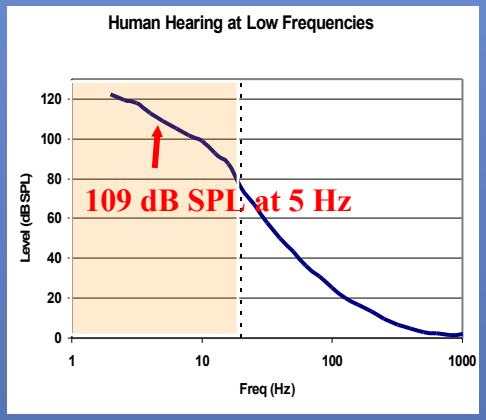
Perception-based protection from low-frequency sounds may not be enough

Alec N. Salt, Ph.D.
&
Jeffery T. Lichtenhan, Ph.D

Department of Otolaryngology
Washington University School of Medicine
St. Louis, Missouri, USA



Hearing (perception) is insensitive to very low frequency sounds

As a result, some have concluded that:

Subaudible, low frequency sound and infrasound from wind turbines do not present a risk to human health. (AWEA, CanWEA Report Colby et al. 2009)

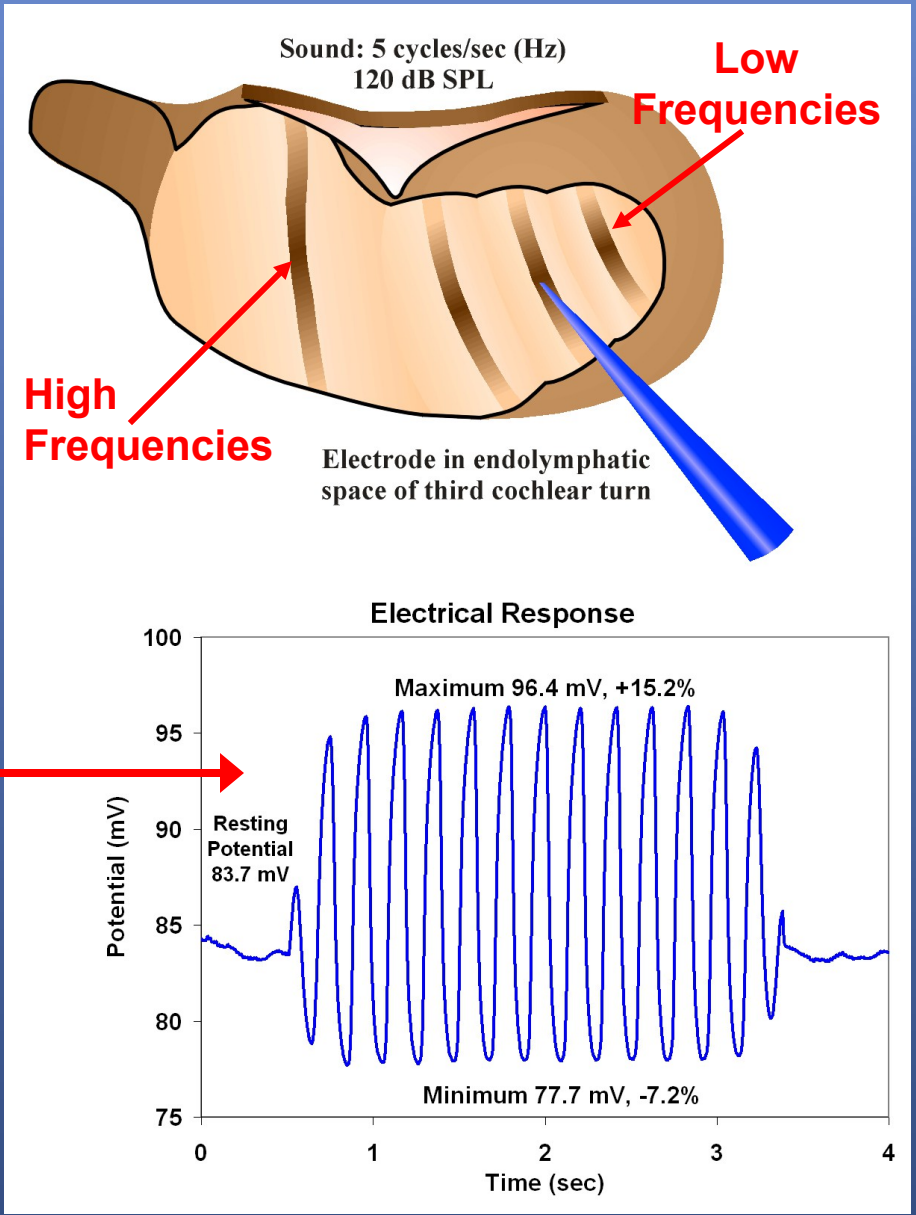
Our data show that the ear is sensitive to infrasound frequencies that are not heard. The electrical responses of the ear **can be substantially larger than to any other type of acoustic stimulation.**

Measurements from the inner ear with tonal stimuli

For most sounds, electrical responses from the ear are never larger than a few mV.

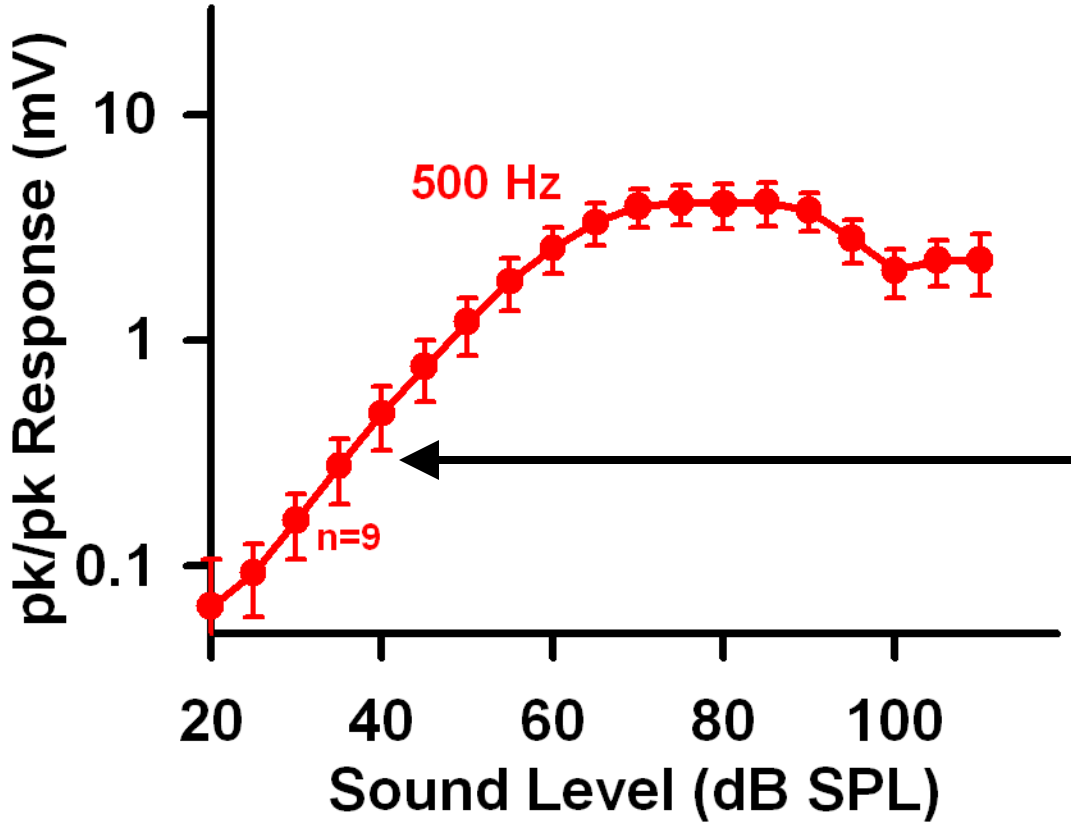
From an electrode in endolymph near the apical (low frequency) end of the ear we measure **enormous** (19 mV) electrical responses with a 5 Hz (infrasound) stimulus.

Much larger responses than with sounds in the normal audible range.



