Responses of the Inner Ear to Infrasound

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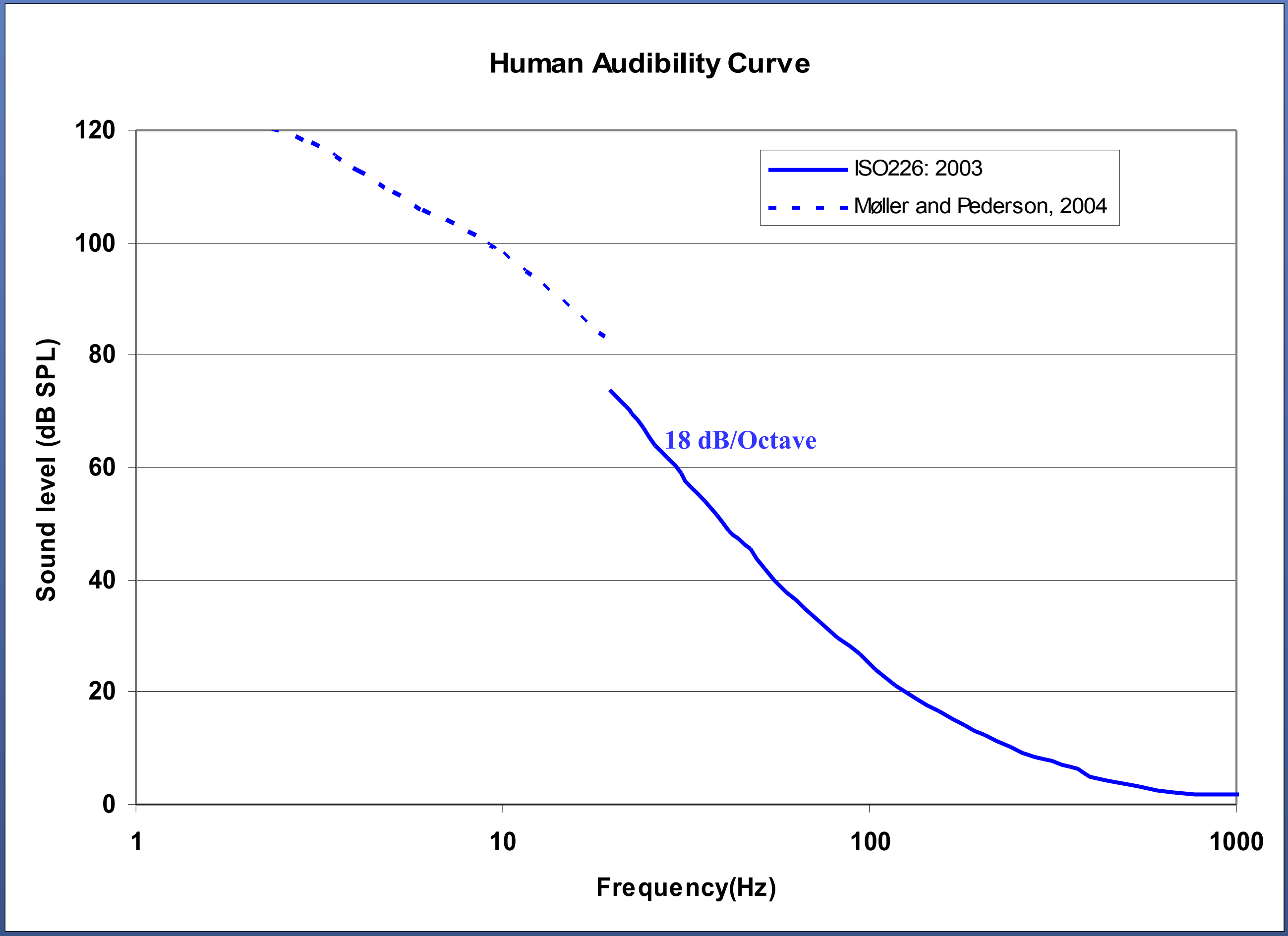
Take-Home Messages from this Talk

- The ear is sensitive and responds to low frequency sounds at levels that are not heard.

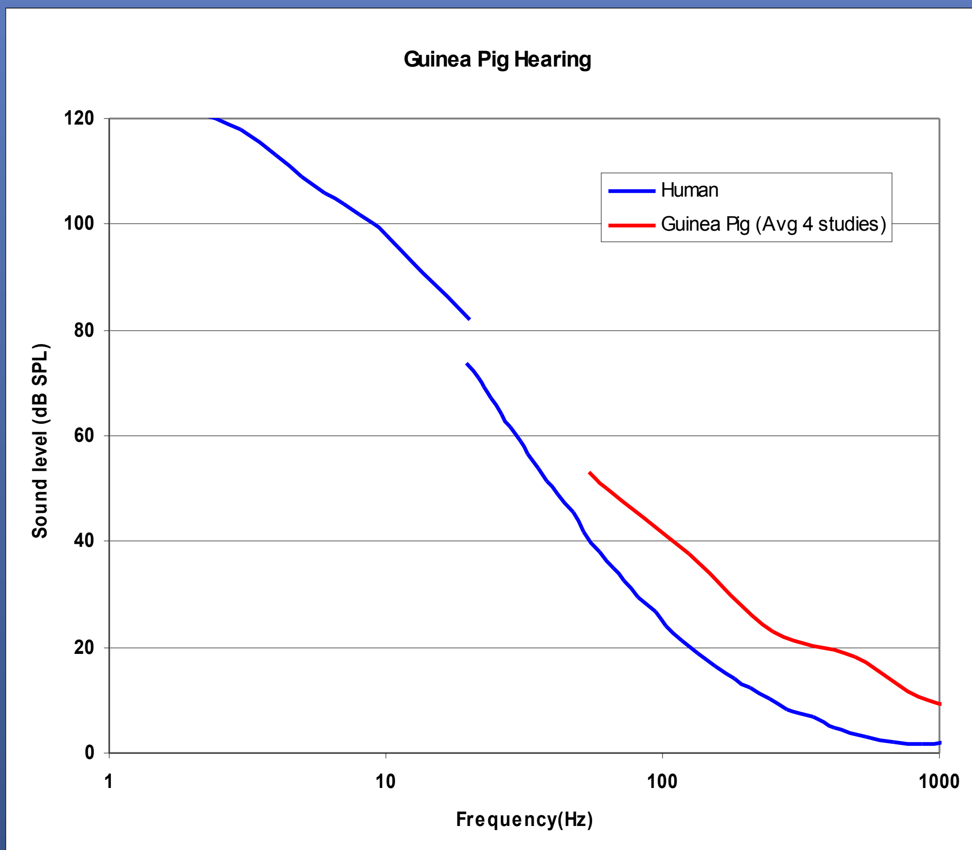
- Low frequency sounds amplitude modulate cochlear responses to higher frequency sounds. This is a biological amplitude modulation that cannot be detected with a sound level meter.

