Development of the Chirp stimulus for the recording of ABRs

Claus Elberling

DTAS, Vejlefjord, September 2011

Background

- Shore and Nuttall (1985)
  - Toneburst with rising frequency, Guinea Pigs
- Lütkenhöner et al. (1990)
  - Chirp based on frequency-specific ABR, ABRs in humans
- Dau et al. (2000)
  - Chirp based on cochlea model, ABRs in humans

- Purpose
  - More efficient broad-band stimulation
  - Shorter recording time/higher precision
  - New born hearing screening
  - More efficient frequency specific stimulation
  - Objective hearing diagnosis

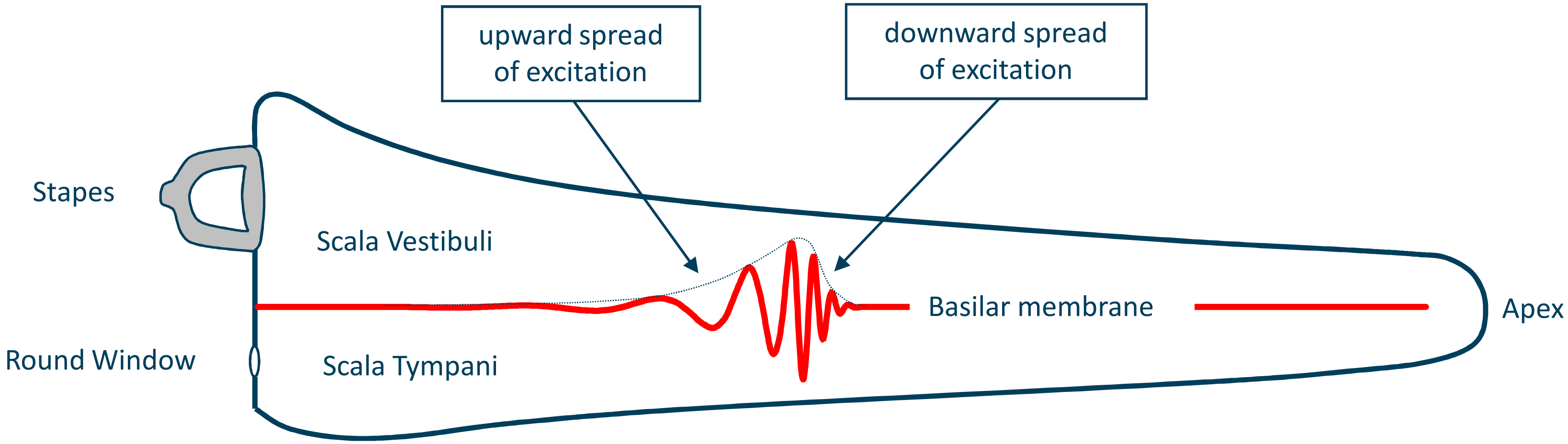
Overview

- Cochlea – and the traveling wave delay
- About the Chirp
- Delay models
- Chirp based on cochlear models
  - ASSR and ABR evaluation
- The direct approach model
- Summary and conclusion

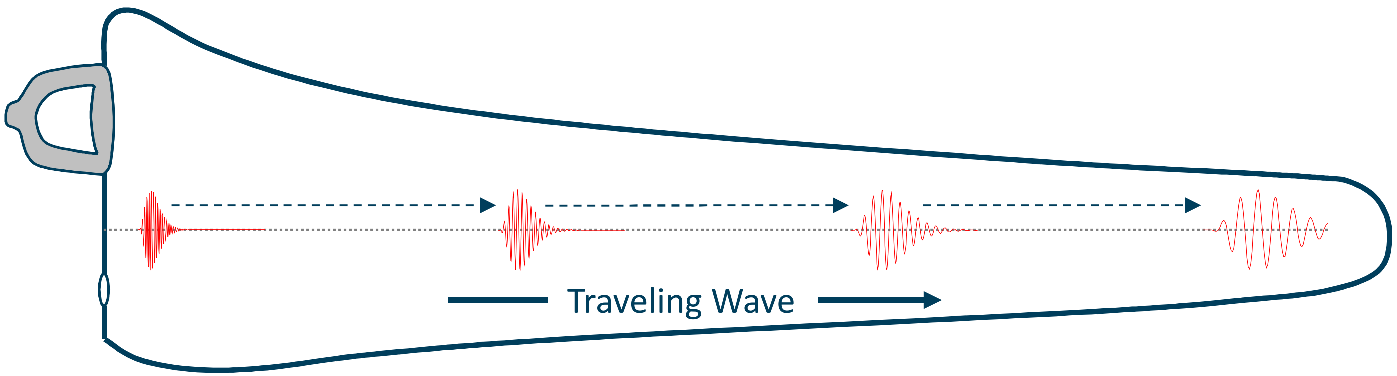
Cochlea – and the traveling wave delay

- How is the cochlea activated by a Click?
- The '*disturbing*' cochlear delay
- What to do about it?

Excitation patterns



Continuous, narrow band stimuli



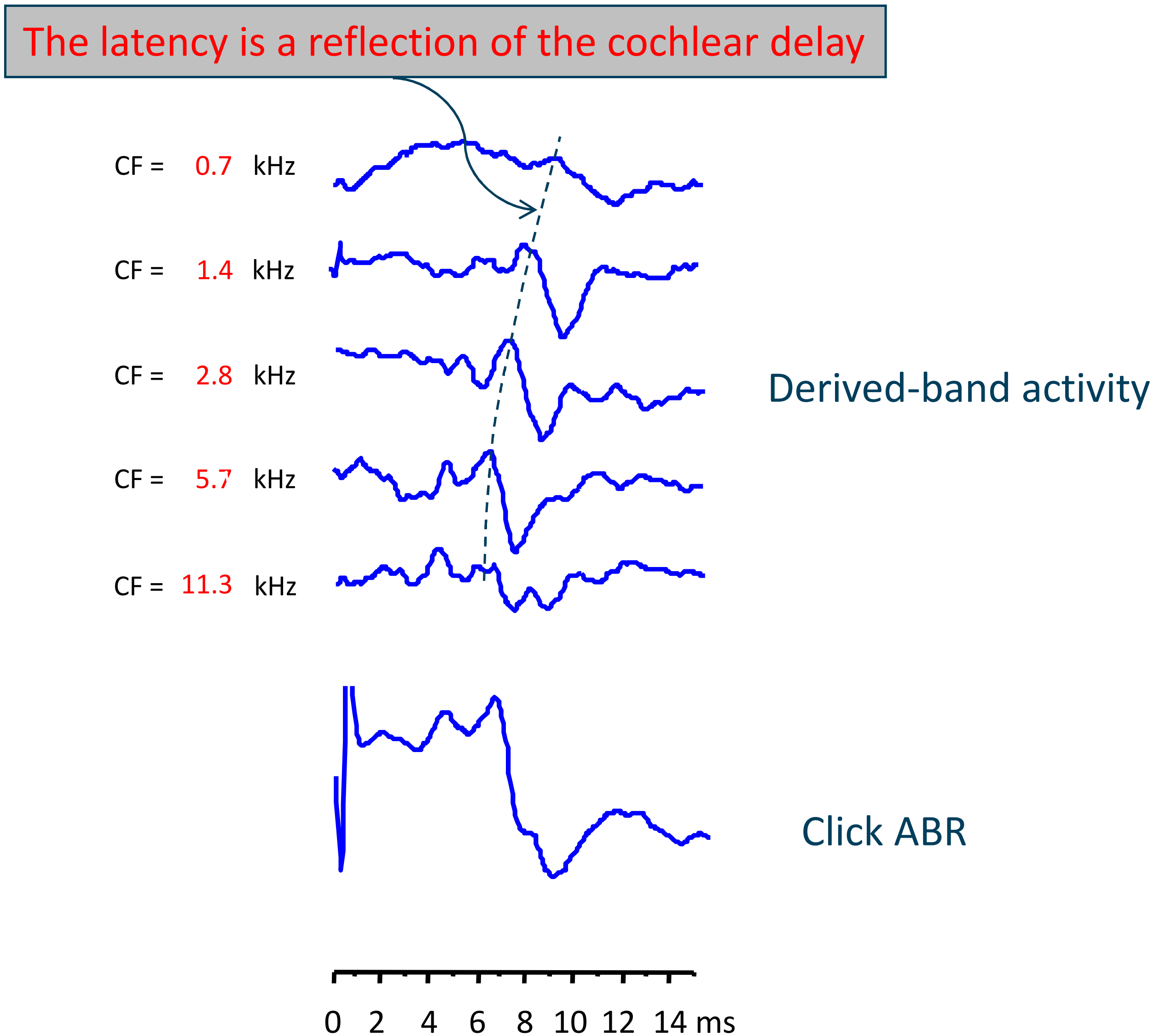
Transient, broad band stimuli

William Demant

A click ABR

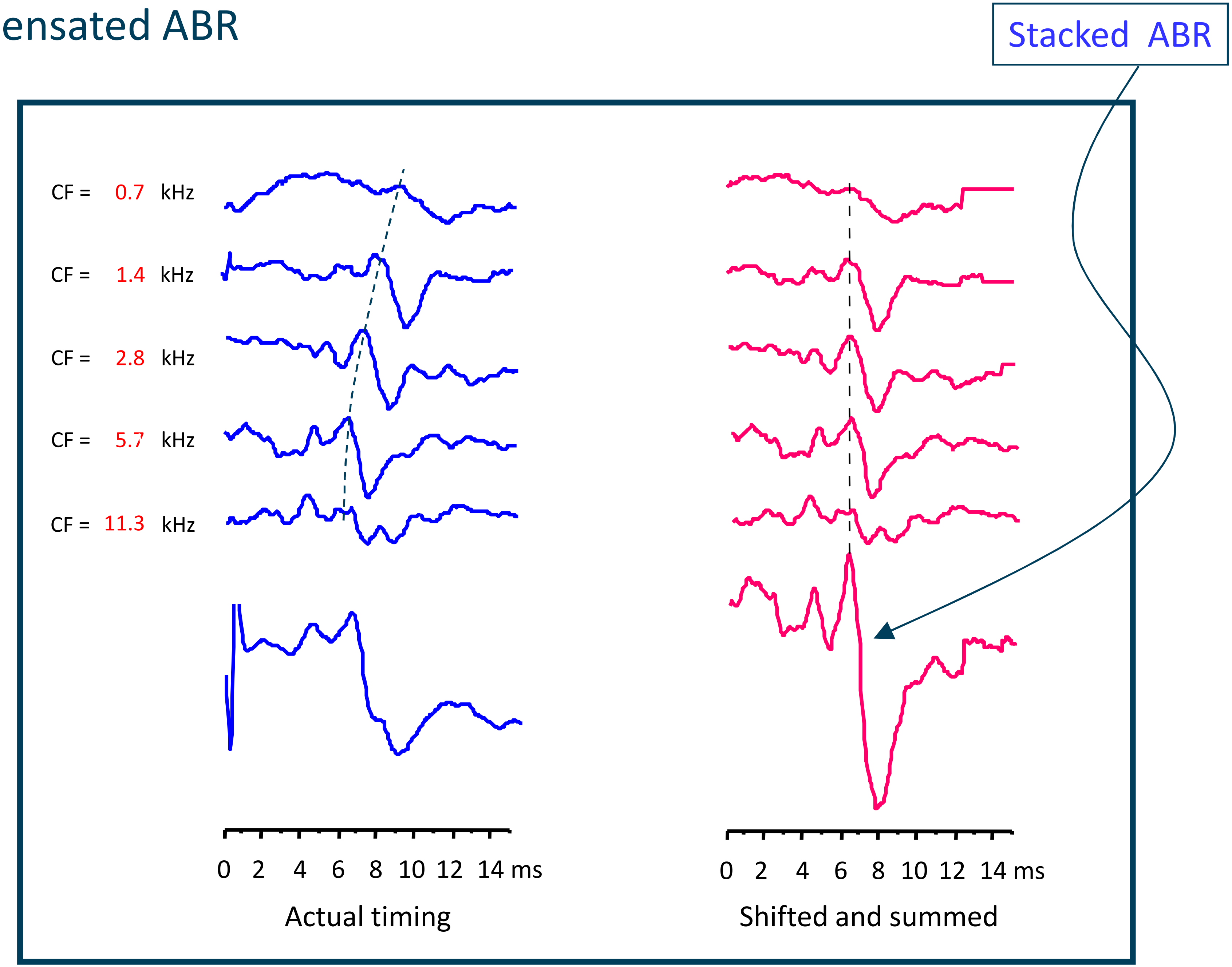
- A click is a *broad-band* stimulus
- A click *ABR* is composed of activity from all frequency-regions along the cochlear partition
- The lower the frequency the longer the latency of the *derived-band* activity