Response Amplitude with Tone Level

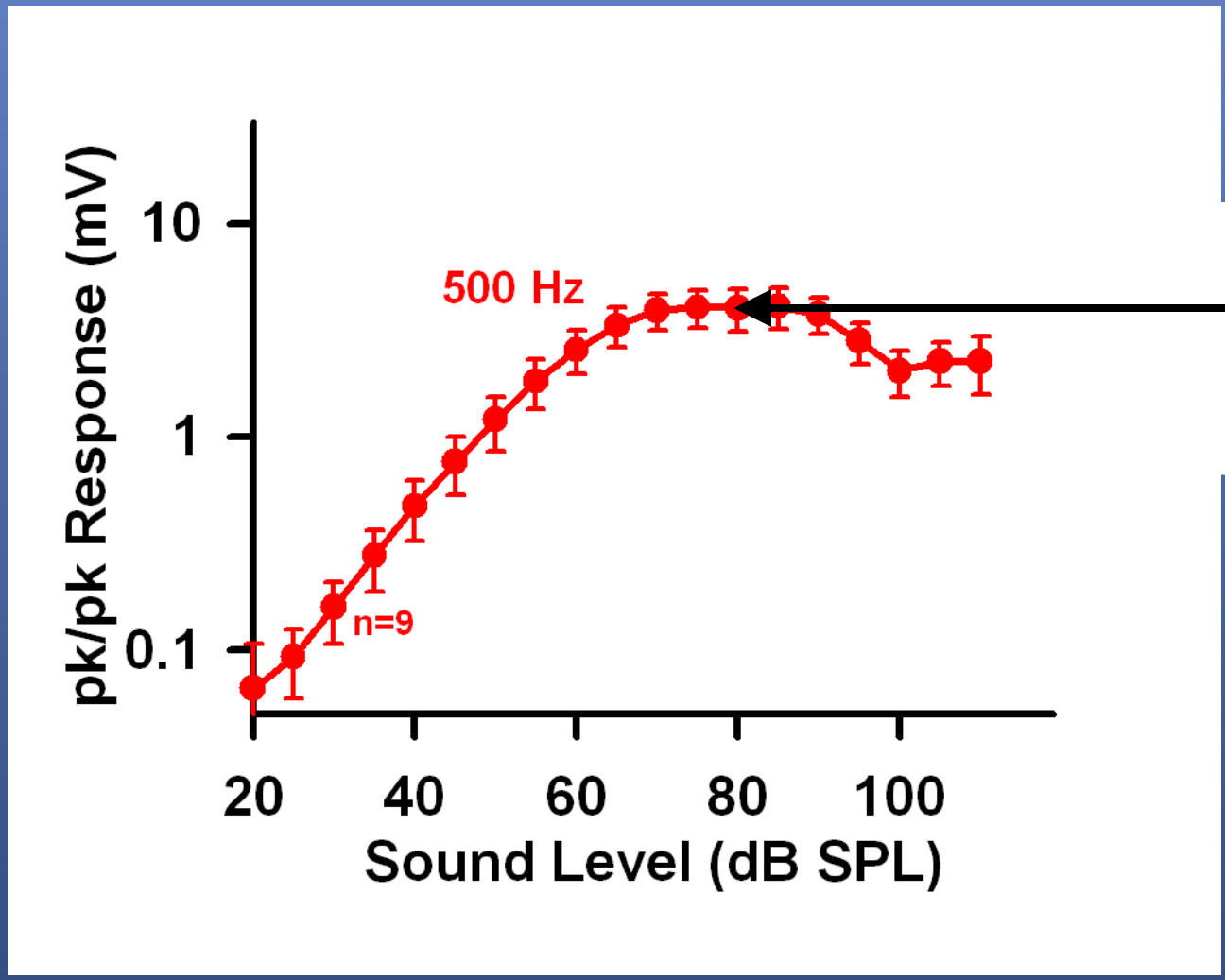
500 Hz perceptual threshold: 18 dB SPL



Linear 1 dB/dB (10X per 20 dB)