Human sensitivity to low frequency sounds



Hearing in guinea pigs compared to humans

Low frequency hearing sensitivity correlates well with cochlear length



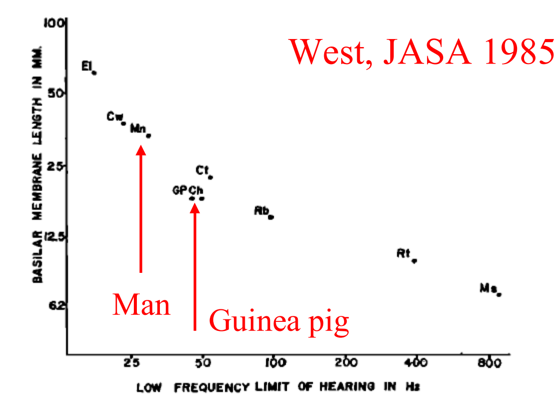
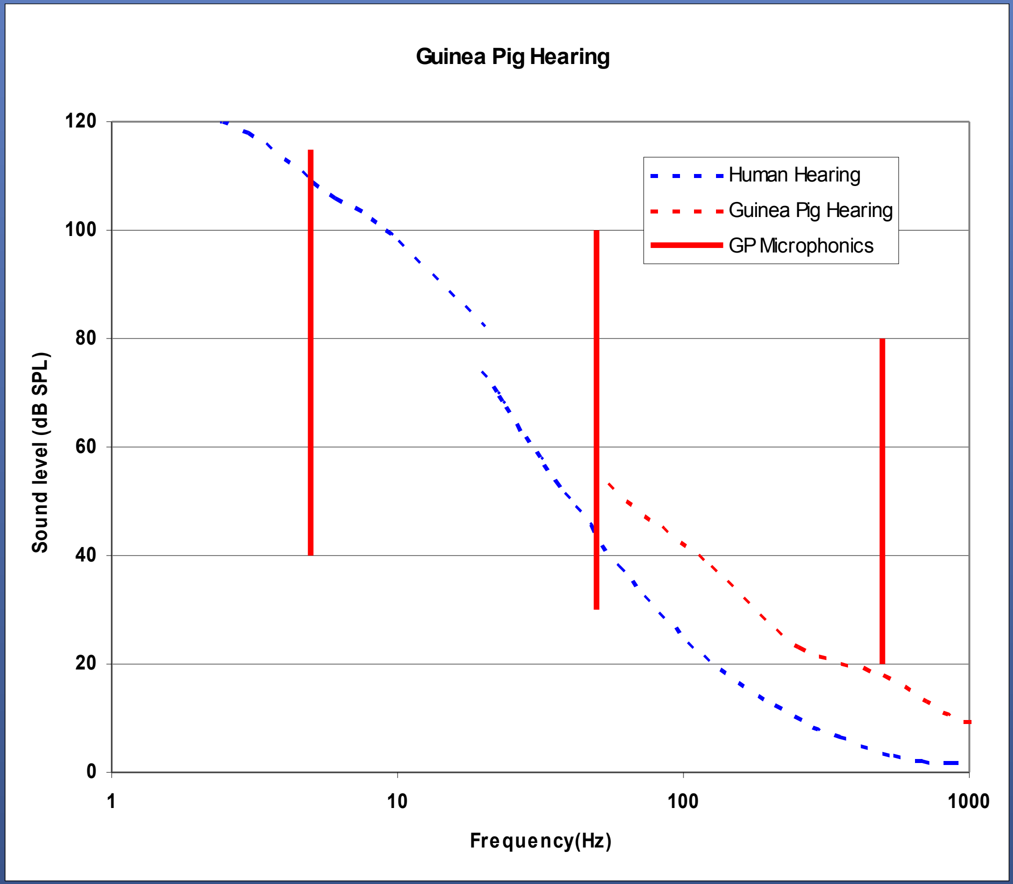