Composition of a click ABR



M. Don – House Ear Institute, 2002

Compensated ABR

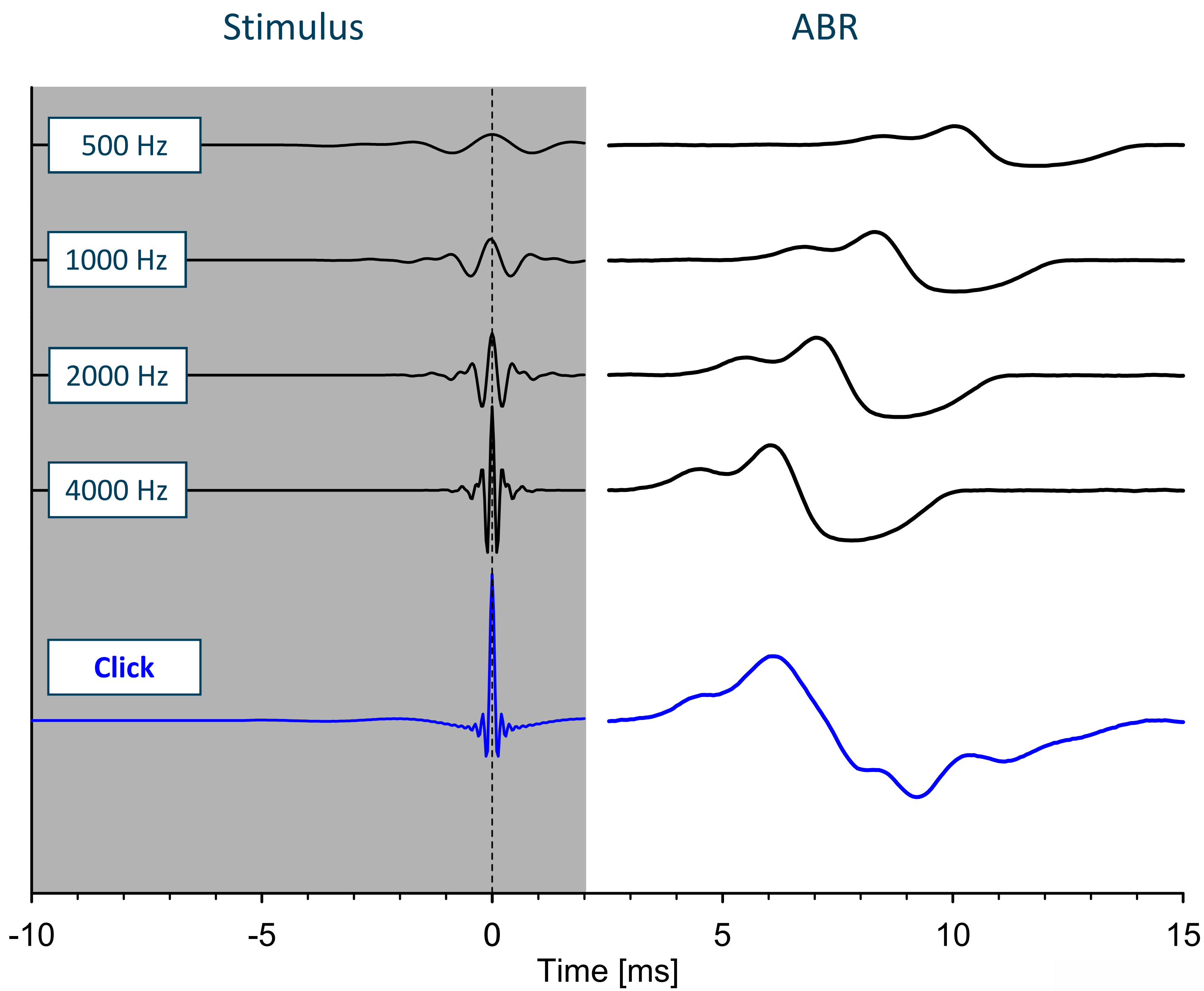


M. Don – House Ear Institute, 2002

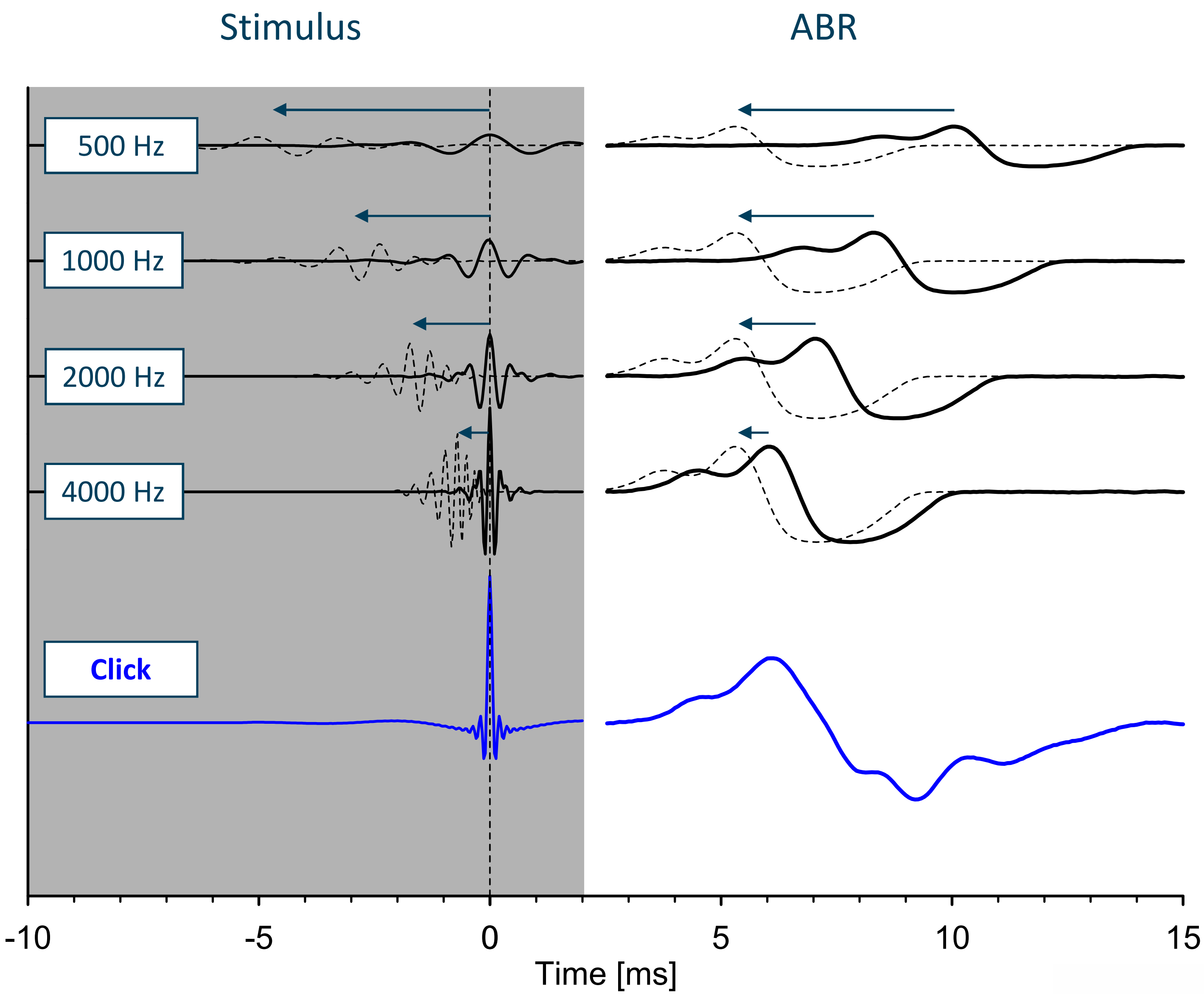
About the Chirp

- One way is to align the activity along the cochlear – this generates the *Stacked ABR*
- Another way is to time-shifting the different frequency components of the click stimulus
- This is done by allowing the low-frequencies to appear before the high-frequencies
- Such a click with re-shuffled frequency components is called a *Chirp*

Distribution of click activity

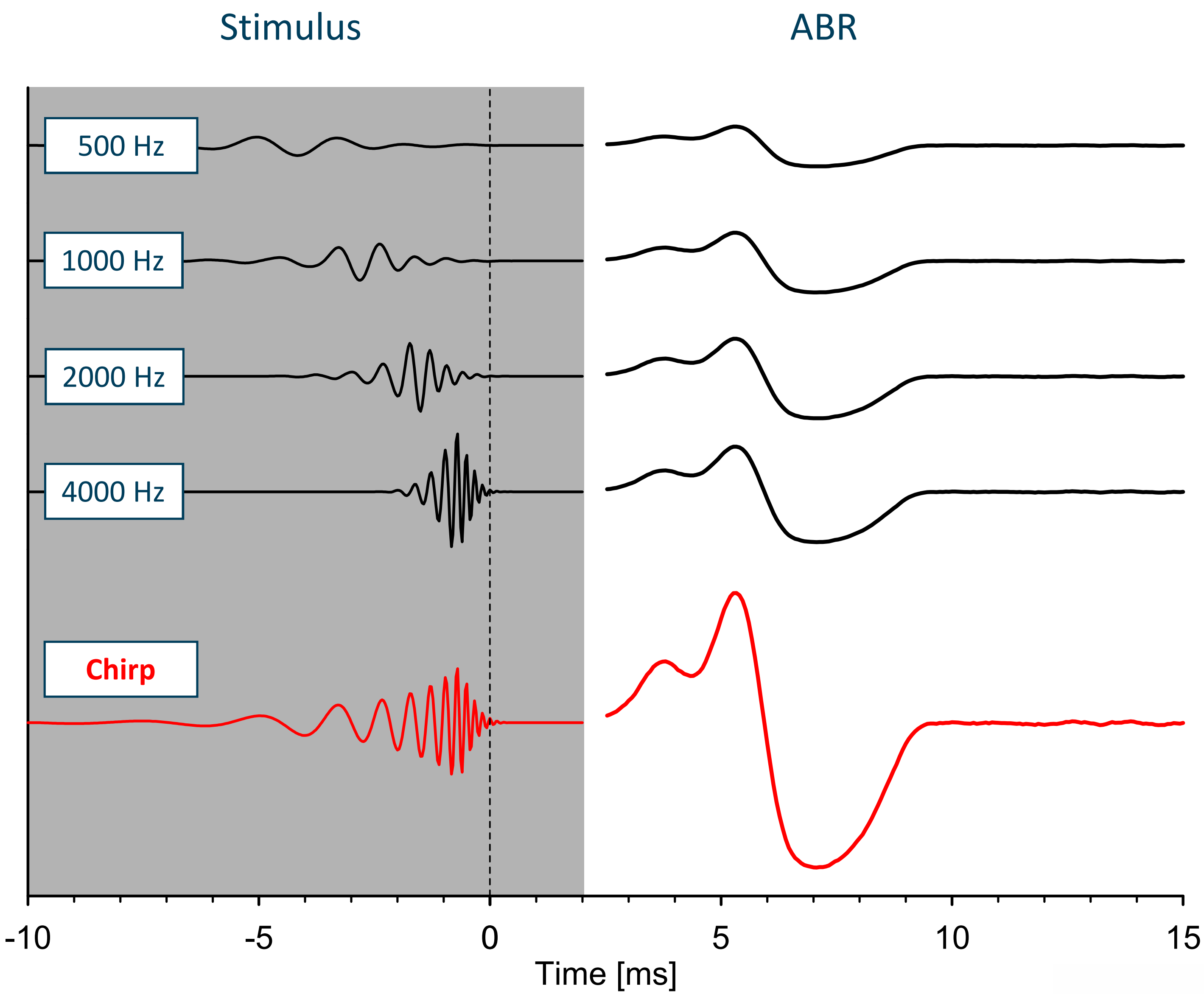


Temporal compensation – (Input compensation)