Response Amplitude with Tone Level

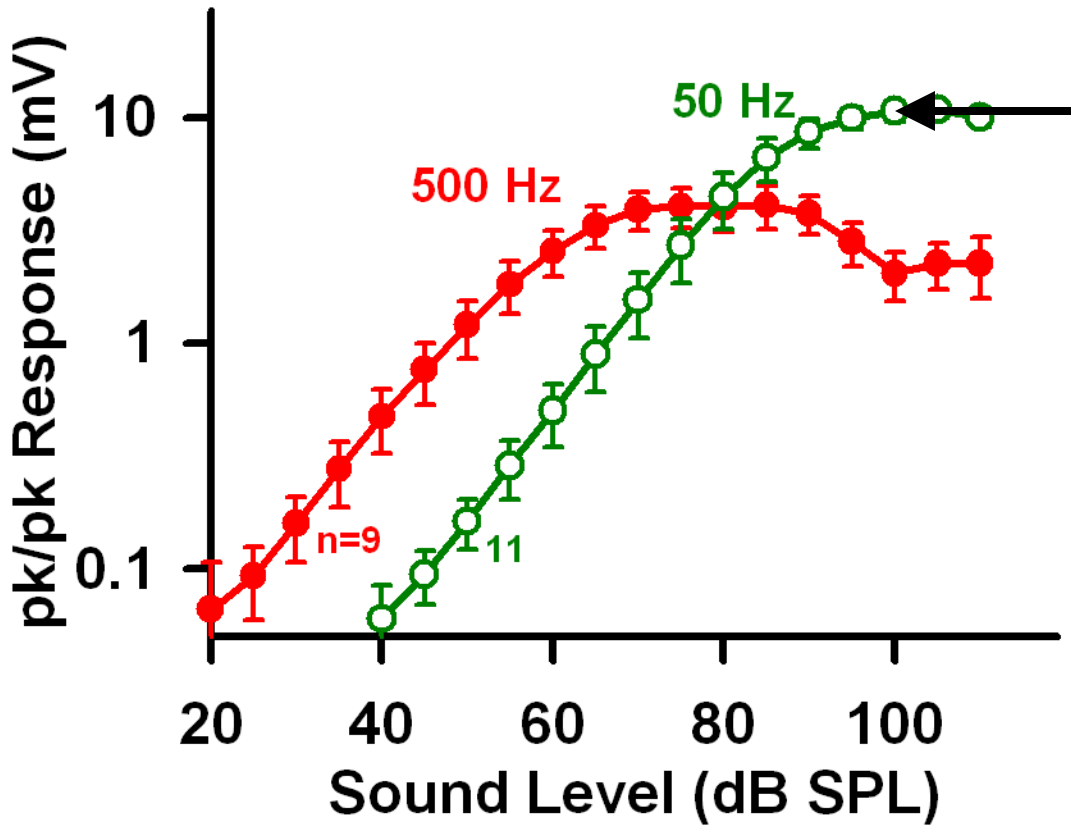
500 Hz perceptual threshold: 18 dB SPL



Responses saturate at 4 mV

Response Amplitude with Tone Level

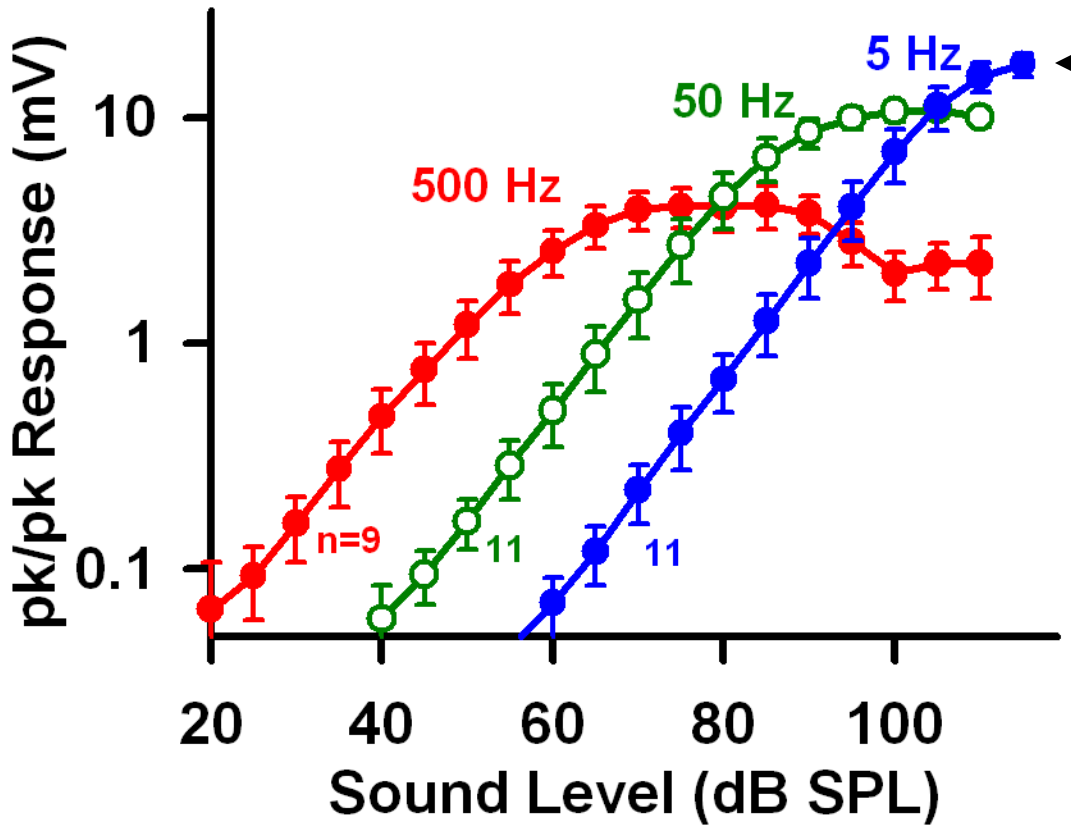
50 Hz perceptual threshold: 53 dB SPL



Responses saturate at 10 mV

Response Amplitude with Tone Level

5 Hz perceptual threshold: ~ 124 dB SPL

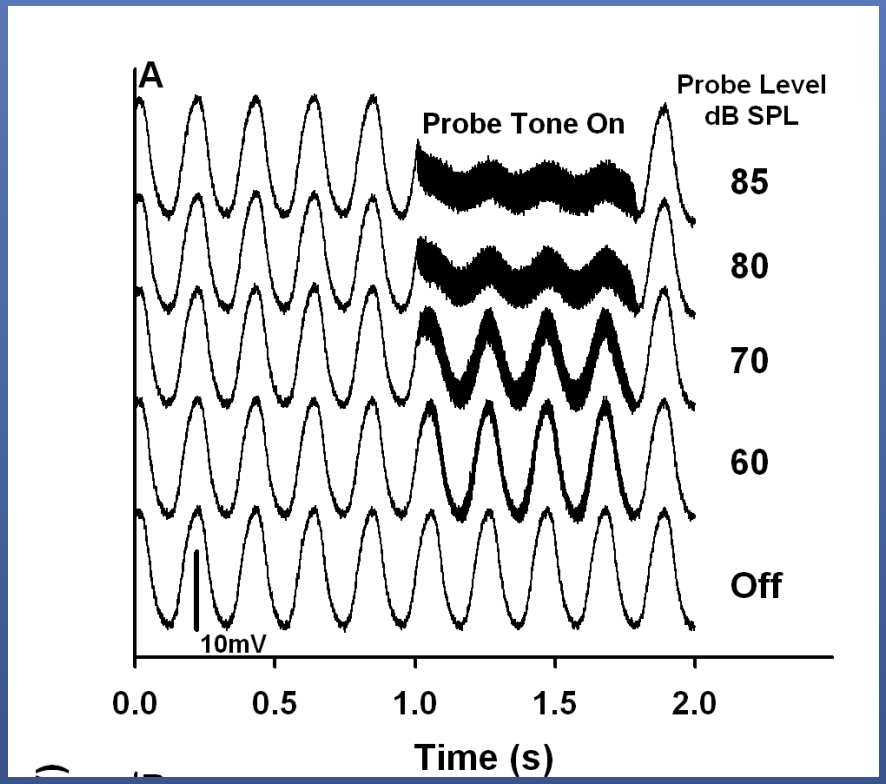


Responses saturate at >17 mV

Larger voltages mean larger transduction currents, more ion transport, more metabolic demand.

The system is being driven harder.

The large responses to infrasound (5 Hz) are suppressed by higher frequency tones (500 Hz)



Initial Conclusions

- The ear generates larger responses to infrasound than it does for low frequency sounds in the audible range.
- Audible low frequency sounds suppress the response to infrasound.

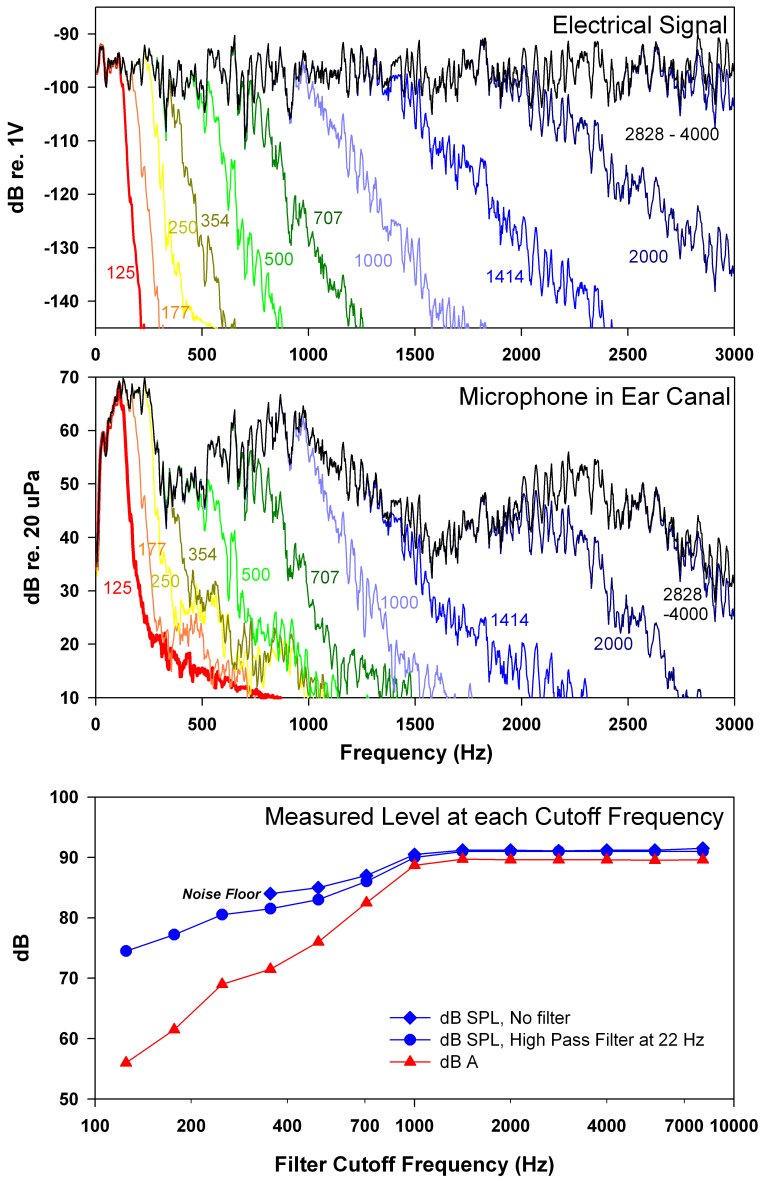
Measurements with low-pass filtered frozen noise

Some types of low pass filtered noise have been shown to be very annoying (Krahé, 2008,2010)

Changing cutoff frequency alters high frequency content **but does not affect sound below 125 Hz.**

As filter cutoff is reduced below 1 kHz, sound becomes quieter, especially when measured as dBA.

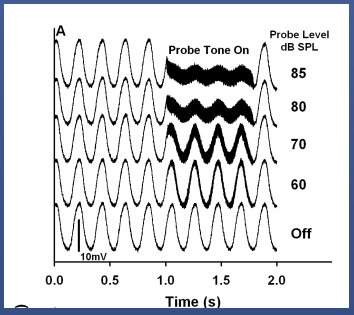
125 Hz cutoff is 56 dBA, which is -33.6 dB re. 8 kHz cutoff noise.

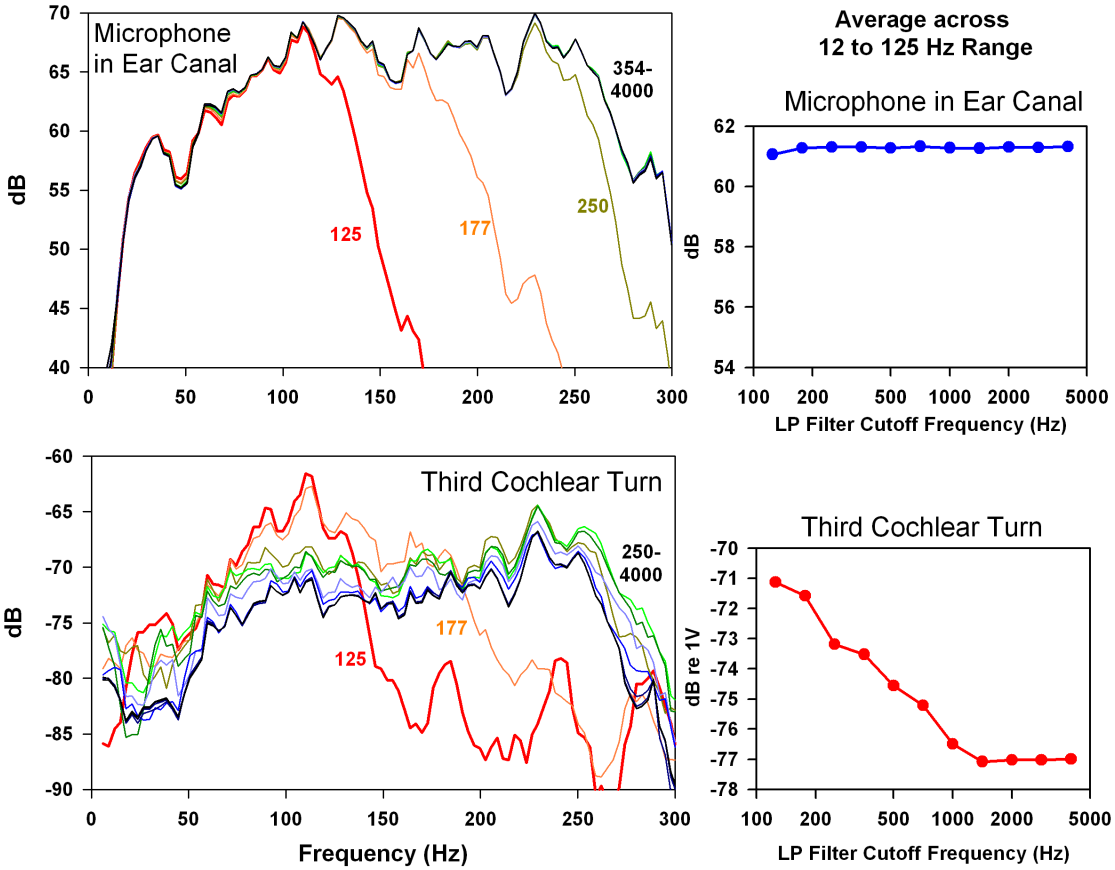


Responses measured simultaneously from the ear canal (mic) and from the inner ear.