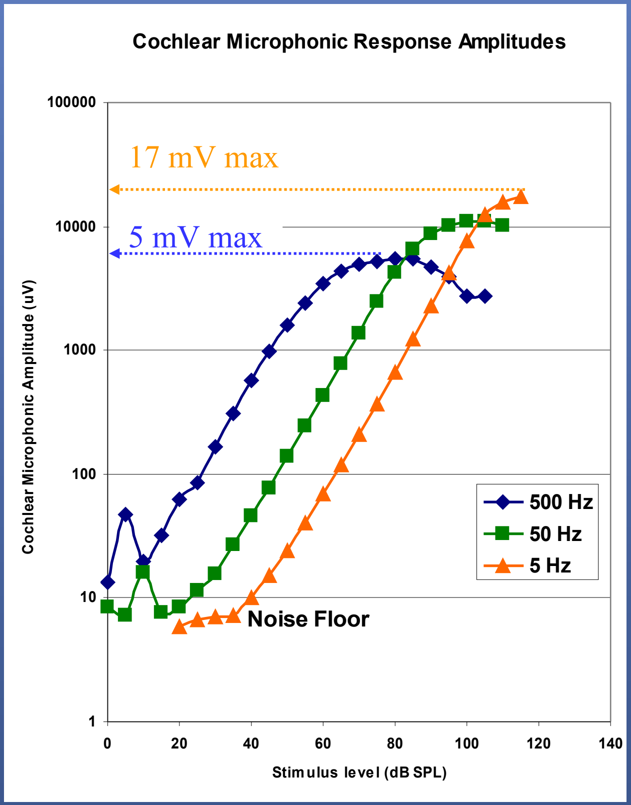
FIG. 8. Length of the basilar membrane versus the low-frequency limit of hearing for different species of ground dwelling mammals at 60 dB SPL, $r = -0.94$ ($P < 0.001$). Abbreviations: Ch—chinchilla, Ct—cat, Cw—cow, El—elephant, GP—guinea pig, Mn—man, Ms—mouse, Rb—rabbit, and Rt—rat.

The guinea pig cochlea is about half the length of the human

Guinea pigs are about 10-20 dB LESS sensitive than humans

Electrical recording from the guinea pig ear (cochlear microphonics)





Recording from scala media of the third turn of guinea pig.

Explanation – Two types of sensory cell in the Ear

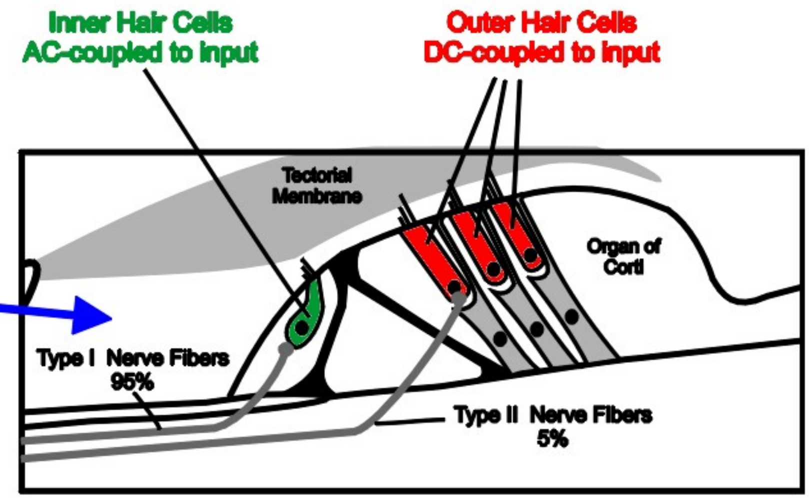


Image Courtesy of Saumil Merchant MD,
Mass Eye and Ear Infirmary, Harvard Medical School

Two types of Hair Cells in the Cochlea

Inner Hair Cells (IHC)	Outer Hair Cells (OHC)
Responsible for HEARING	Generate Cochlear Microphonics
	Hairs attached to Tect. Memb.
Hairs do NOT contact Tect. Memb.	*Respond to DISPLACEMENT
	(displacement constant with frequency for fixed input level)
*Respond to VELOCITY	DC-coupled output

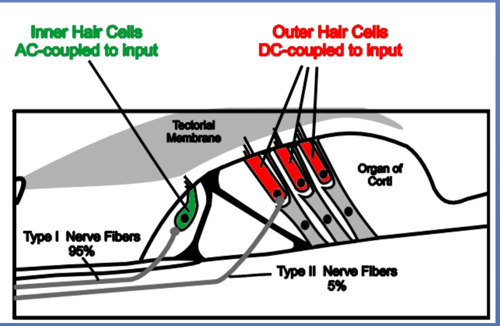
(velocity decreases 6 dB/oct as frequency is lowered)

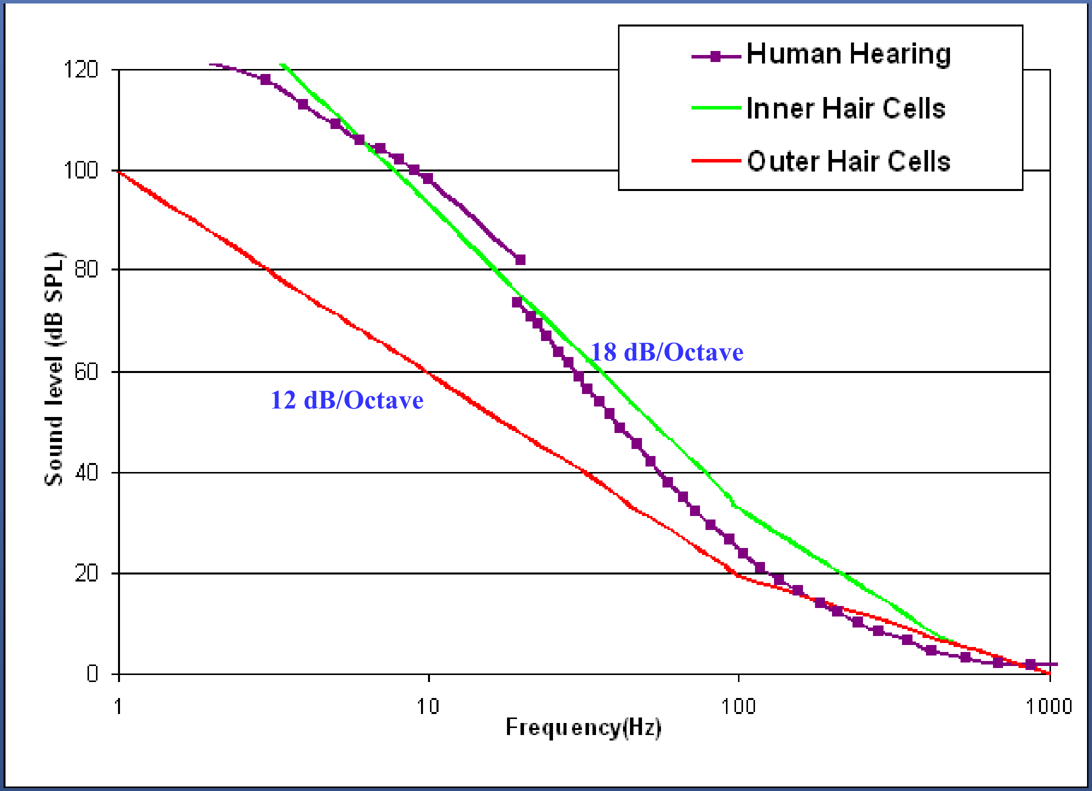
* *Based on Cheatham and Dallos, 2001*

AC-Coupled output

Calculated Hair Cell Sensitivity of Humans

Cheatham and Dallos JASA 2001;110:2034.