William Demant

The Chirp

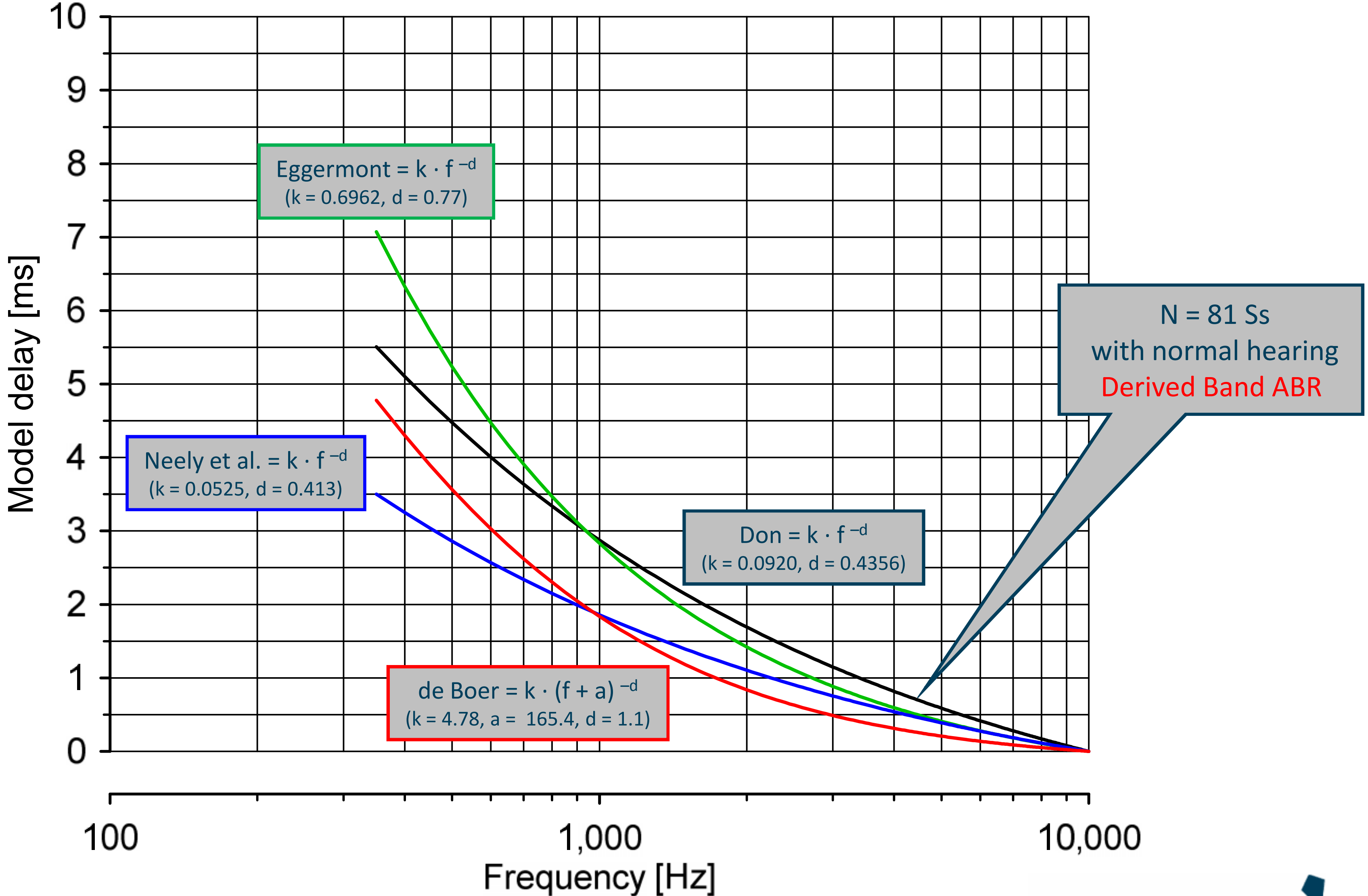


William Demant

Delay models

- Numerous models of the human traveling time exist
- Here four delay models will be shown:
  - based on a cochlear model (de Boer, 1980)
  - based on derived-band ACAP recordings (Eggermont, 1976)
  - based on derived-band ABR recordings (Don, 2005)
  - based on tone-burst ABR recordings (Neely et al, 1988)

Different models of the traveling time



William Demant

Chirp based on cochlear models

Auditory steady-state responses to chirp stimuli based on cochlear traveling wave delay[a)]

Claus Elberling[b)]
Oticon A/S, "Eriksholm," DK-3070 Snekkersten, Denmark

Manuel Don
Electrophysiology Laboratory, House Ear Institute, Los Angeles, California 90057

Mario Cebulla
ENT Clinic, Julius Maximilians-University, D-97080 Würzburg, Germany

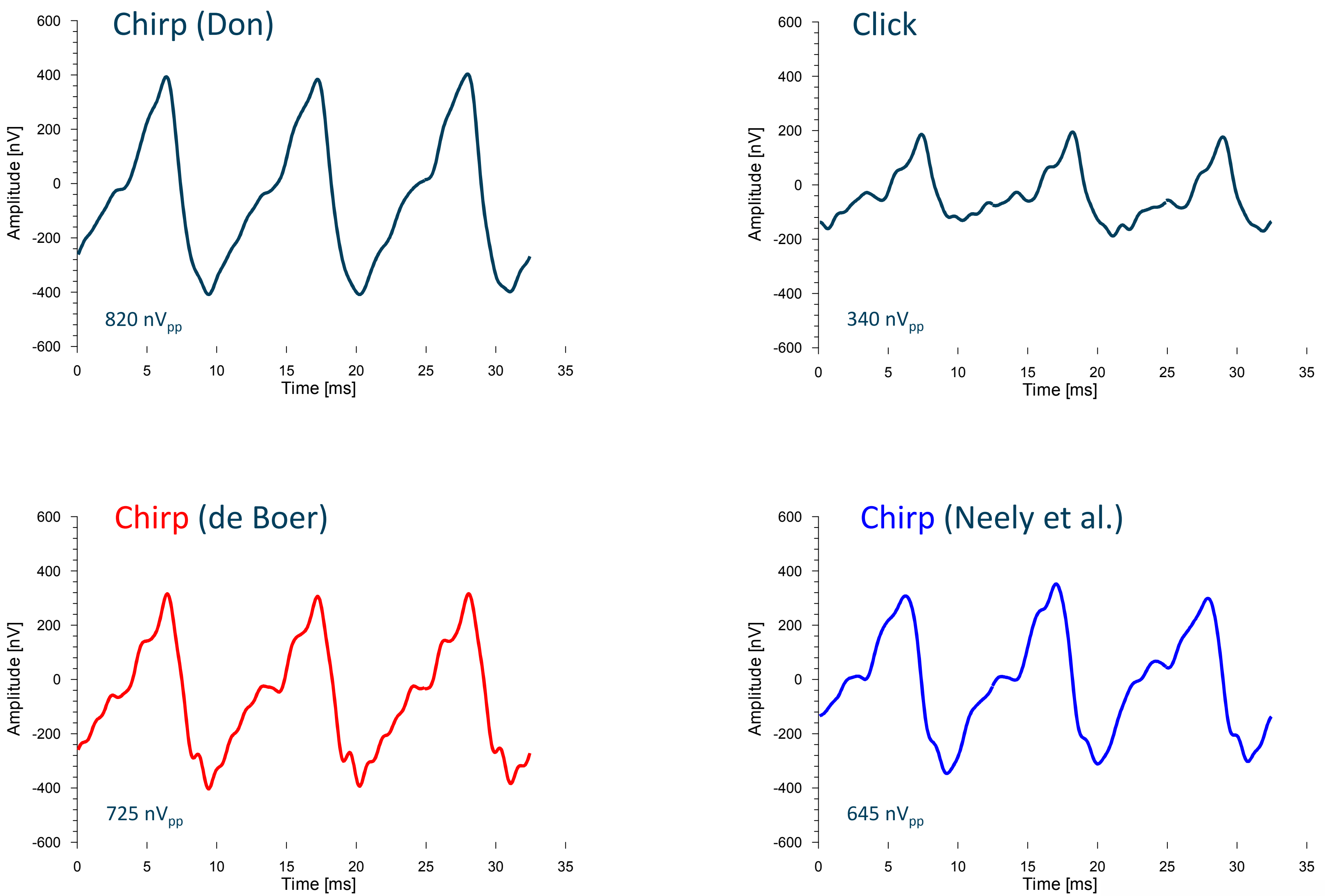
Ekkehard Stürzebecher
WDH Denmark, c/o D-15370 Petershagen, Germany

(Received 22 January 2007; revised 9 August 2007; accepted 22 August 2007)

This study investigates the use of chirp stimuli to compensate for the cochlear traveling wave delay. The temporal dispersion in the cochlea is given by the traveling time, which in this study is estimated from latency-frequency functions obtained from (1) a cochlear model, (2) tone-burst auditory brain stem response (ABR) latencies, (3) and narrow-band ABR latencies. These latency-frequency functions are assumed to reflect the group delay of a linear system that modifies the phase spectrum of the applied stimulus. On the basis of this assumption, three chirps are constructed and evaluated in 49 normal-hearing subjects. The auditory steady-state responses to these chirps and to a click stimulus are compared at two levels of stimulation (30 and 50 dB nHL) and a rate of 90/s. The chirps give shorter detection time and higher signal-to-noise ratio than the click. The shorter detection time obtained by the chirps is equivalent to an increase in stimulus level of 20 dB or more. The results indicate that a chirp is a more efficient stimulus than a click for the recording of early auditory evoked responses in normal-hearing adults using transient sounds at a high rate of stimulation. [DOI: 10.1121/1.2783985]