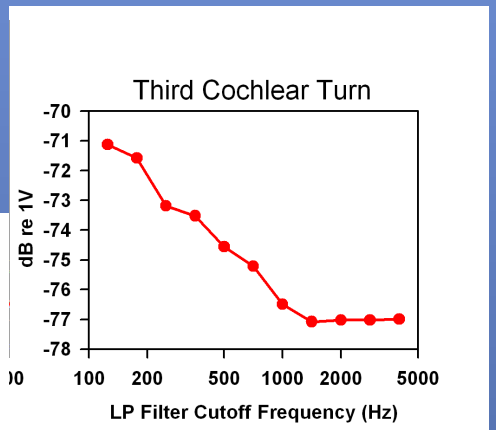
Responses from the ear are larger when high frequency components are absent.

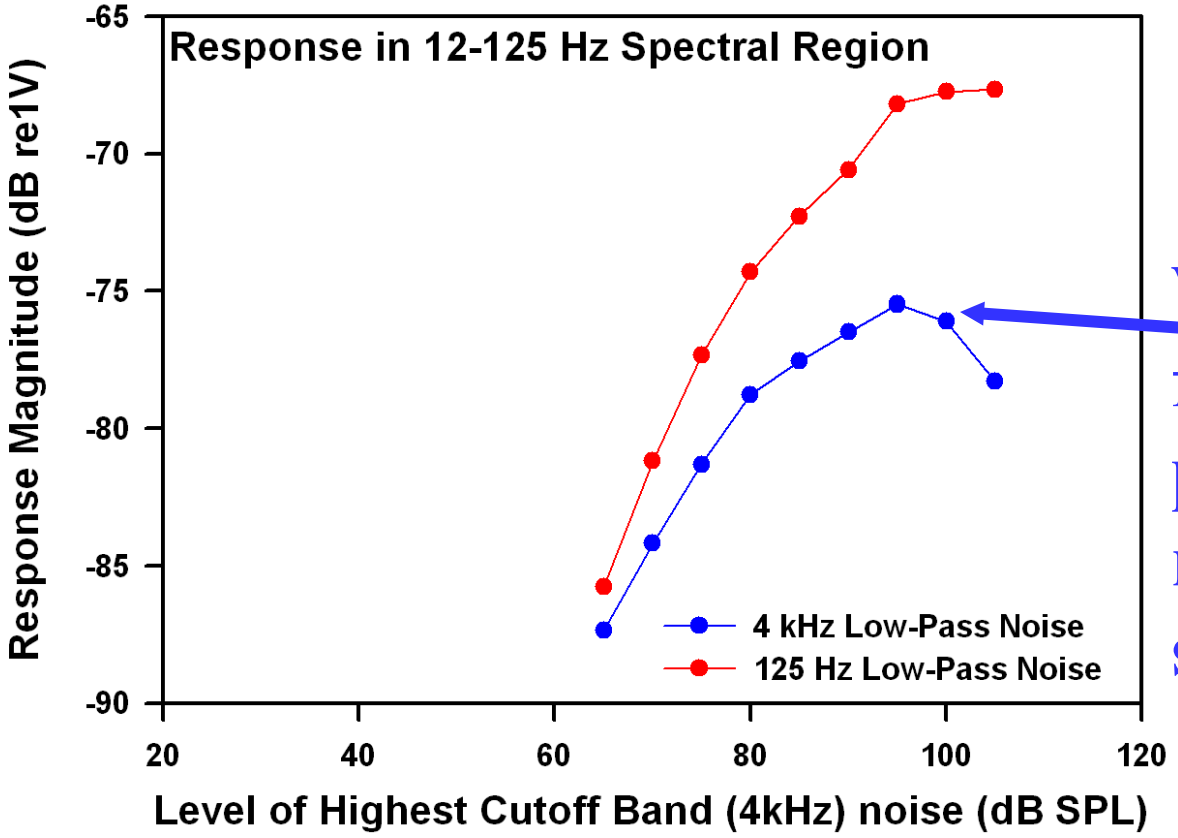
Similar to previous results with tones.