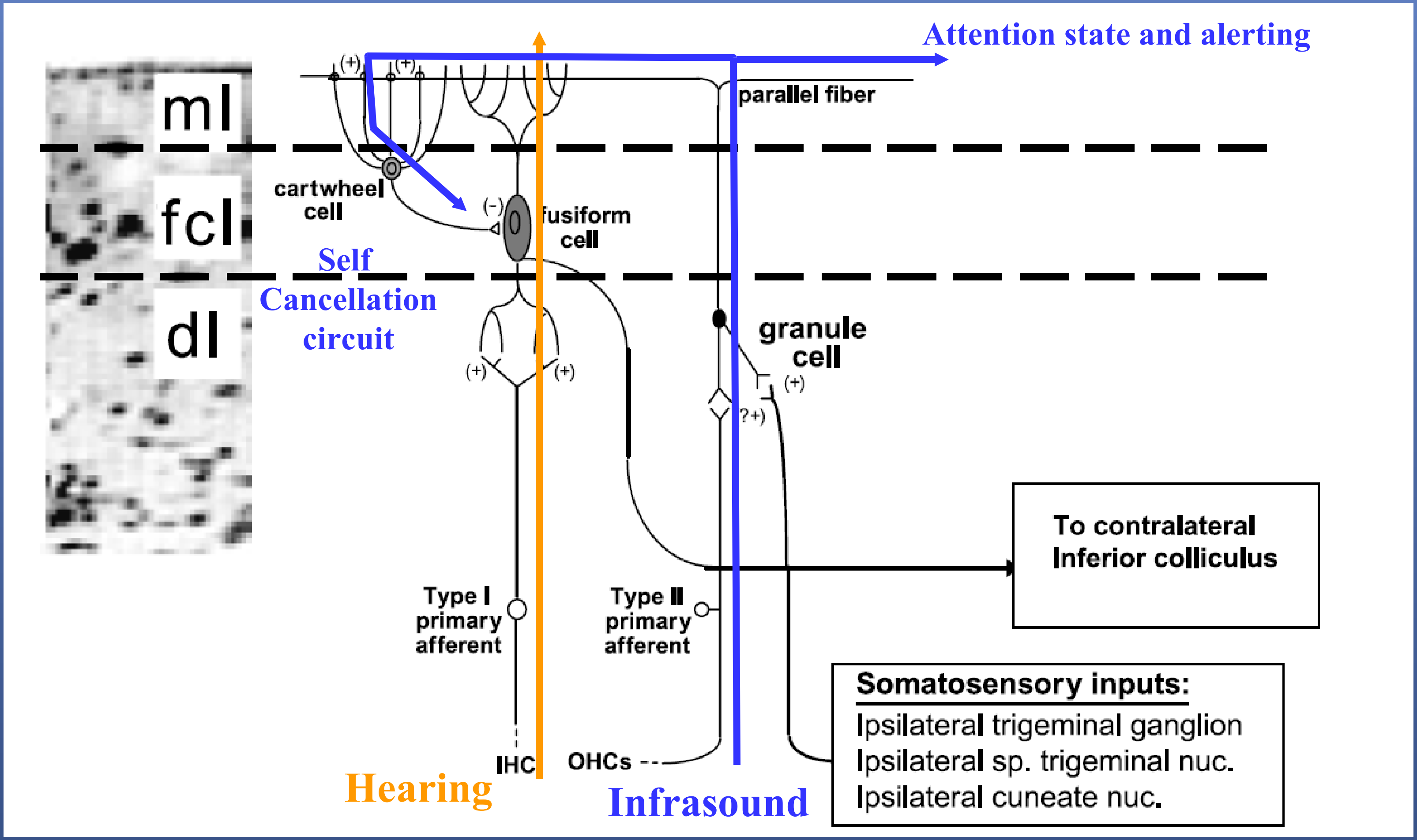




We hear through our INNER HAIR CELLS. As they are insensitive to infrasound, we don't hear the infrasound.

OUTER HAIR CELLS generate the cochlear microphonic response. They are stimulated at ~40 dB lower sound levels at low frequencies.

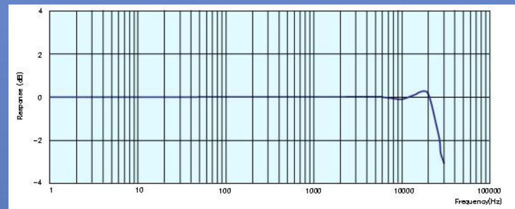
Connections within the brain



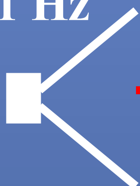
From Kaltenbach and Godfrey, 2006

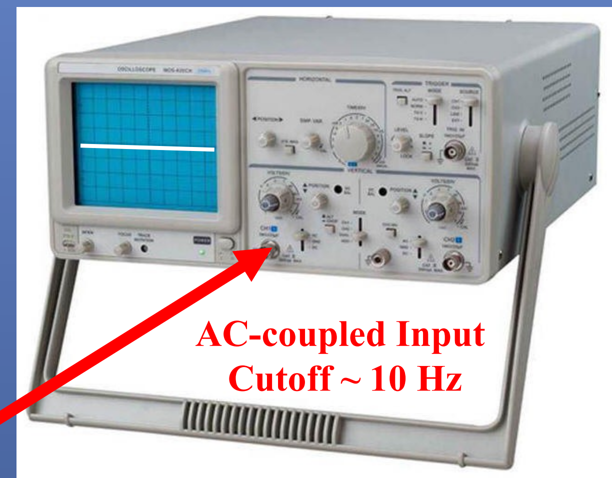
Analogy

Microphone Frequency Response



1 Hz





Does the absence of a signal on the scope mean that this microphone/ SLM is insensitive to low frequencies ?