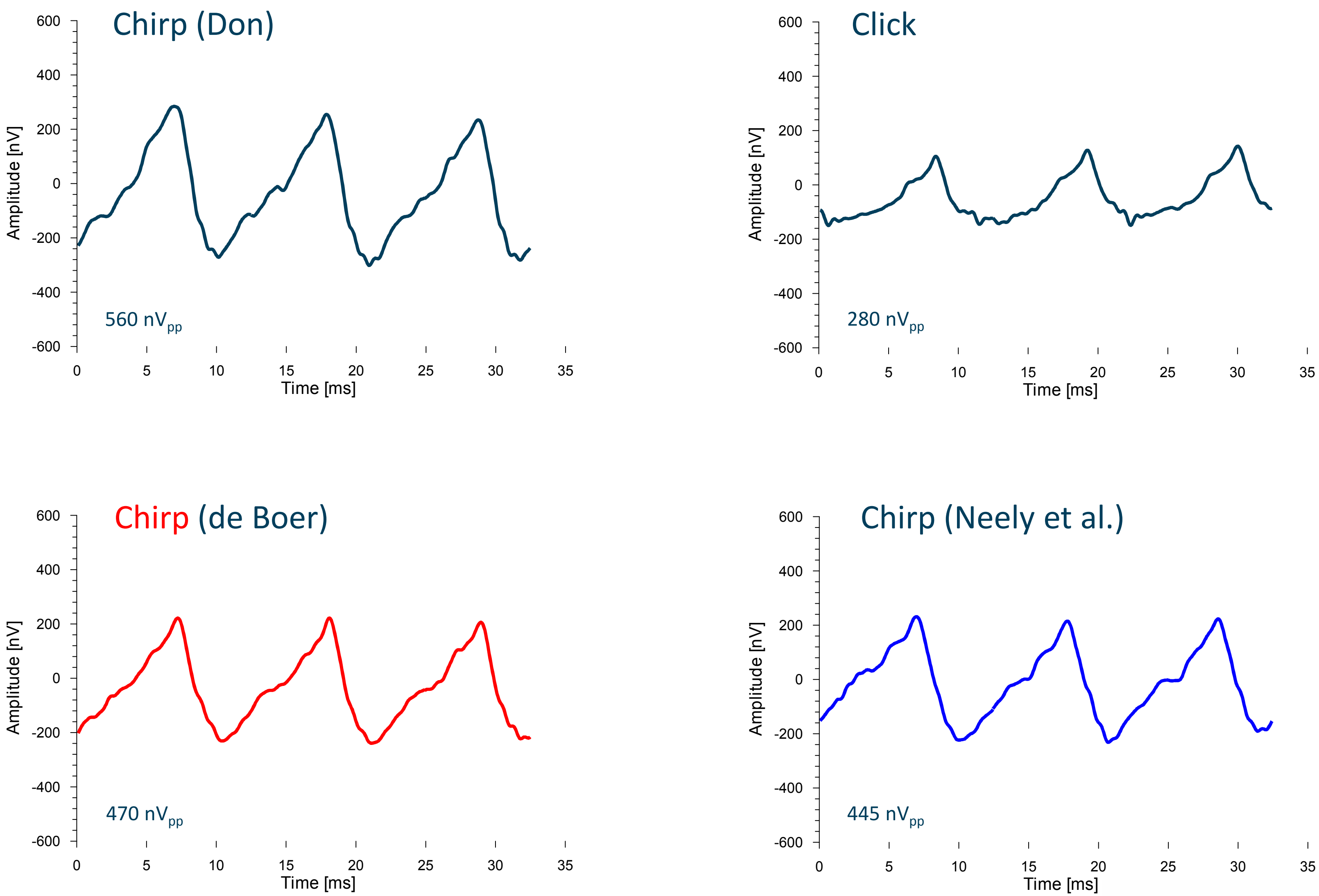
PACS number(s): 43.64.Qh, 43.64.Bt, 43.64.Ri [WPS] Pages: 2772–2785

Grand Average ASSR temporal waveforms [N = 49]
50 dBnHL



William Demant

Grand Average ASSR temporal waveforms [N = 49]
30 dBnHL



William Demant

Chirp based on cochlear models

Auditory brainstem responses to a chirp stimulus designed from derived-band latencies in normal-hearing subjects

Claus Elberling[a)]
Oticon A/S, "Eriksholm," DK-3070 Snekkersten, Denmark

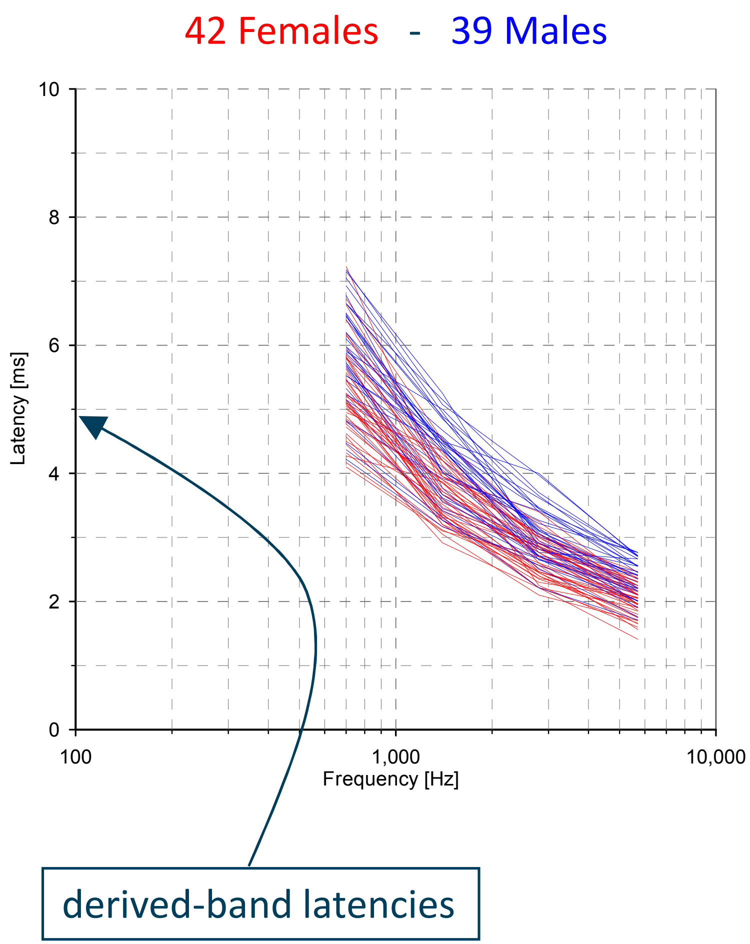
Manuel Don
Electrophysiology Laboratory, House Ear Institute, Los Angeles, California 90057

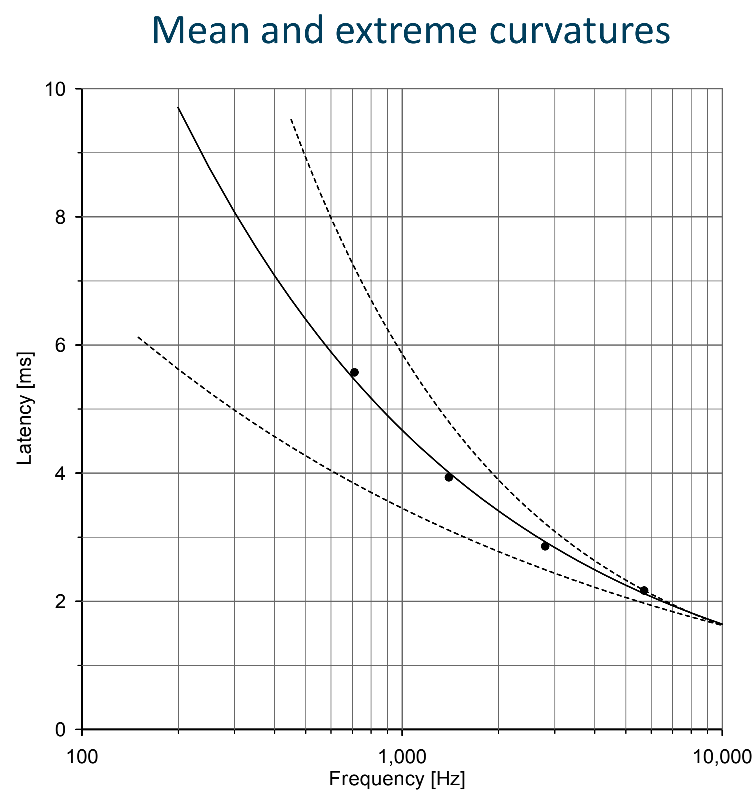
(Received 1 July 2008; revised 27 August 2008; accepted 27 August 2008)

In an attempt to compensate for the temporal dispersion in the human cochlea, a chirp has previously been designed from estimates of the cochlear delay based on derived-band auditory brain-stem response (ABR) latencies [Elberling *et al.* (2007). "Auditory steady-state responses to chirp stimuli based on cochlear traveling wave delay," J. Acoust. Soc. Am. **122**, 2772–2785]. To evaluate intersubject variability and level effects of such delay estimates, a large dataset is analyzed from 81 normal-hearing adults (fixed click level) and from a subset thereof (different click levels). At a fixed click level, the latency difference between 5700 and 710 Hz ranges from about 2.0 to 5.0 ms, but over a range of 60 dB, the mean relative delay is almost constant. Modeling experiments demonstrate that the derived-band latencies depend on the cochlear filter buildup time and on the unit response waveform. Because these quantities are partly unknown, the relationship between the derived-band latencies and the basilar membrane group delay cannot be specified. A chirp based on the above delay estimates is used to record ABRs in ten normal-hearing adults (20 ears). For levels below 60 dB nHL, the gain in amplitude of chirp-ABRs to click-ABRs approaches 2, and the effectiveness of chirp-ABRs compares favorably to Stacked-ABRs obtained under similar conditions. [DOI: 10.1121/1.2990709]