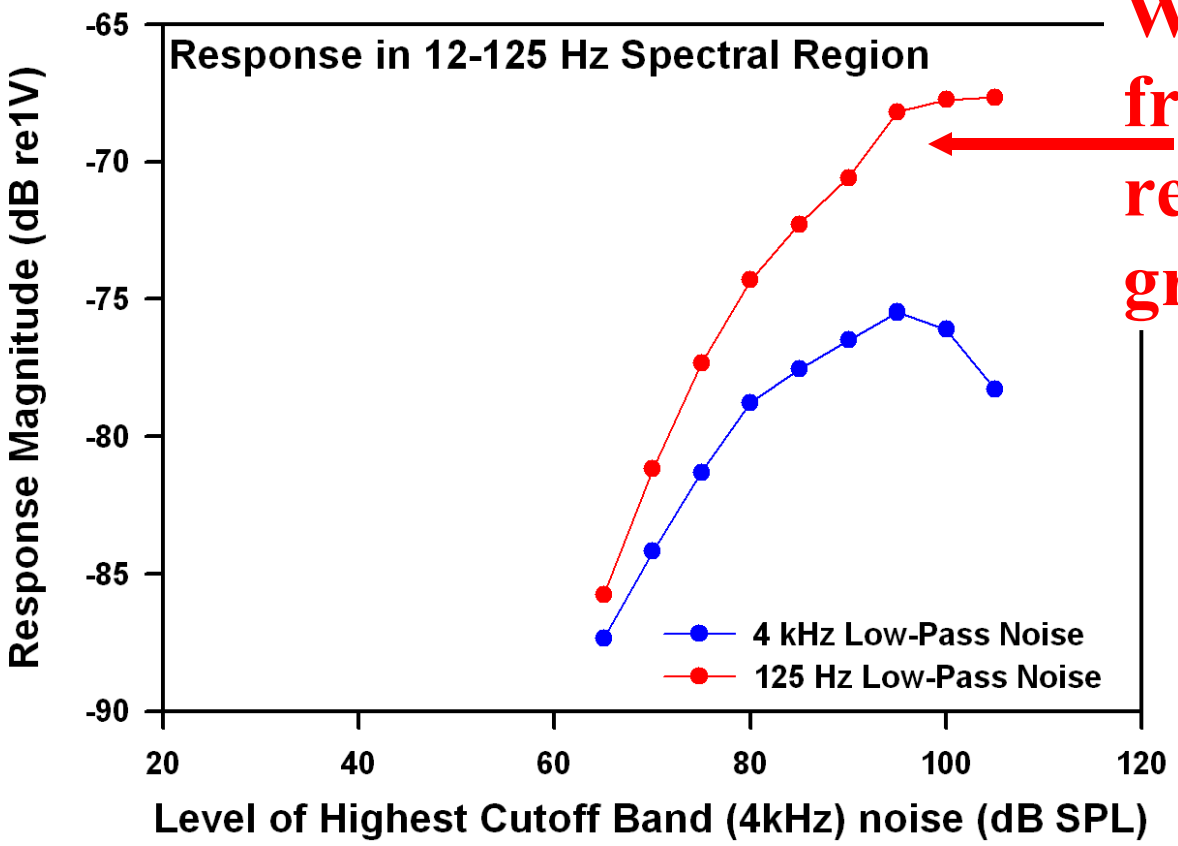
Responses with level





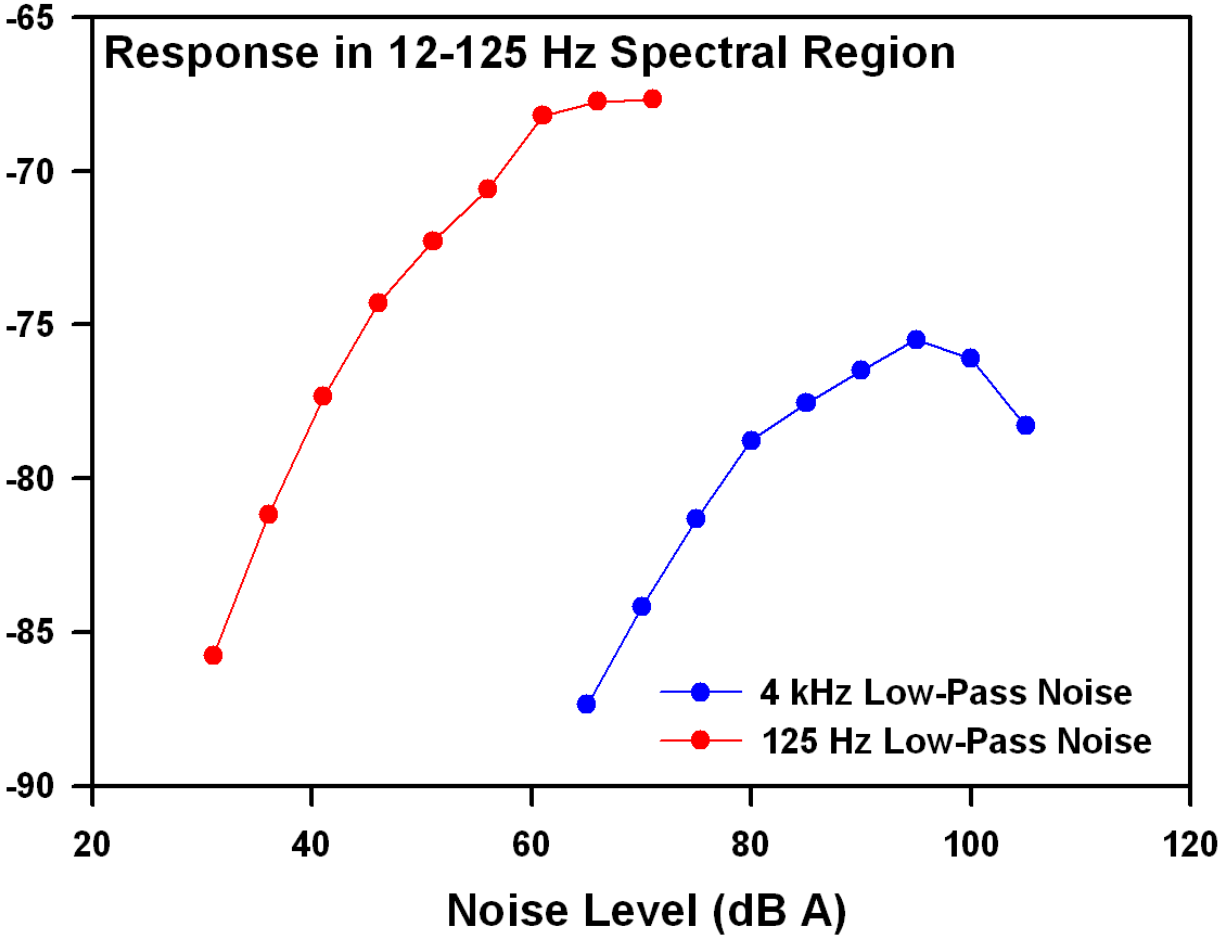
With higher frequencies present, responses saturate

Responses with level

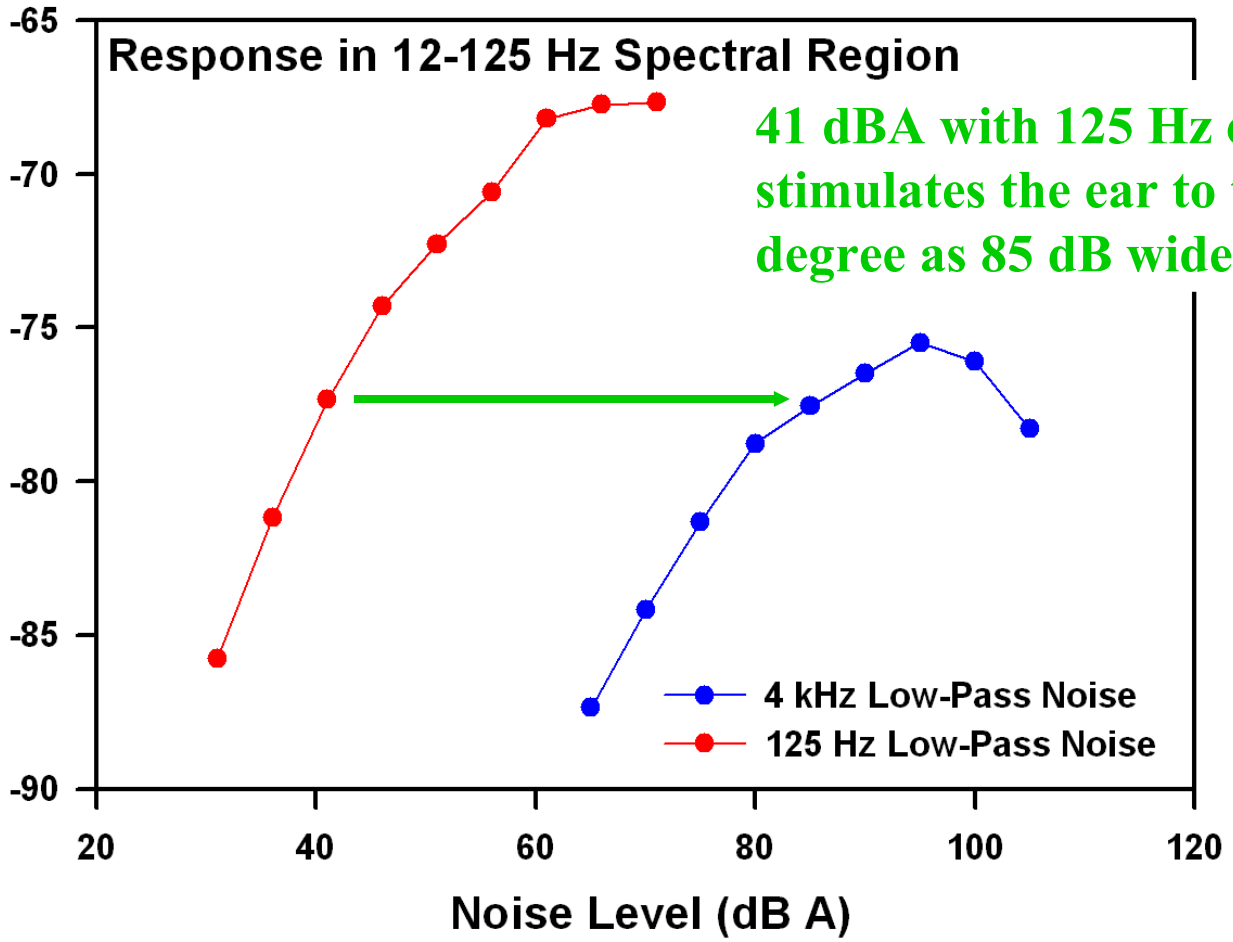


Without higher frequencies, responses keep growing

Same Responses plotted vs A-weighted sound level

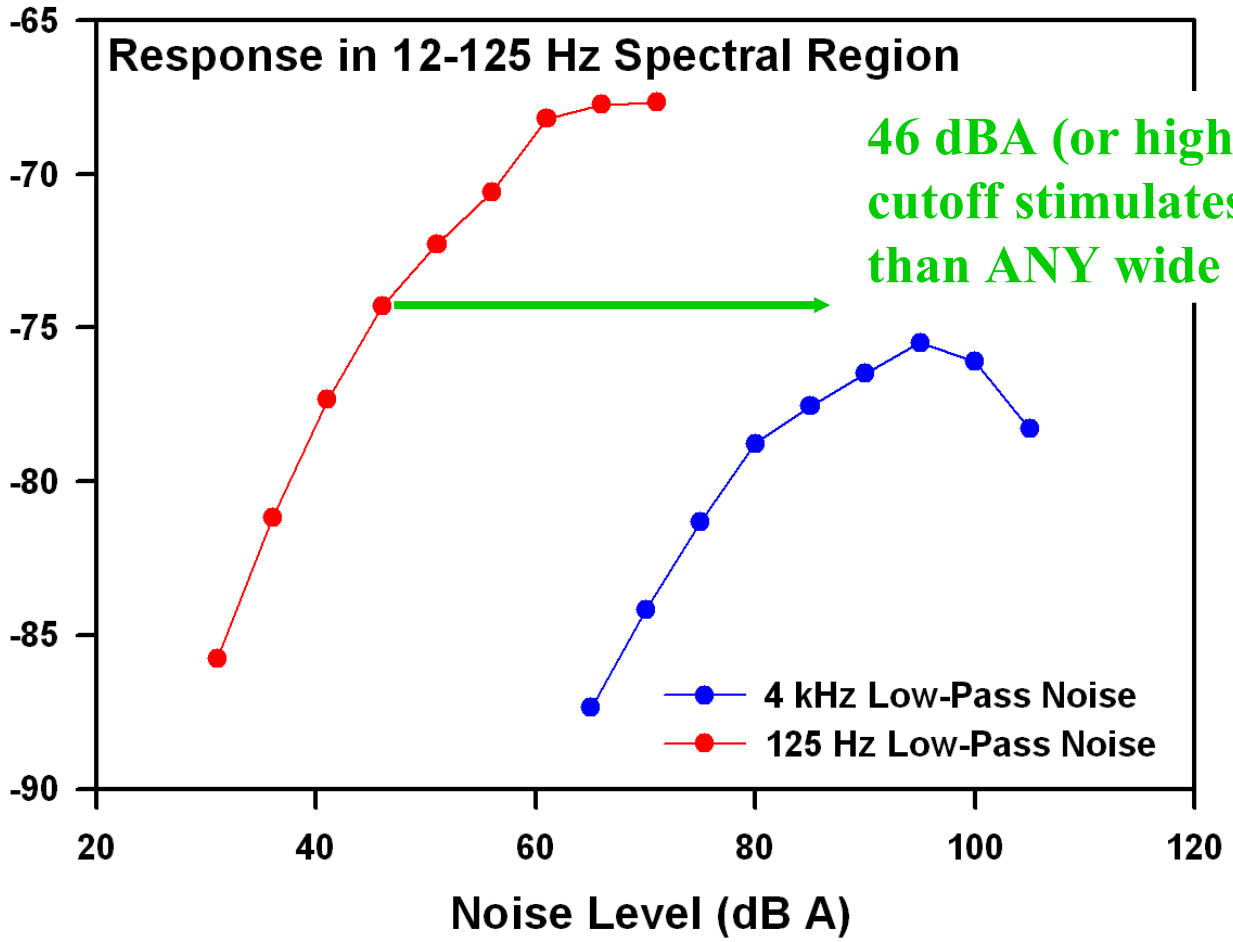


Responses vs A-weighted sound level



41 dBA with 125 Hz cutoff stimulates the ear to the same degree as 85 dB wide band noise