No - as we are looking at an AC-coupled signal we cannot determine whether the SLM is responding at 1 Hz.

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HEARING RESEARCH

Low-frequency modulation of inner hair cell and organ of Corti responses in the guinea pig cochlea

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Received 26 August 1996; revised 8 February 1997; accepted 20 February 1997

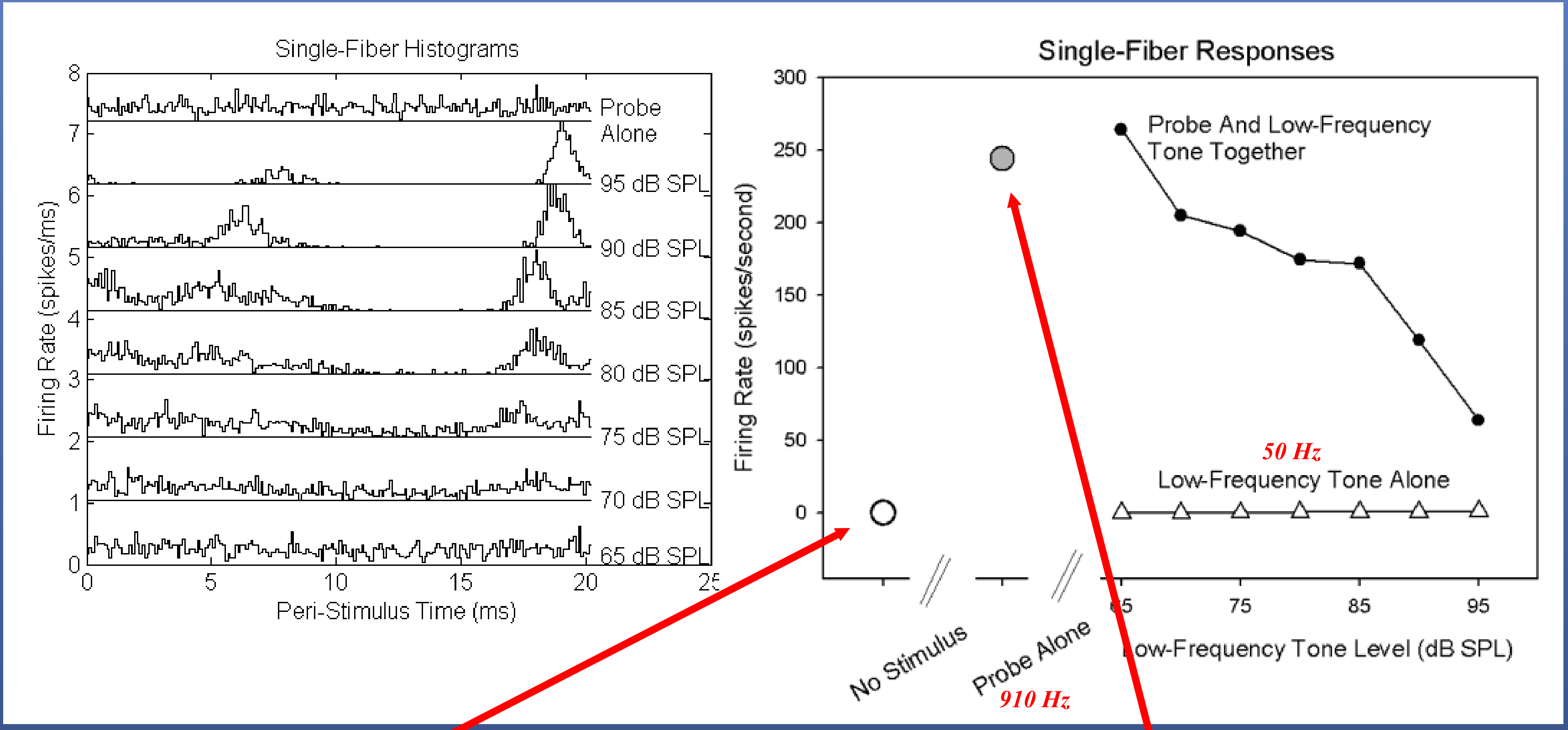
This concept is not "radical" or new

In discussion of how low frequency tones affect OHC transduction:

contribute to the bias effect. It is also assumed that biasing initially occurs prior to IHC transduction (Patuzzi et al., 1984b, 1989; Geisler et al., 1990; Russell and Kössl, 1992b; Ruggero et al., 1992; Rhode and Cooper, 1993). This is because IHCs are velocity detectors at low frequencies and are, therefore, less sensitive to the low-frequency biasing tones. Thus, at the lowest effective bias levels, the changes initiated in OHCs, and reflected in the gross CM, influence feedback and ultimately the displacement pattern of the basilar mem-

Low frequencies cause amplitude modulation of responses to higher frequency stimuli

Auditory nerve fiber responses from cat collected by Jeff Lichtenhan, Harvard Medical School



Unresponsive with no stimulus

910 Hz probe stimulates the fiber

Low frequencies cause amplitude modulation of responses to higher frequency stimuli