PACS number(s): 43.64.Qh, 43.64.Bt, 43.64.Ri [BLM] Pages: 3022–3037

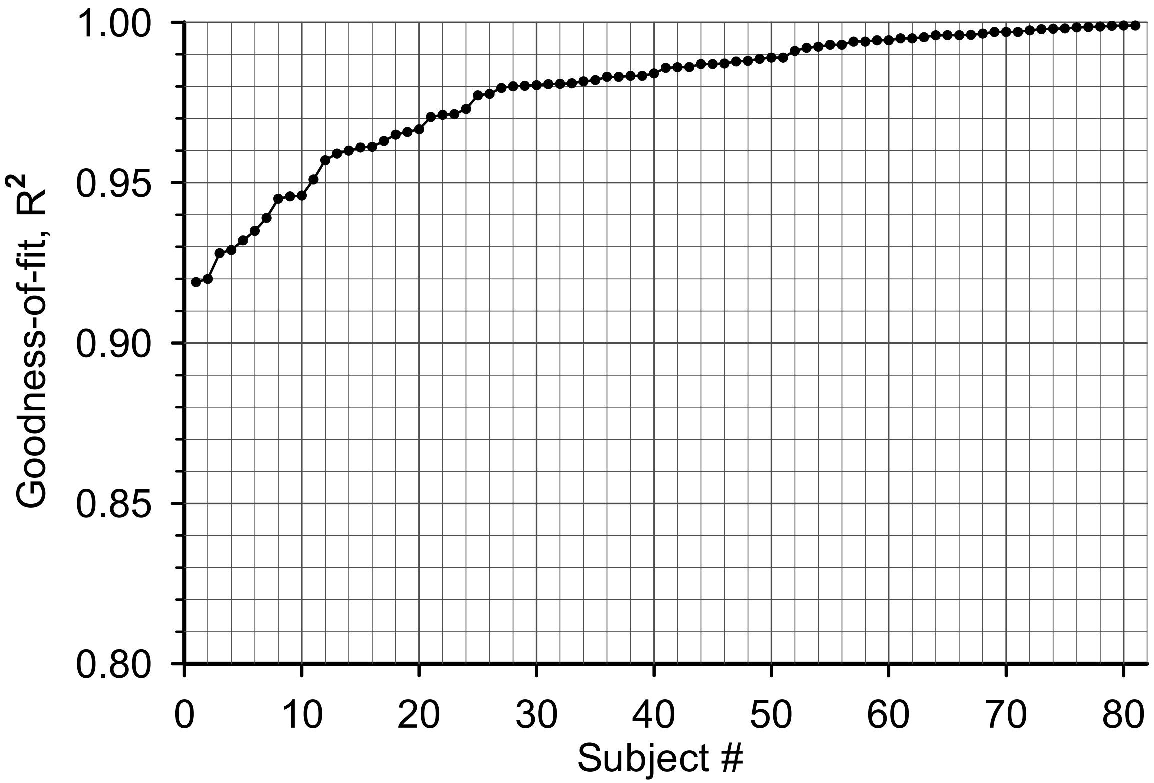
Power function: $\tau = k \cdot f^{-d}$





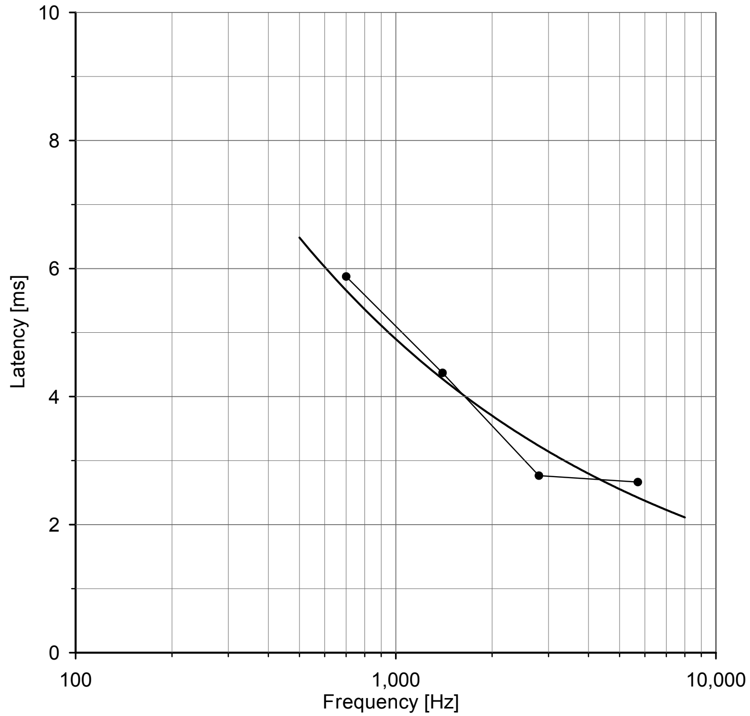
William Demant

Power function: $\tau = k \cdot f^{-d}$

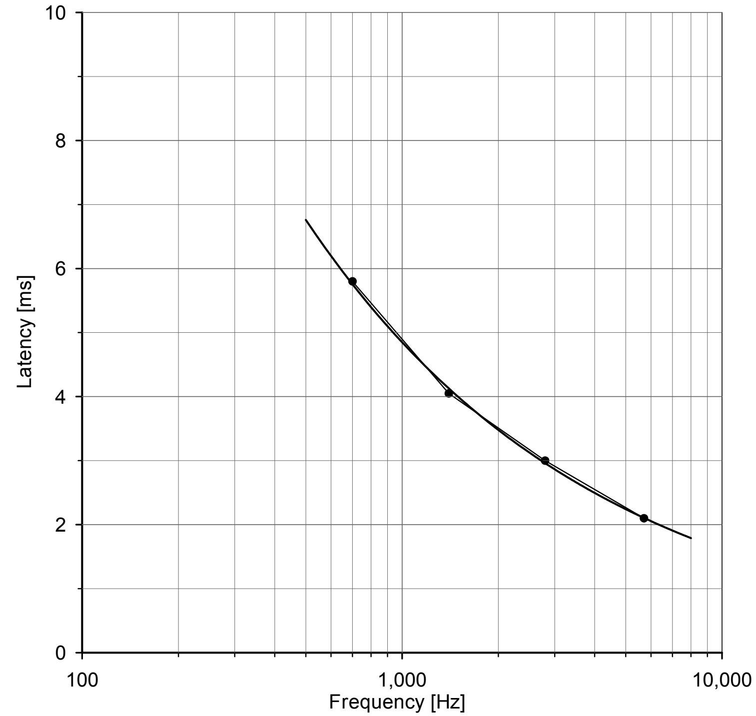


Power function: $\tau = k \cdot f^{-d}$

Poorest fit

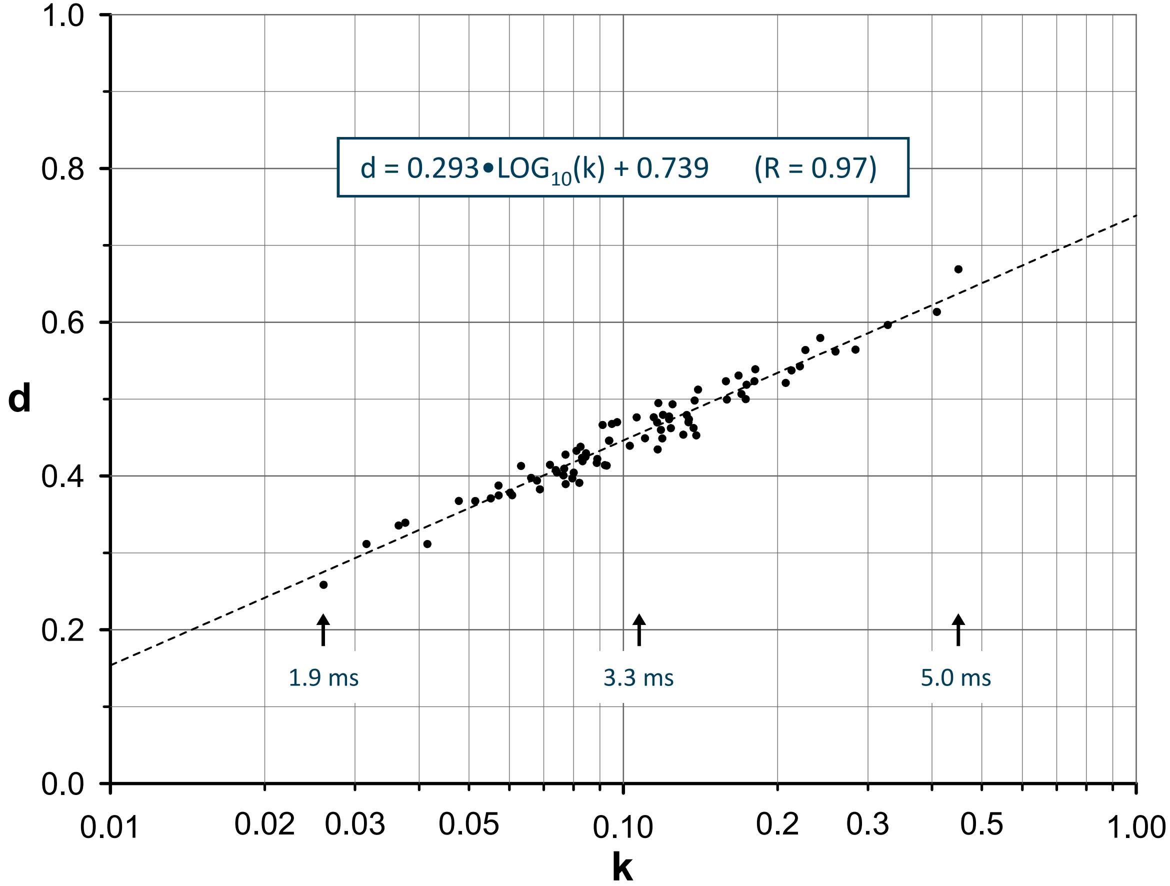


Best fit



William Demant

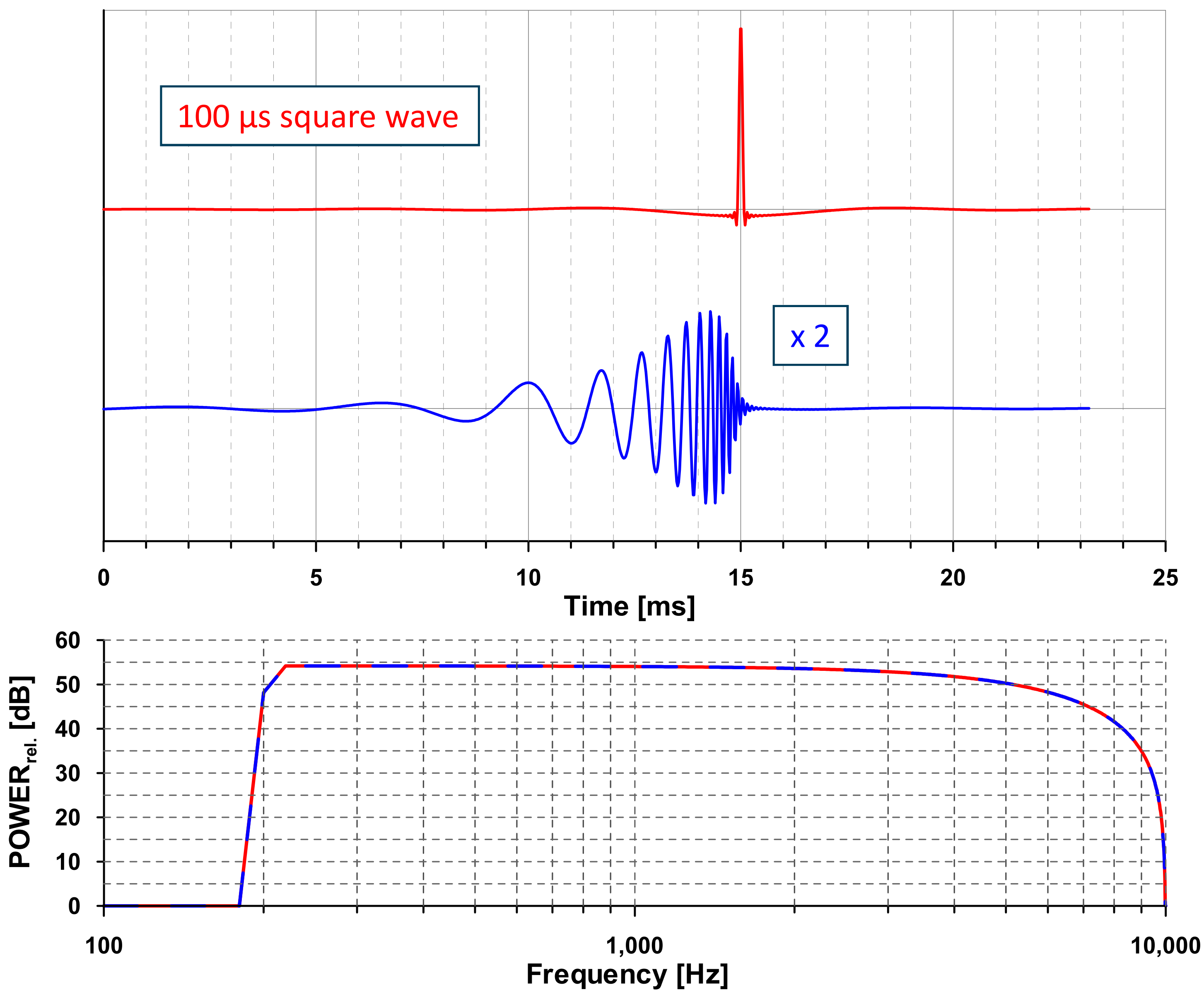
Power function: $\tau = k \cdot f^{-d}$



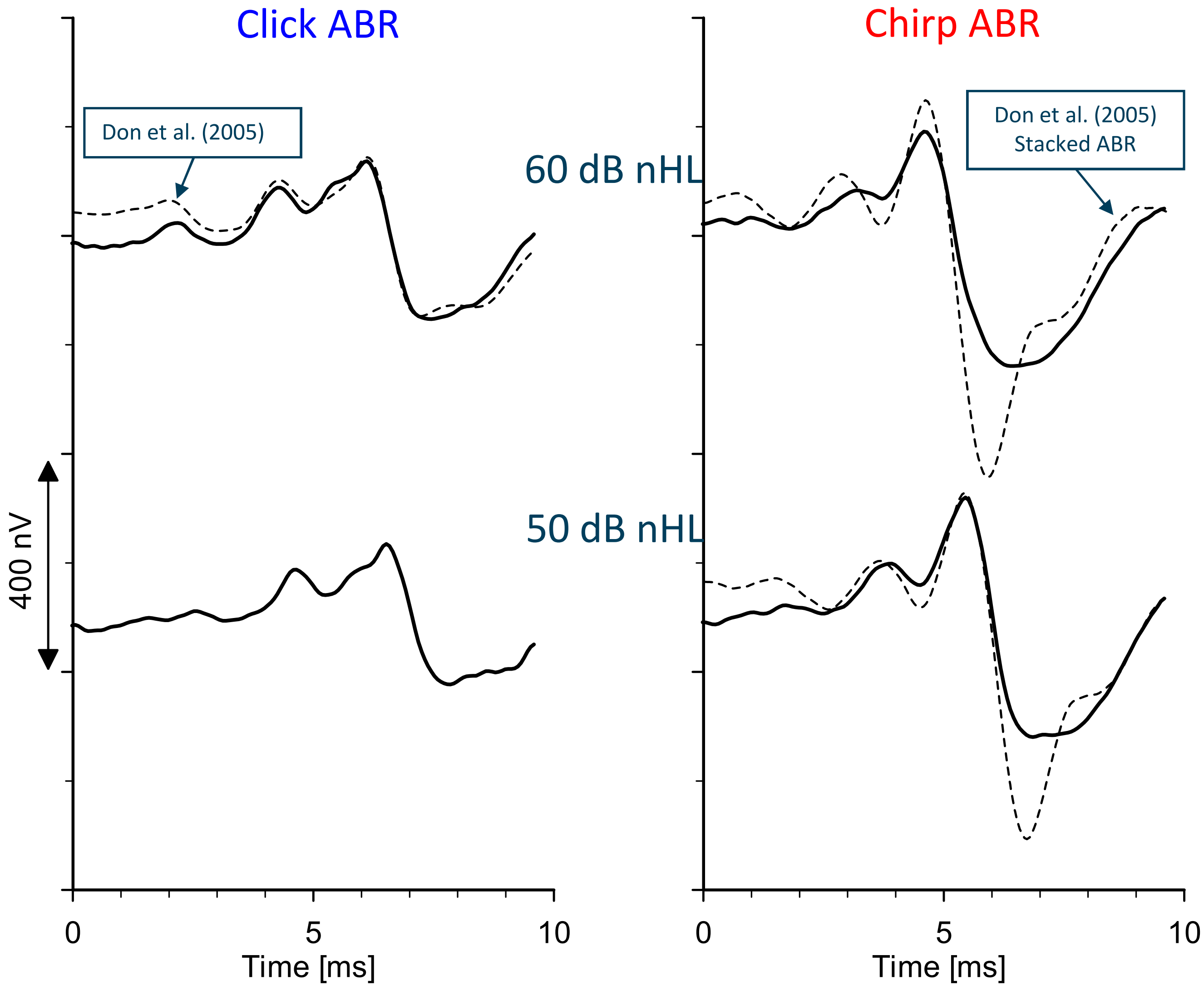
William Demant

Click and Chirp (200 – 10,000 Hz)

The Click and the Chirp have the same 'polarity' and identical amplitude spectra (~ |SIN(X)|/X).



Grand Averages



William Demant

Chirp based on cochlear models

J. Acoust. Soc. Am. 128, 215-223 (2010)

Evaluating auditory brainstem responses to different chirp stimuli at three levels of stimulation

Claus Elberling[a)]
William Demant Holding A/S, Kongebakken 9, DK-2765 Smørum, Denmark

Johannes Callø
Interacoustics A/S, Drejervænget 8, DK-5610 Assens, Denmark

Manuel Don
Electrophysiology Laboratory, House Ear Institute, 2100 W. 3rd Street, Los Angeles, California 90057

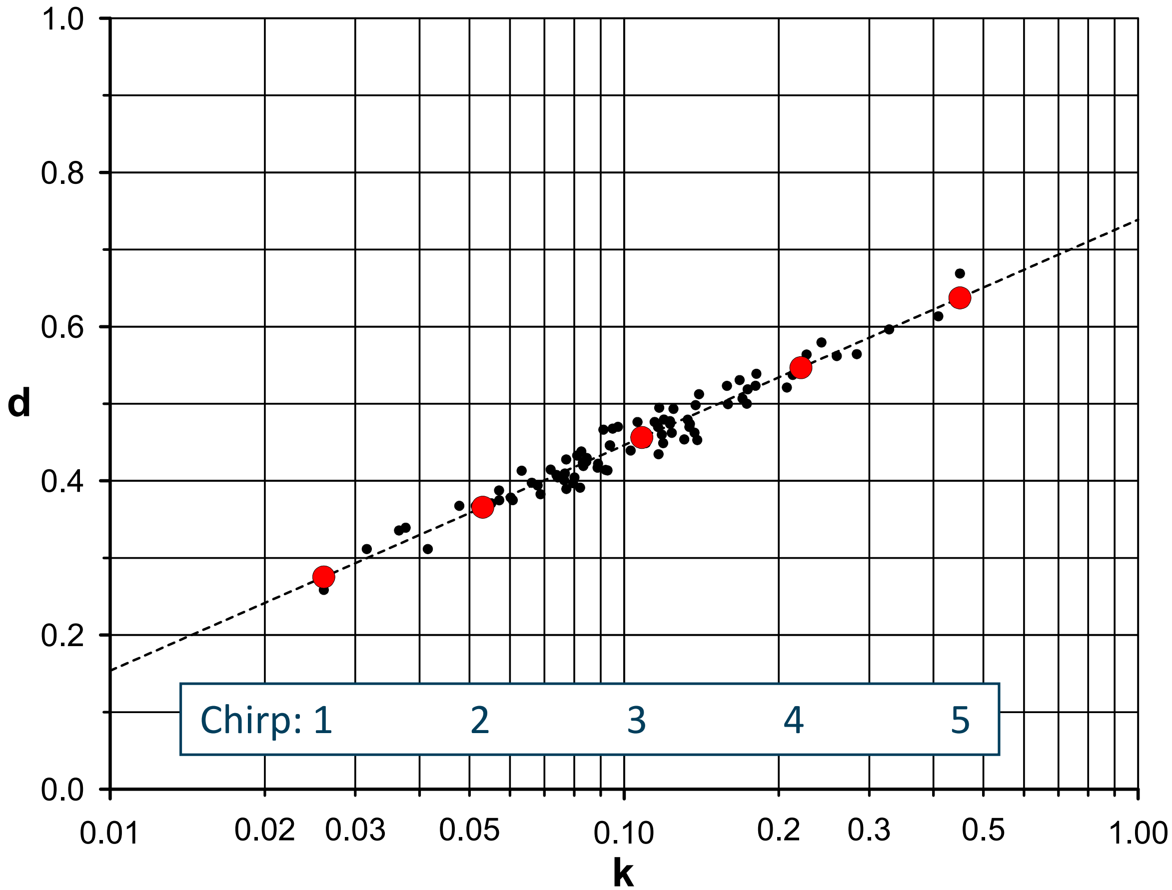
(Received 25 November 2009; revised 15 March 2010; accepted 28 March 2010)