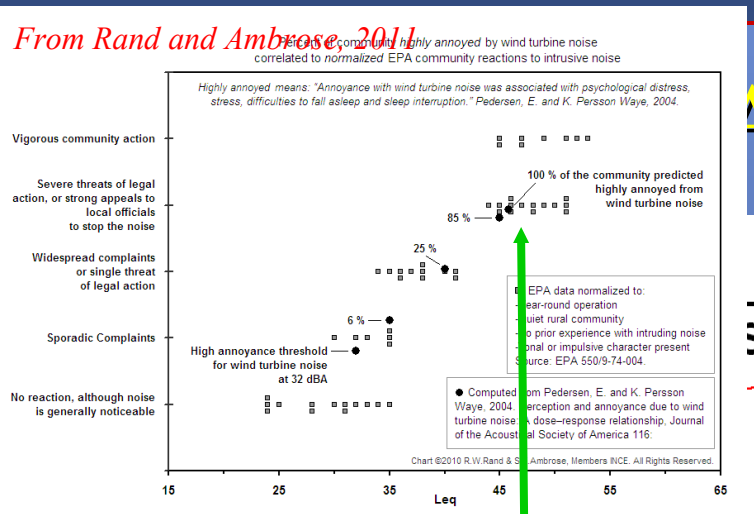
Responses vs A-weighted sound level

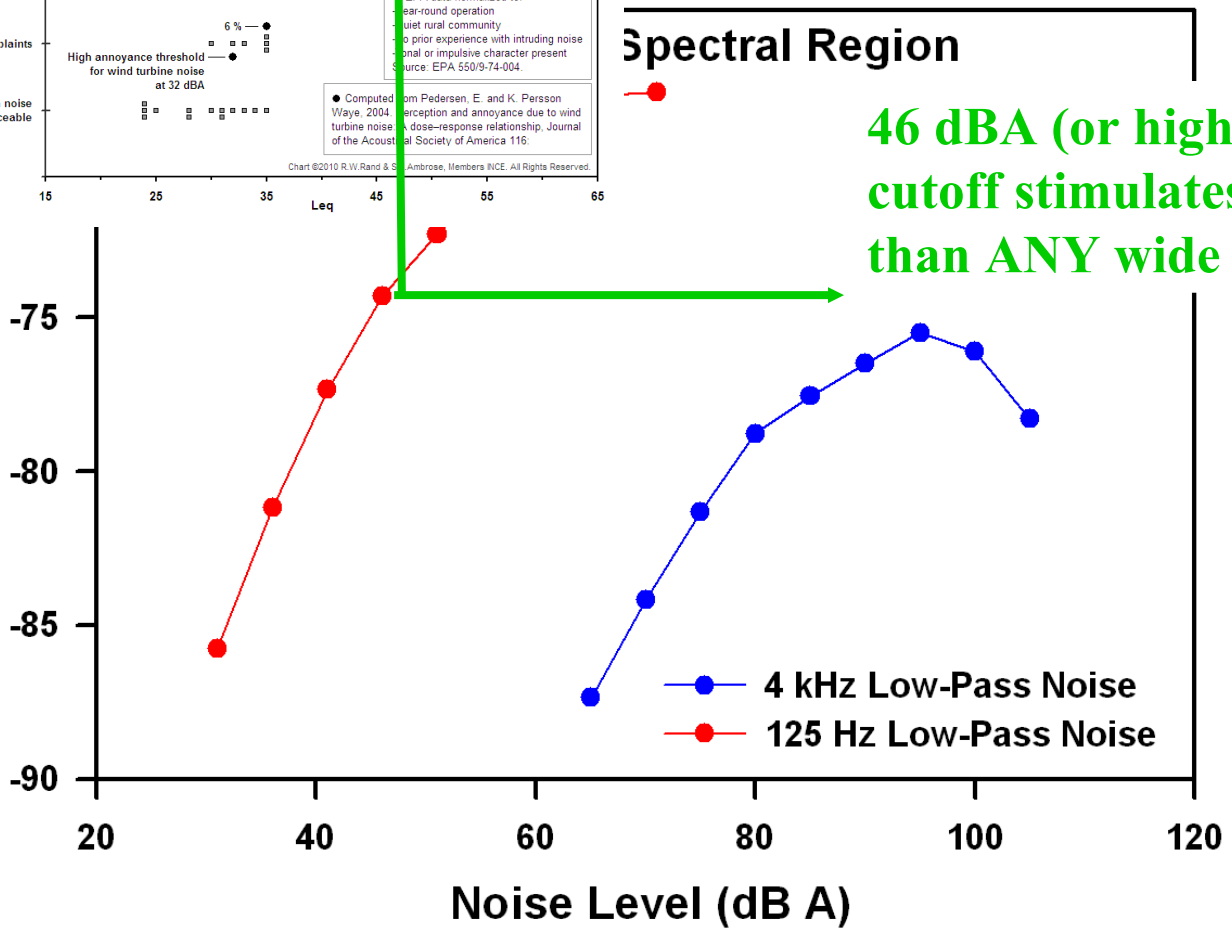


46 dBA (or higher) with 125 Hz cutoff stimulates the ear more than ANY wide band noise level.

From Rand and Ambrose, 2011

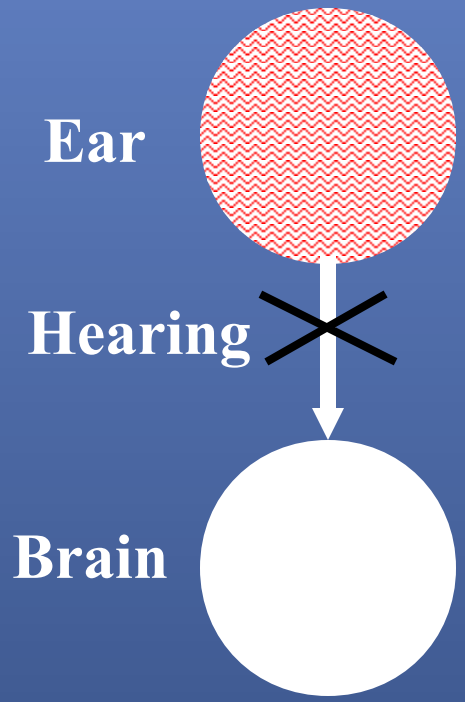
A-weighted sound level





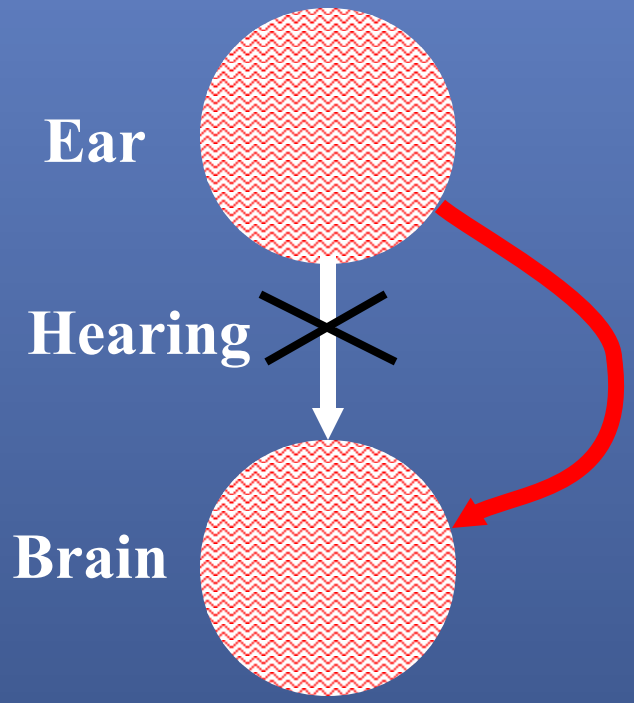
46 dBA (or higher) with 125 Hz cutoff stimulates the ear more than ANY wide band noise level.

Low frequency sounds are strongly stimulating the ear at low dBA levels.



Although an influence on the body is not be mediated though perception……

Low frequency sounds are strongly stimulating the ear at low dBA levels.