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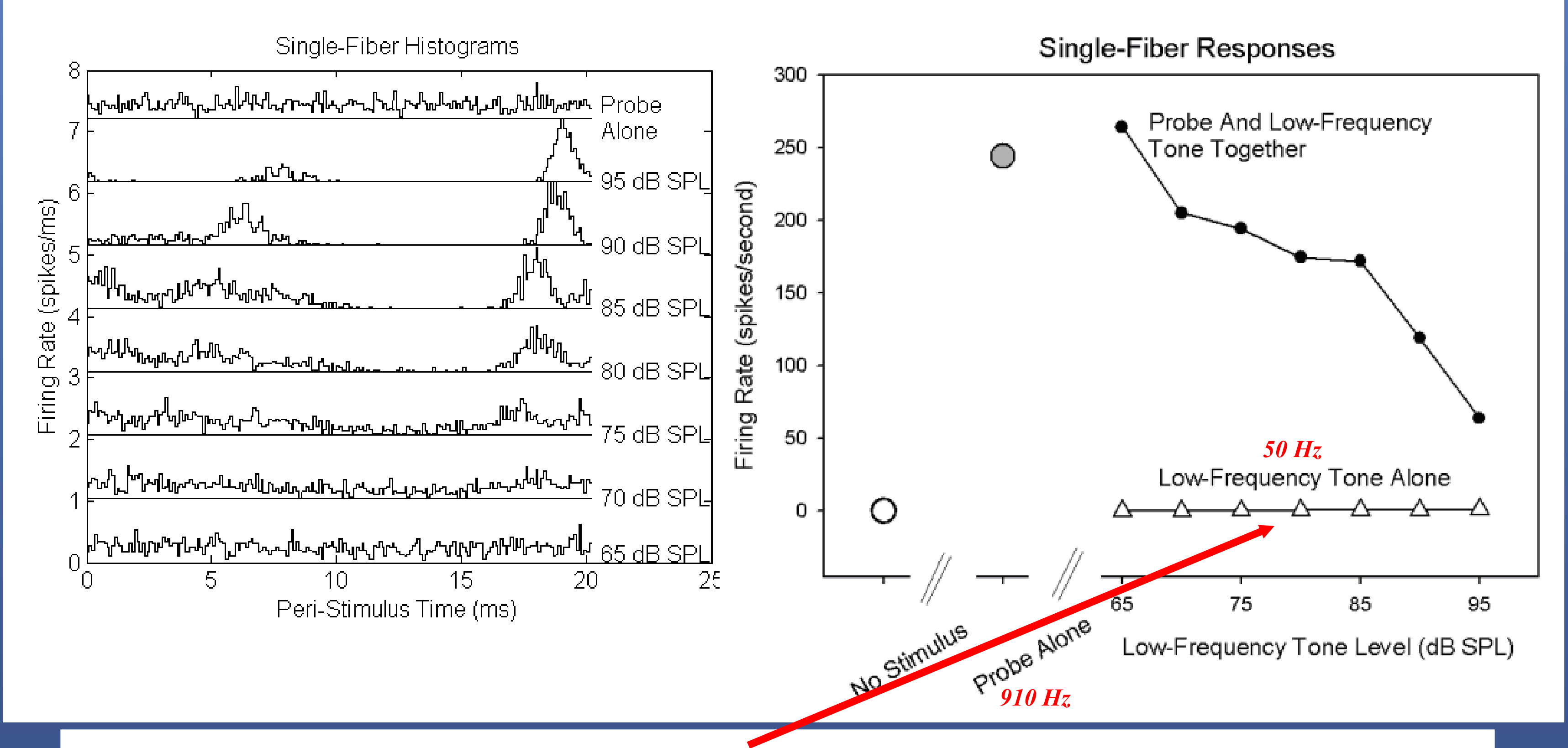

Alone, the 50 Hz tone doesn't affect the fiber at any level

Low frequencies cause amplitude modulation of responses to higher frequency stimuli