Auditory brainstem responses (ABRs) are recorded in ten normal-hearing adults (20 ears) in response to a standard 100 μs click and five chirps having different durations (sweeping rates). The chirps are constructed from five versions of a power function model of the cochlear-neural delay that is based on derived-band ABR latencies from $N=81$ normal-hearing adults [Elberling, C., and Don, M. (2008). J. Acoust. Soc. Am. **124**, 3022–3037]. The click and the chirps have identical amplitude spectra and, in general, for each of the three stimulus levels 60, 40, and 20 dB nHL, the ABRs to the chirps are significantly larger than the ABRs to the click. However, the shorter chirps are the most efficient at higher levels of stimulation whereas the longer chirps are the most efficient at lower levels. It is suggested that two different mechanisms are responsible for these observed changes with stimulus level—(1) upward spread of excitation at higher levels, and (2) an increased change of the cochlear-neural delay with frequency at lower levels.
 [DOI: 10.1121/1.3397640]

PACS number(s): 43.64.Ri, 43.64.Qh, 43.64.Bt [WPS] Pages: 215–223

William Demant

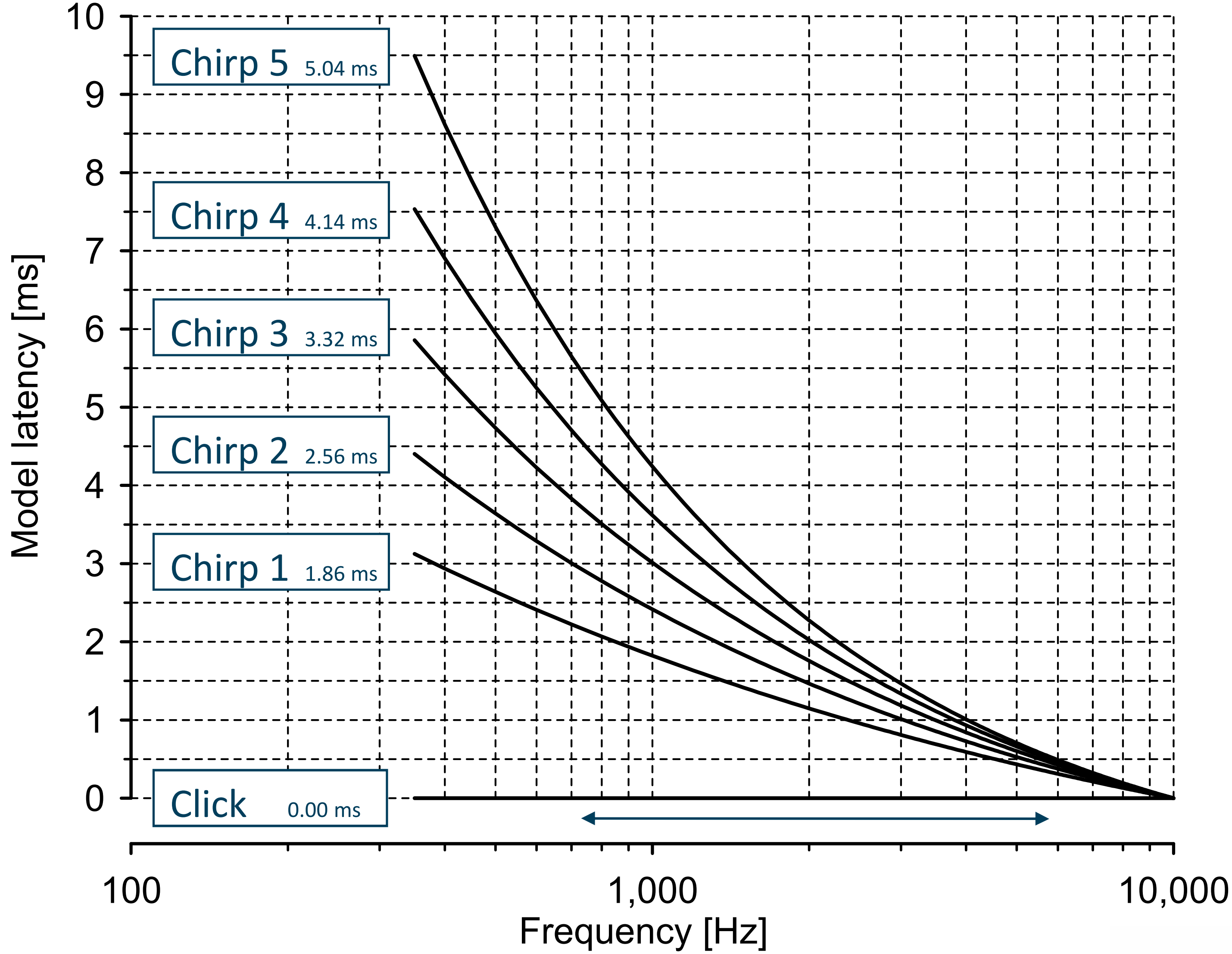
Five different chirps



k	d	Chirp
0.4501	0.6373	**5**
0.2207	0.5468	**4**
0.1083	0.4563	**3**
0.0531	0.3658	**2**
0.0260	0.2753	**1**