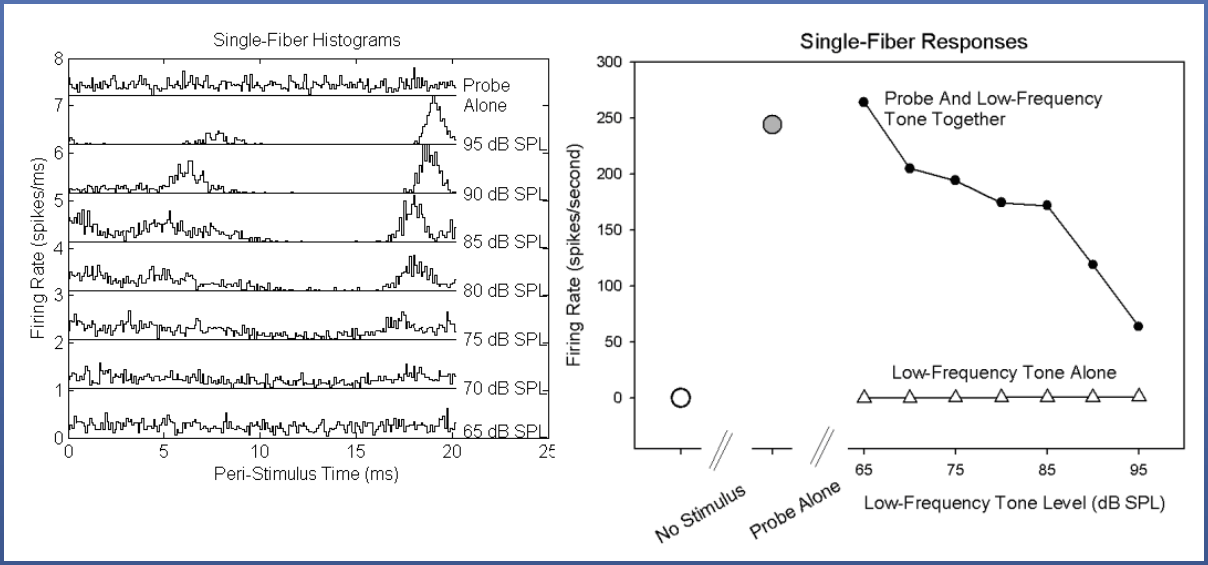


We also need to consider scientifically-plausible mechanisms **that do not involve perception** of the low frequency sound.

There are at least 3 possibilities

1) Infrasound-induced amplitude modulation

- Low frequency and infrasound cause amplitude modulation of sounds you can hear that is well-established in auditory neuroscience, described as low frequency biasing.
- This is BIOLOGICAL in origins and cannot be measured with a sound level meter.



Data recorded from single auditory nerve fiber.

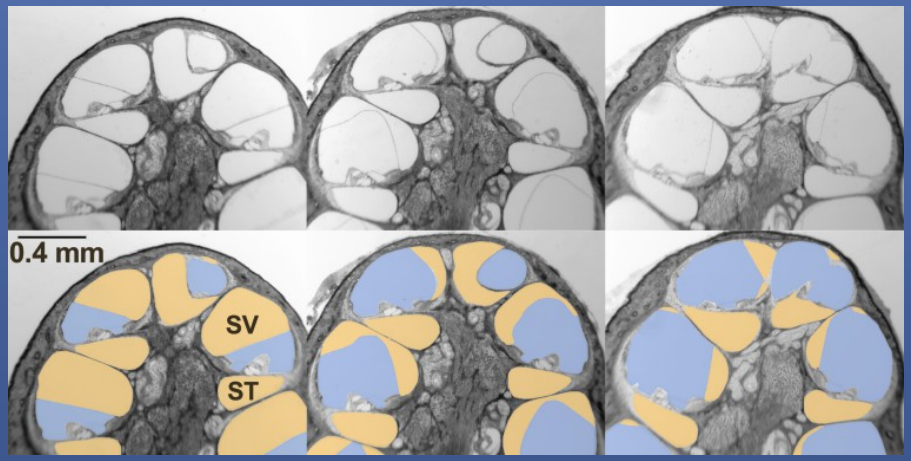
Salt & Lichtenhan 2011

Expected symptoms: Pulsating sounds, annoyance, stress .

2) Endolymphatic Hydrops (fluid disturbance)

- Low frequency sound at non-damaging levels for just 3 minutes causes a swelling of the endolymphatic space - endolymphatic hydrops.
- As the most compliant part of the endolymphatic system is the saccule, this could lead to saccular disturbance.

Normal **Mild Hydrops** **Severe Hydrops**



JARO 5: 203–214 (2004)
DOI: 10.1007/s10162-003-4032-z

JARO
Journal of the Association for Research in Otolaryngology

Acute Endolymphatic Hydrops Generated by Exposure of the Ear to Nontraumatic Low-Frequency Tones

Alec N. Salt

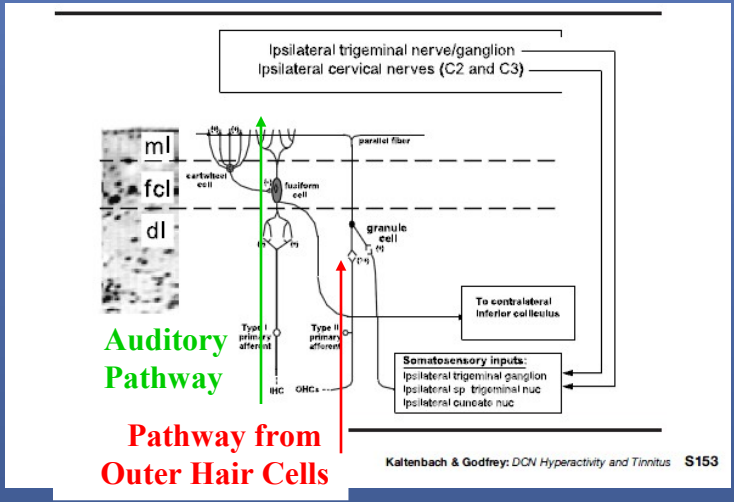
Department of Otolaryngology, Washington University School of Medicine, St. Louis, MO 63110, USA

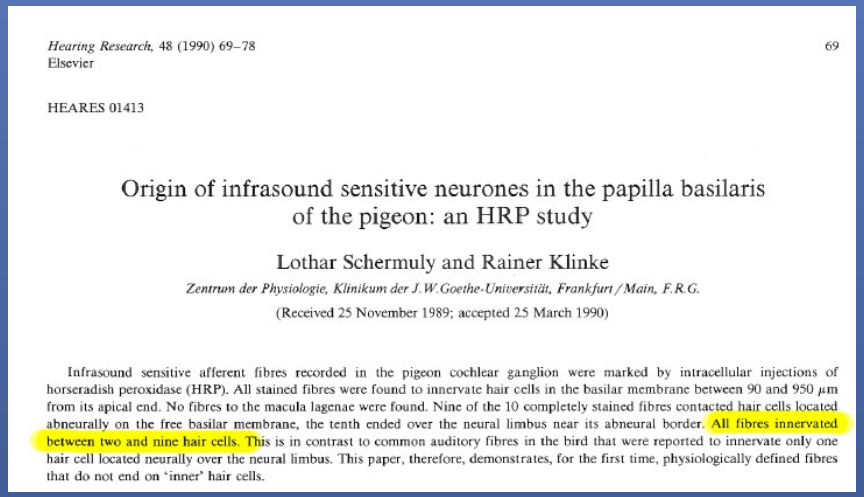
Received: 18 August 2003; Accepted: 18 December 2003; Online publication: 4 May 2004

Expected Symptoms: fullness, unsteadiness, tinnitus, "seasickness", possibly vertigo.

3) Non-perceived neural pathways

- 5% of auditory nerve fibers connect multiple outer hair cells (the source of our large responses) to the brain.
- Similar fibers that innervate multiple hair cells in birds respond strongly to infrasound.





Hearing Research, 48 (1990) 69–78
Elsevier

69

HEARES 01413

Origin of infrasound sensitive neurones in the papilla basilaris of the pigeon: an HRP study

Lothar Schermuly and Rainer Klinke

Zentrum der Physiologie, Klinikum der J.W.Goethe-Universität, Frankfurt/Main, F.R.G.

(Received 25 November 1989; accepted 25 March 1990)

Infrasound sensitive afferent fibres recorded in the pigeon cochlear ganglion were marked by intracellular injections of horseradish peroxidase (HRP). All stained fibres were found to innervate hair cells in the basilar membrane between 90 and 950 μm from its apical end. No fibres to the macula lagenae were found. Nine of the 10 completely stained fibres contacted hair cells located abneurally on the free basilar membrane, the tenth ended over the neural limbus near its abneural border. All fibres innervated between two and nine hair cells. This is in contrast to common auditory fibres in the bird that were reported to innervate only one hair cell located neurally over the neural limbus. This paper, therefore, demonstrates, for the first time, physiologically defined fibres that do not end on 'inner' hair cells.

- *Expected Symptoms: Sleep disturbance, stress, leading to secondary effects such as elevated blood pressure and memory disturbances.*

To Summarize

- There are at least 3 processes, each with supporting scientific data, by which low frequency stimulation could influence people.