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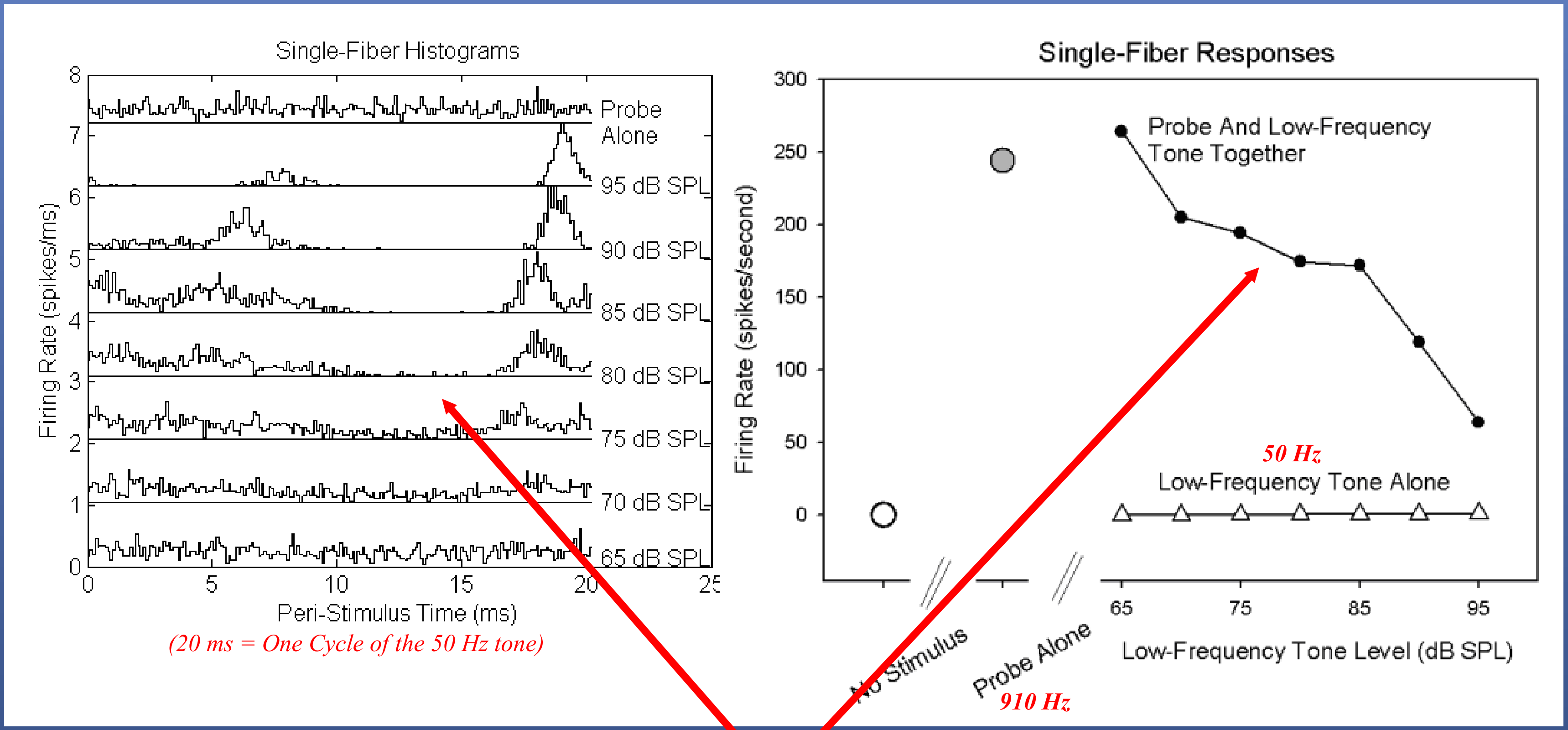
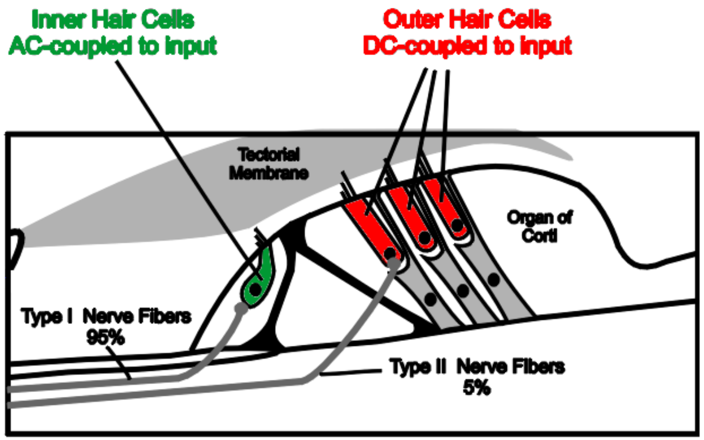


When combined, the 50 Hz tone amplitude modulates the 910 Hz responses

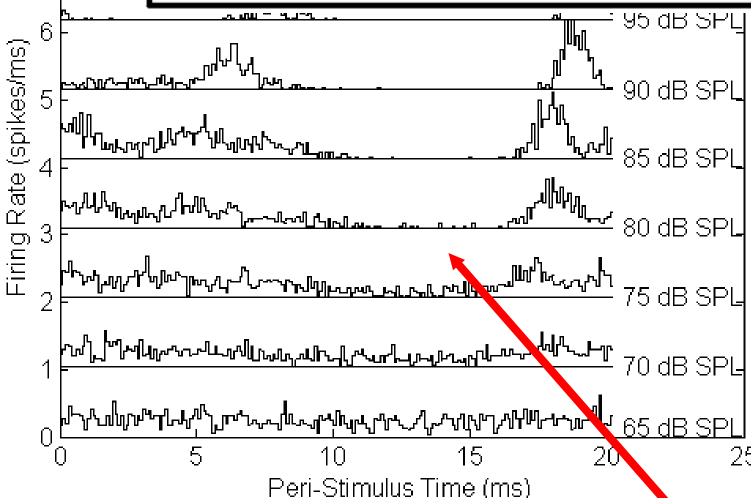
This form of amplitude modulation by sub-audible low frequency sounds is biological in origins and cannot be measured with a sound level meter

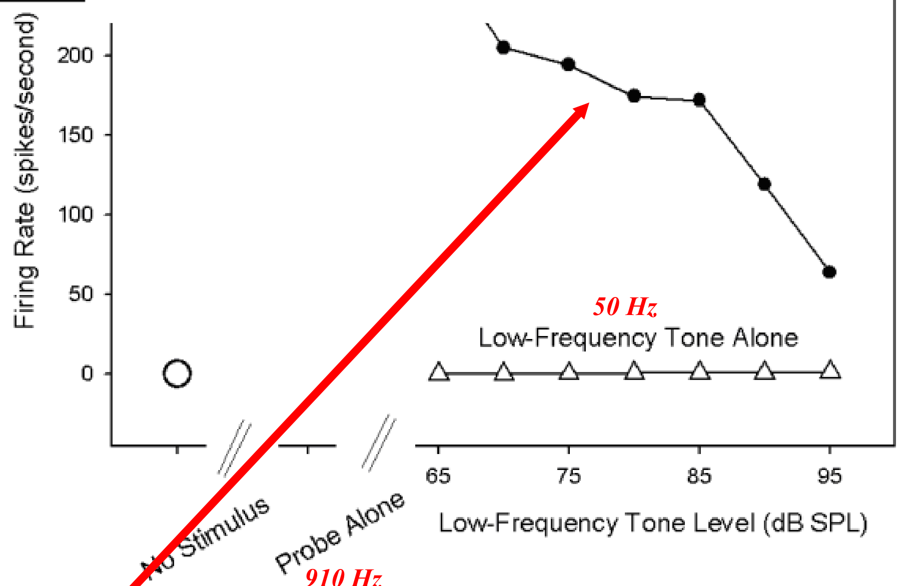
Lo … on

Audito … School



Can only get this result where IHC are insensitive to the 50 Hz tone while the OHC detect and respond to it by changing their amplification.





