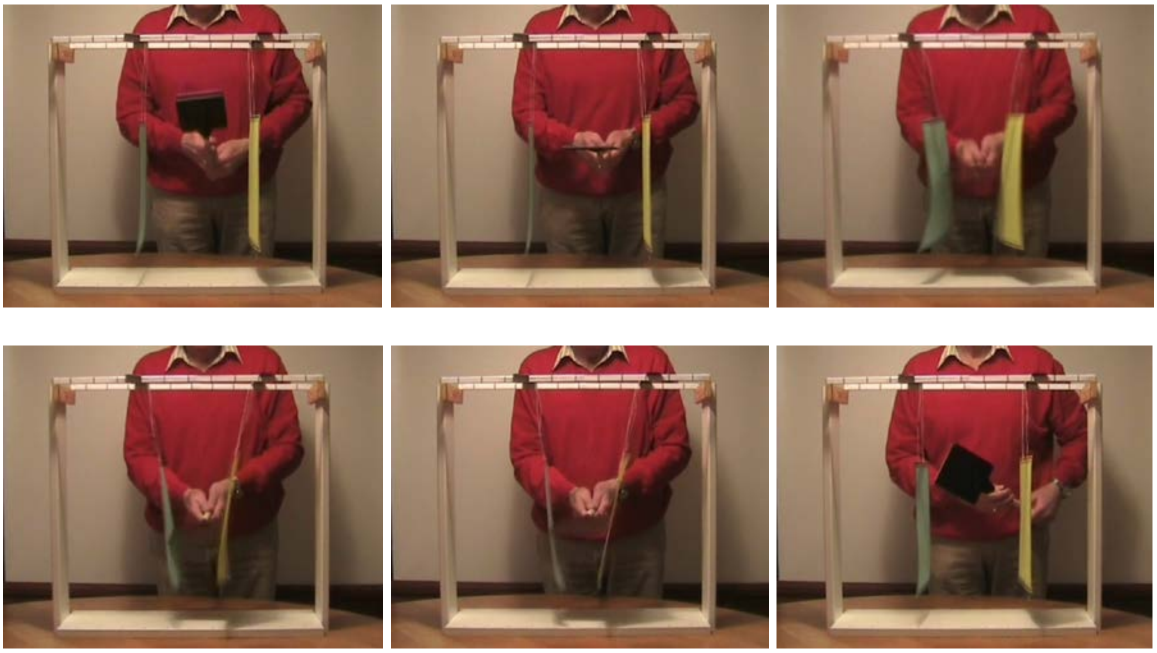
In front of the membrane a wire cross is closely mounted. Striking light from above forms a bended shadow of the wire cross on the membrane if that membrane is moving away – so inwards the tube – while during movement outwards of the membrane the shadow won’t be present because the wire cross is laid on the bending membrane.

The obtained results I found in both experiments?

The evoked motion patterns are exactly identical to what I could predict out of the theory I have presented last year on this List.

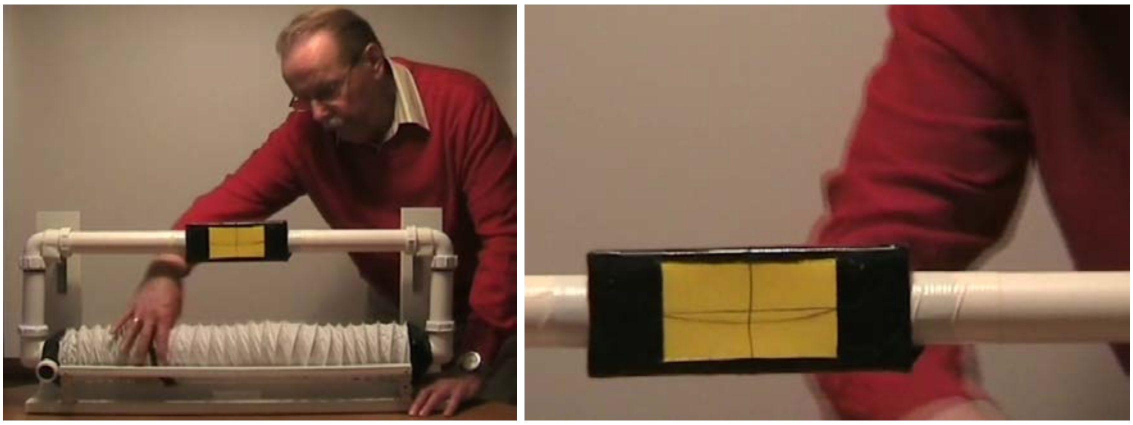
The two sheets of paper are not at all moving in outward direction as was suggested. They are moving in opposite direction, so towards the core line of the alternating flow. And under a steady alternating stimulus (with constant amplitude) they both do that with a stationary deflection on which an alternating deflection is superposed with doubled frequency.
This indicates that both sheets experience the influence of an alternating and in average lower pressure evoked in the space between the two sheets.