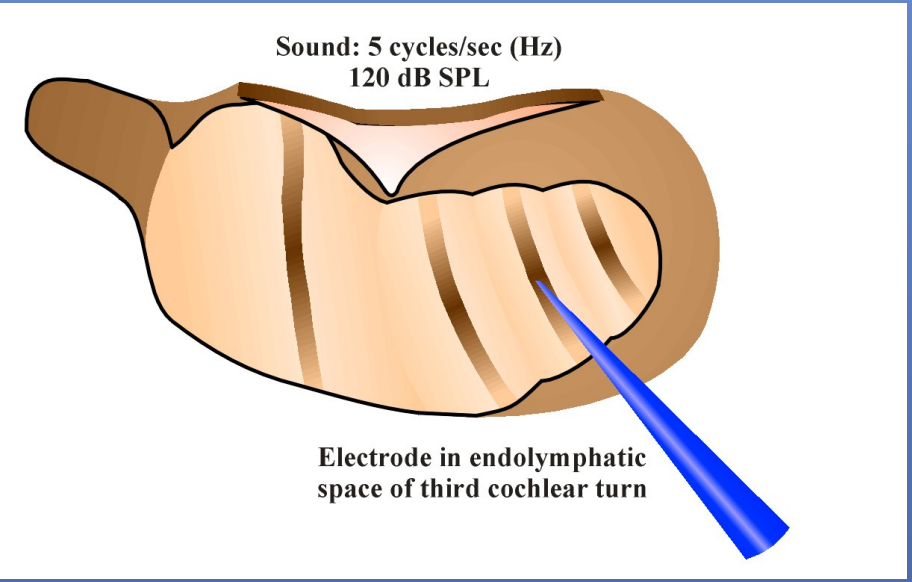
The assertion that effects of low frequencies can ONLY be mediated by hearing the sound is simply untenable.

Final Conclusions

- The ear generates larger responses to infrasound than it does for low frequency sounds in the audible range.
- Audible low frequency sounds suppress the response to infrasound.
- Optimal masking of low frequency responses to noise occurs with frequencies of 150 Hz -1.5 kHz.
- There are a number of scientifically plausible pathways, unrelated to perception, by which low frequency sounds could influence someone.
- We need to better understand how low frequencies affect the ear before we dismiss their influence on people.

Additional Slides for questions

Measurements from the inner ear of guinea pigs



Guinea pigs vs Humans

Guinea pig hearing is about 15 dB less sensitive than humans

BUT

We make our measurements with the middle ear open, which makes them ~10-15 dB more sensitive at low frequency.

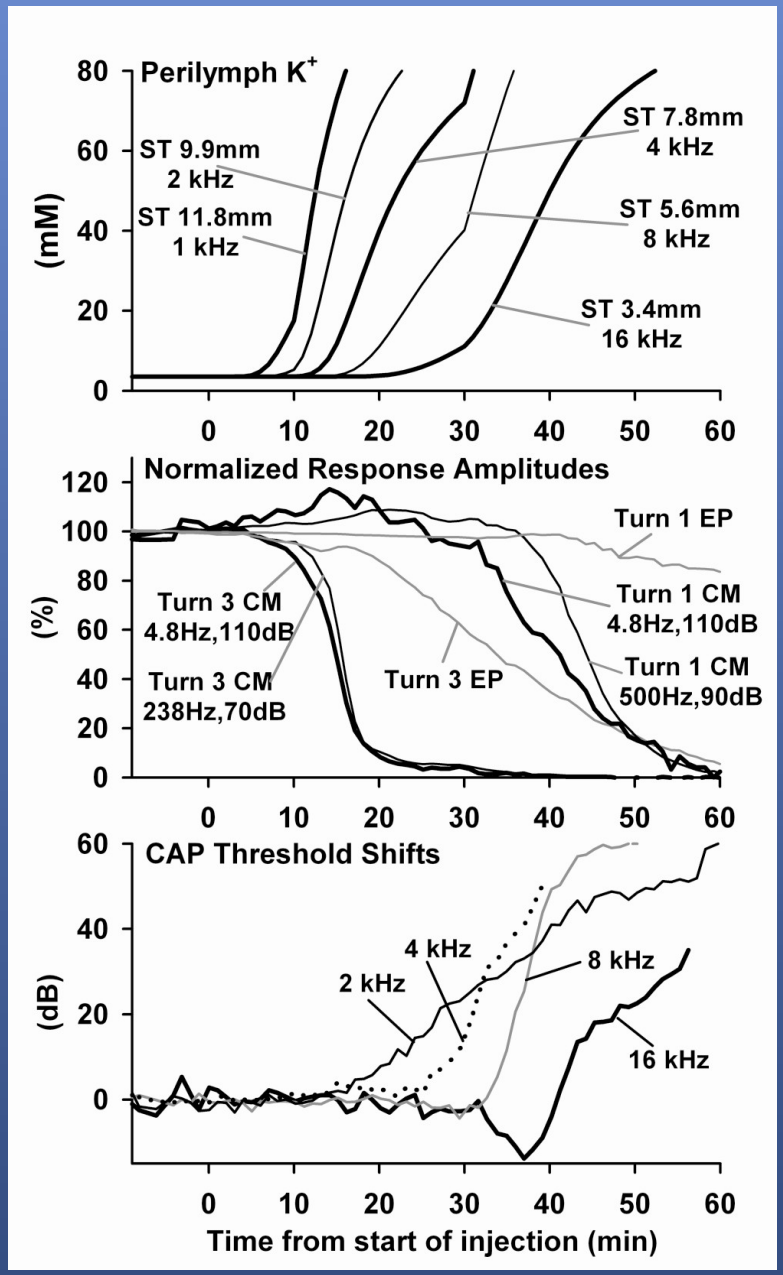
The sensitivity we measure will be comparable to humans.

Demonstration that measured responses to infrasound are generated locally in the apical turns

Response changes are shown for an injection of toxic KCl (150 mM) into the cochlear apex. The calculated elevation of K at various locations is shown at the top. K progressively moves from apex to base with time.

Lower Panel: Compound APs are suppressed progressively with frequency, showing the basal movement.

Middle Panel: Response from turn 3 with 4.8 Hz stimulation is ablated before CAP thresholds start rising. This confirms the response is locally generated near the recording site.



Infrasound Production by Dun Law Wind Farm, UK

From Styles et al. 2005, Keele University

Peak spectral output at ~ 0.5 Hz with harmonics up to ~ 7 Hz.

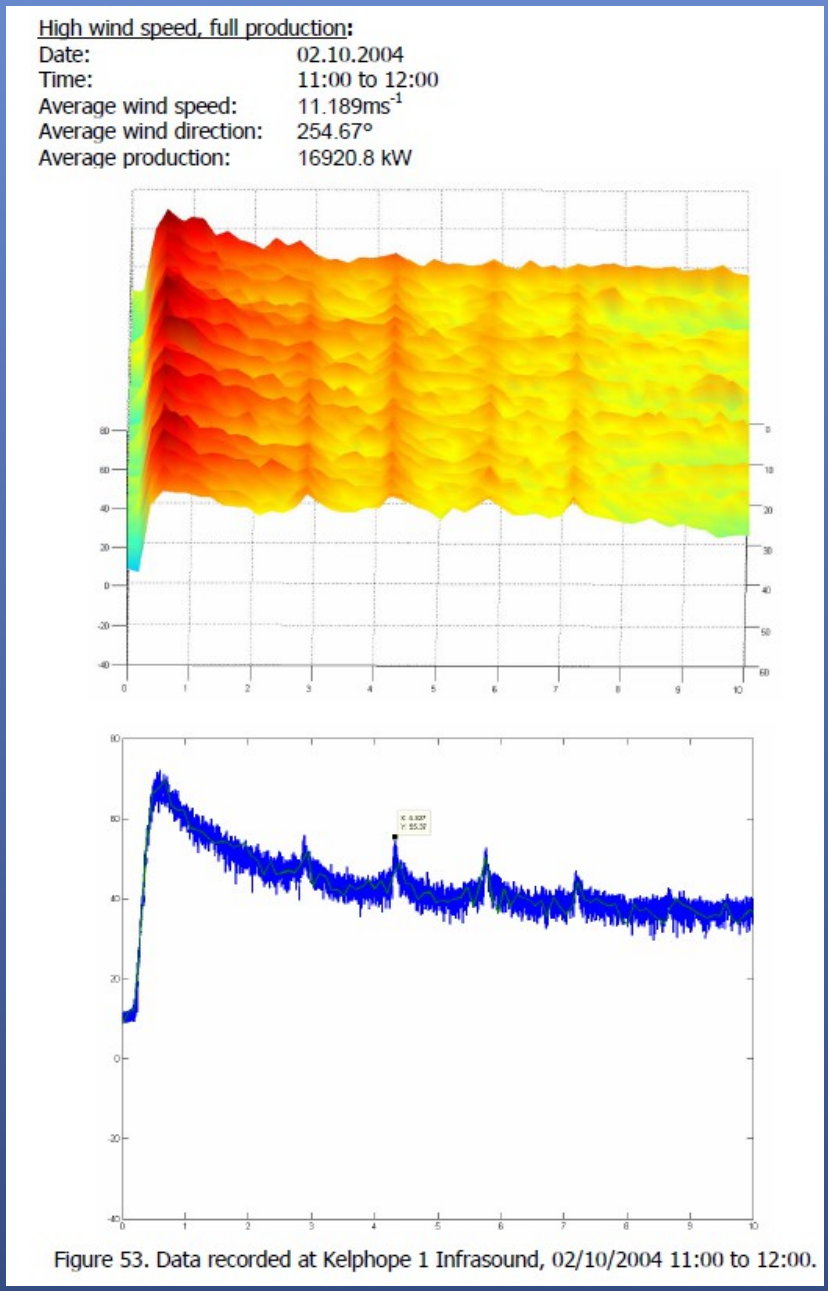


Figure 53. Data recorded at Kelphope 1 Infrasound, 02/10/2004 11:00 to 12:00.