When combined, the 50 Hz tone amplitude modulates the 910 Hz responses

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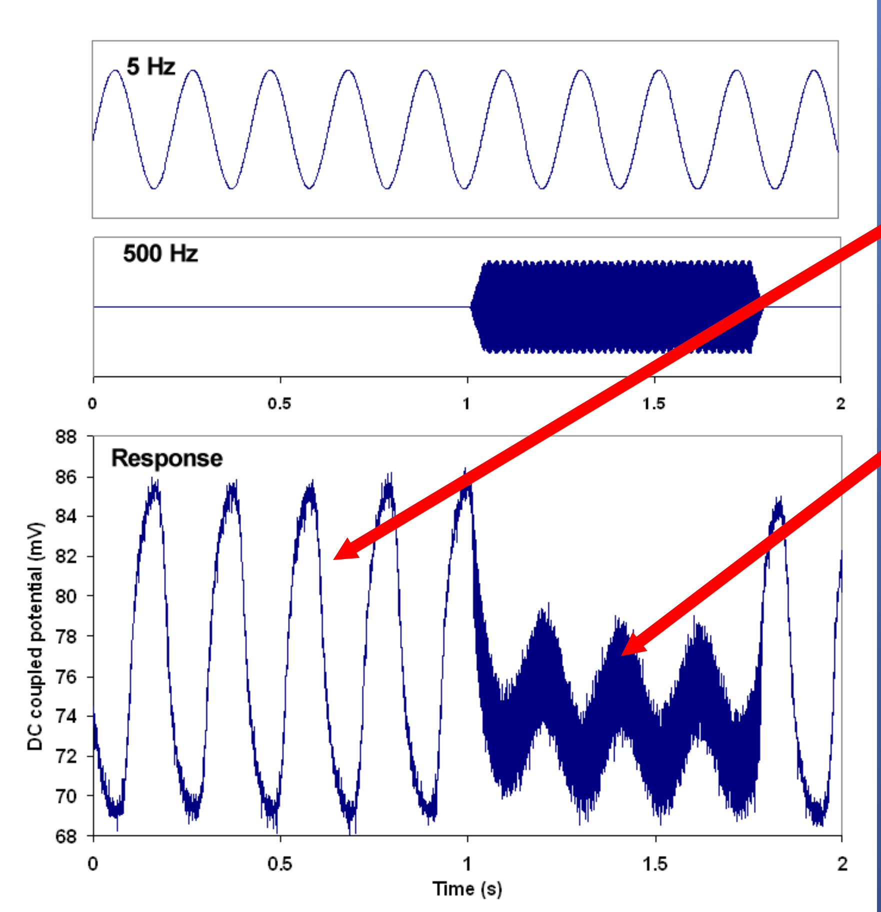
Infrasound responses are suppressed by higher frequency stimuli (i.e. sounds that are heard)



Cochlear Microphonic response (generated by outer hair cells) to a 5 Hz stimulus.

5 Hz response is suppressed by a superimposed 500 Hz tone.

Responses and sensitivity to low frequency sounds will depend on the "listening environment".

Maximum sensitivity to infrasound will occur when ambient sound levels are low.

Conclusions

- The outer hair cells of the ear are DC-coupled to movements of the sensory structure and respond to infrasound stimuli at moderate levels.
- Low frequency stimulation of the outer hair cells may be used in the brain to eliminate infrasound from hearing. It is also linked to attention state and arousal so stimulation could disturb sleep.
- Outer hair cell responses to infrasound are maximal when ambient sound levels are low.
- Low frequency sounds produce a biological amplitude modulation of nerve fiber responses to higher frequency stimuli. This is completely different from the amplitude modulation of sounds detected by a sound level meter.

Acknowledgements

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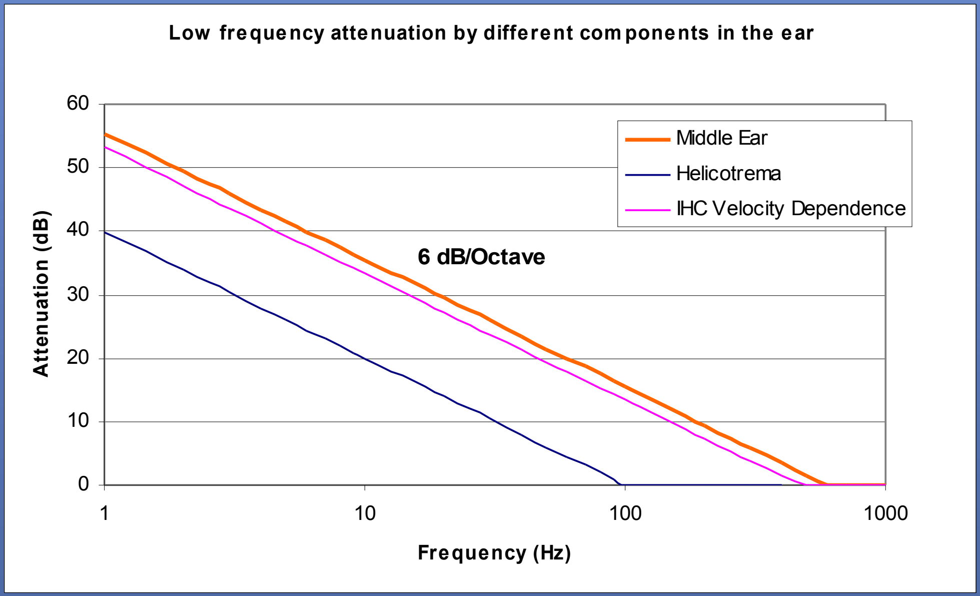
Helicotrema effects

Helicotrema in HUMAN is expected to attenuate frequencies below 100 Hz by 6 dB/octave



Plugging helicotrema in guinea pigs increases sensitivity below 100 Hz by about 6 dB/octave