This behavior is shown in the following multi moment presentation:



The tube experiment also shows that the membrane in the wall is always moving inwards – so towards the core line of the tube. And superposed on a constant deflection inwards the membrane also deflects periodically with double frequency related to the original stimulus frequency.

This is given in the following impression:



Without any doubt this is indicating that at least squaring of the input stimulus plays a dominating role.

[Note: To make it even more convincing for everyone I will place a video registration of these experiments fairly soon on internet, like Walter Lewin does with his physics courses.]

For now the only clear and firm conclusion I can draw is that the suggestions on this item of Dick Lion and others are wrong. The medium in the tube is moving as a whole. And therefore these experimental results, in combination with the theoretical solution of the non-stationary

Bernoulli equation, are one of the reasons that the transmission line concept cannot play a role in it either.

The second reason for rejecting the traveling wave concept is the following:

I also have studied the different possibilities for ‘traveling waves’ in literature. And then especially I have looked at the conditions, parameters and geometrical dimensions under which such waves can exist.

In short (you don’t need expensive literature retrievals, because you can read a summary of the possible wave forms in Wikipedia) we can state that there are three forms to distinguish:

1. Rayleigh waves

Rayleigh waves are a type of surface acoustic waves which travel on solid materials.
The typical speed of these waves is slightly less than that of so-called shear waves. And it is by a factor (dependent on the elastic constants) given by the bulk material. This speed is of the order of 2–5 km/s.
For a sound signal with a 1000 Hz frequency this means that the minimal wavelength is approximately 2 meter. While the BM has a length of approximately 35 millimeter, it is impossible to make a realistic combination for application in the cochlea.
Besides that Rayleigh waves are surface waves where the thickness of the material must be relatively high related to the concerned wavelength.
With a fraction of a millimeter thickness for the BM you can forget that this type of wave can play a role in the BM vibrations.

2. Love waves

In the field of elastodynamics, Love waves, named after A. E. H. Love, are described as horizontally polarized shear waves guided by an elastic layer, which is "welded" to an elastic half space (so a very thick part of bulk material) on one side while bordering a vacuum on the other side. In literature can be found that the wavelength of these waves is relatively longer than that of Rayleigh waves.
And also these conditions and parameters are nowhere found in the cochlear partition.

3. Lamb waves

Lamb waves propagate in solid plates. They are elastic waves whose particle motion lies in the plane that contains the direction of wave propagation and the plate normal (the direction perpendicular to the plate). In 1917, the English mathematician Horace Lamb published his classic analysis and description of acoustic waves of this type.
The wave propagation velocities of the two possible modes in Lamb waves are comparable with that of the Rayleigh wave. And therefore they also don’t provide for a possible application in the traveling wave description inside the cochlea.
In other words: we also cannot make a realistic fit with Lamb waves inside the cochlea.

Of course everybody can persist in believing that until now registered auditory experimental results justify the formulated hypothesis that such types of waves can exist in the cochlea.
Then however you are forced to answer the following question:

> On what underlying physics grounds is it possible that material quantities and acoustic process parameters inside the cochlea can be altered in such a way that as a result the wavelength of 1.5 meter for a 1000 Hz stimulus in bulk perilymph fluid can be altered in less than 1.5 millimeter?

As can be seen from the Rayleigh, Love and Lamb waves the circumstances and material properties cannot provide for a scaling factor better than 0.5 from bulk material sound velocity to the concerned type of wave.
Be aware that inside the cochlea a scaling factor of 0.001 or even smaller will have to be possible. This can be considered as completely impossible.

What remains is that just as I stated before:

> **The described non-stationary Bernoulli effect, that provides for the sound energy stimulus everywhere in front of the BM, is driving the BM vibrations.**

And dear Randy this last statement above is my answer to your following remark:

** I have always wondered about what drives BM vibrations **

It is the everywhere present sound energy stimulus that drives the BM.

My following contribution will show the implication of all this for the rest of your request.

Kind regards

Willem Heerens