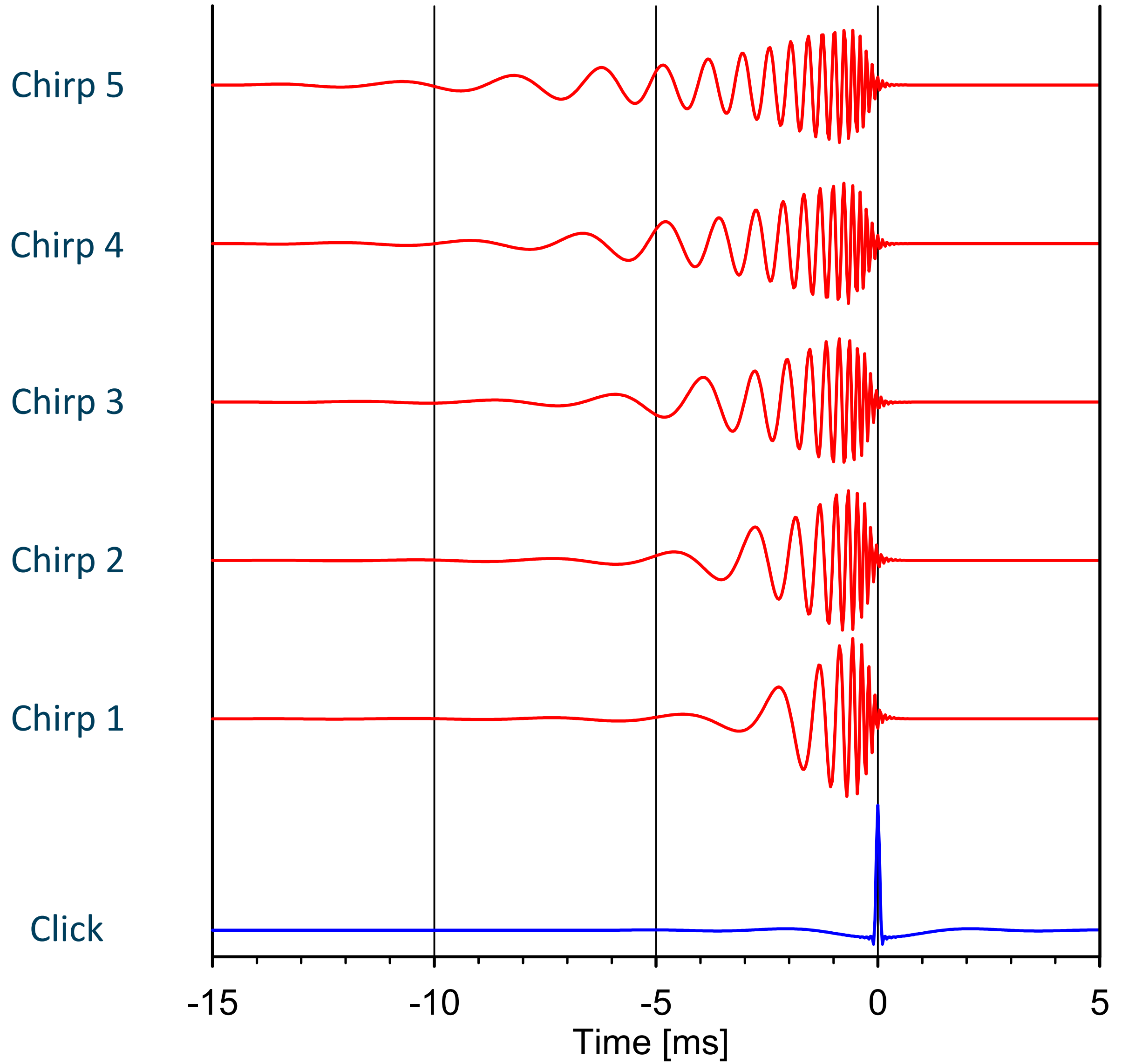
William Demant

Five different chirps



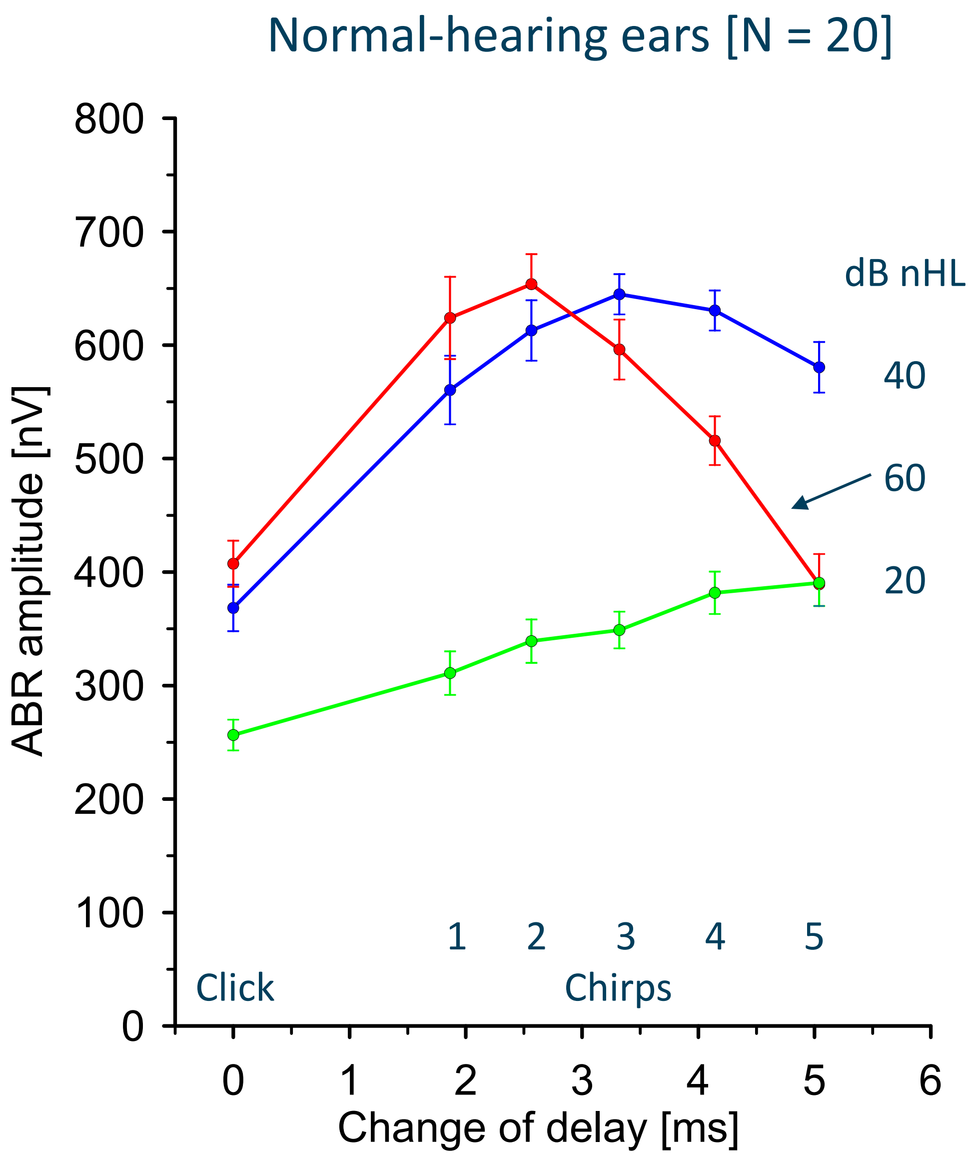
William Demant

Five different chirps



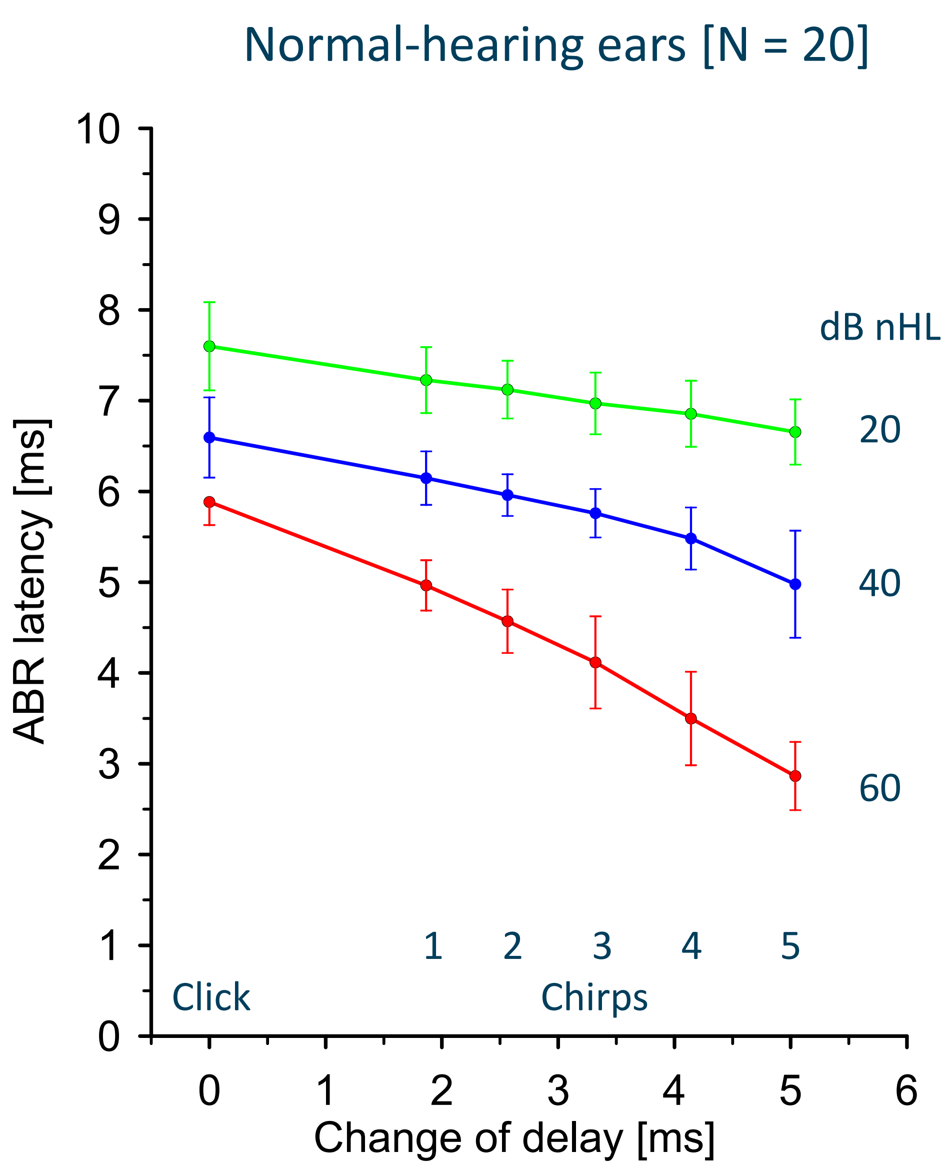
William Demant

Five different chirps



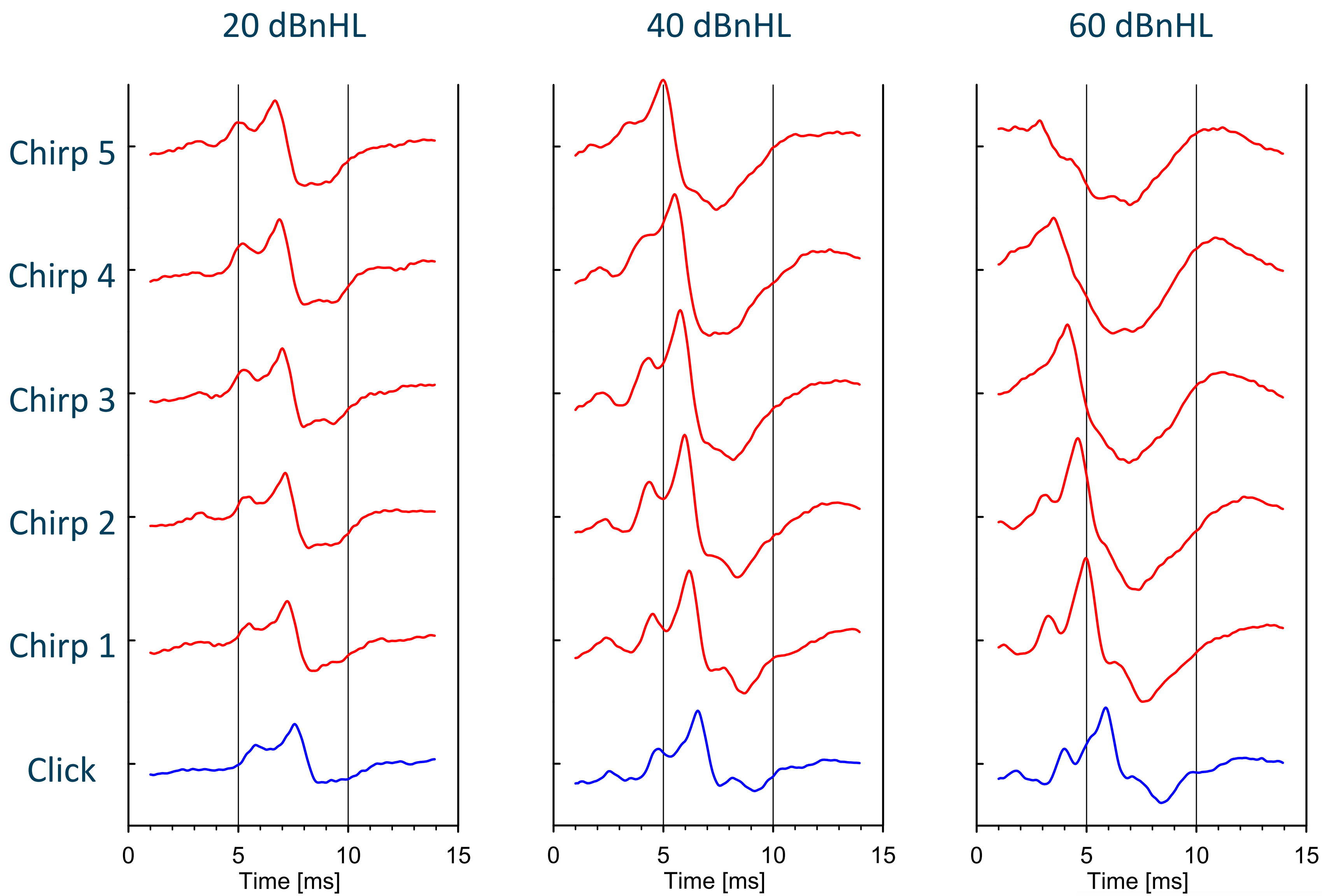
William Demant

Five different chirps



William Demant

Five different chirps

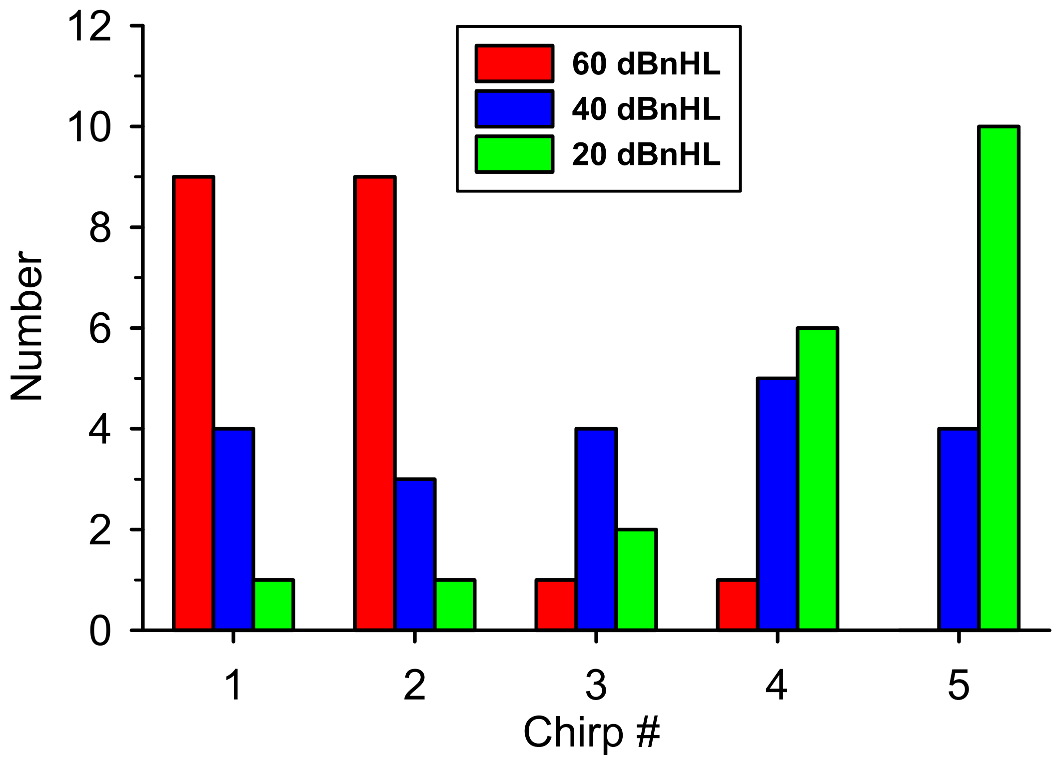


William Demant

Five different chirps

Normal-hearing ears [N = 20]

Number of recordings with the largest response amplitude



The direct approach model

A direct approach for the design of chirp stimuli used for the recording of auditory brainstem responses

Claus Elberling[a)]
William Demant Holding A/S, Kangebakken 9, DK-2765 Smørum, Denmark

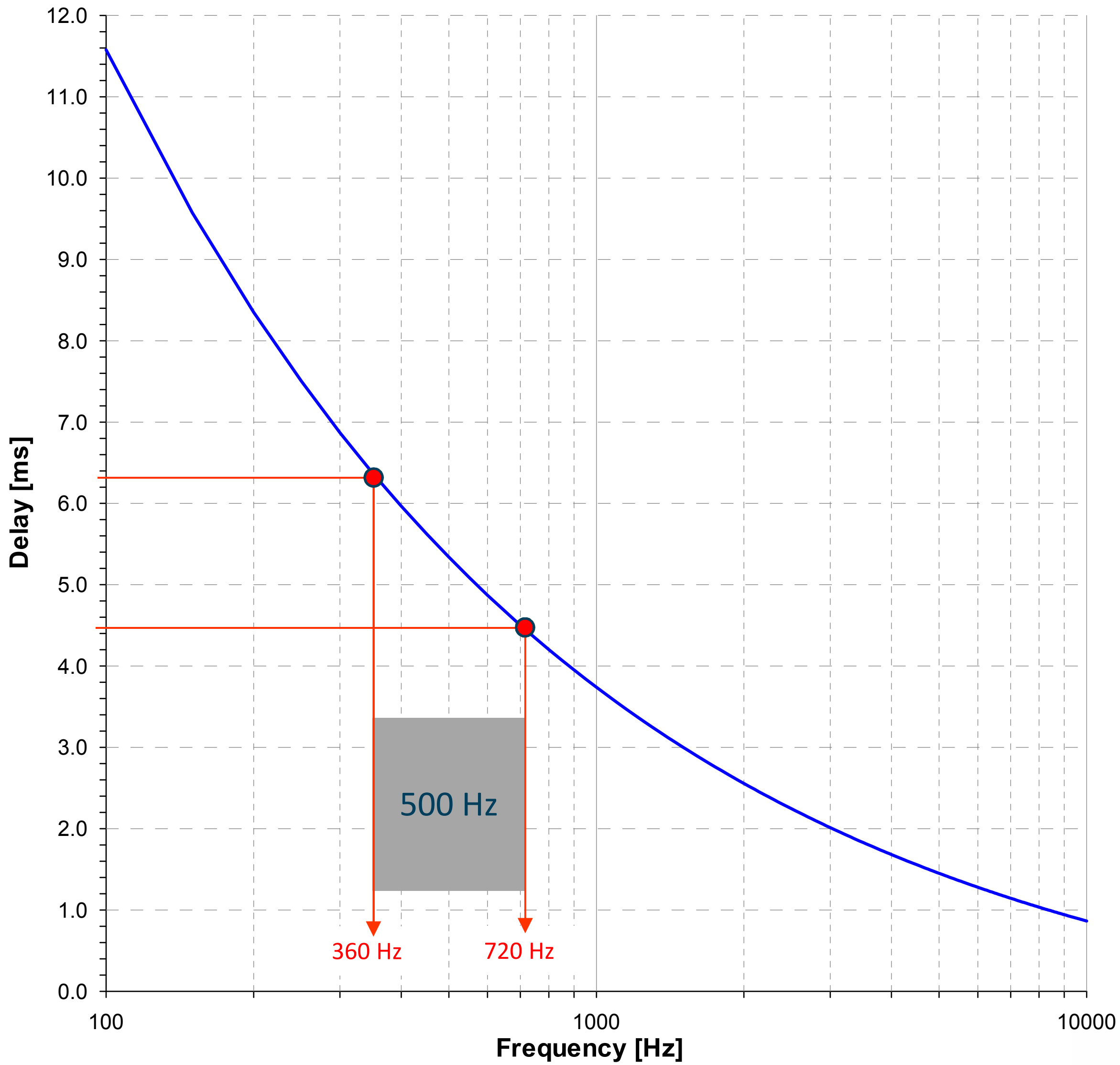
Manuel Don
Electrophysiology Laboratory, House Ear Institute, 2100 West 3rd Street, Los Angeles, California 90057

(Received 29 April 2010; revised 21 August 2010; accepted 23 August 2010)

A recent study evaluates auditory brainstem responses (ABRs) evoked by chirps of different durations (sweeping rates) [Elberling *et al.* (2010). J. Acoust. Soc. Am. **128**, 215–223]. The study demonstrates that shorter chirps are most efficient at higher levels of stimulation whereas longer chirps are most efficient at lower levels. Mechanisms other than the traveling wave delay, in particular, upward spread of excitation and changes in cochlear-neural delay with level, are suggested to be responsible for these findings. As a consequence, delay models based on estimates of the traveling wave delay are insufficient for the design of chirp stimuli, and another delay model based on a direct approach is therefore proposed. The direct approach uses ABR-latencies from normal-hearing subjects in response to octave-band chirps over a wide range of levels. The octave-band chirps are constructed by decomposing a broad-band chirp, and constitute a subset of the chirp. The delay compensations of the proposed model are similar to those found in the previous experimental study, which thus verifies the results of the proposed model.
 [DOI: 10.1121/1.3489111]

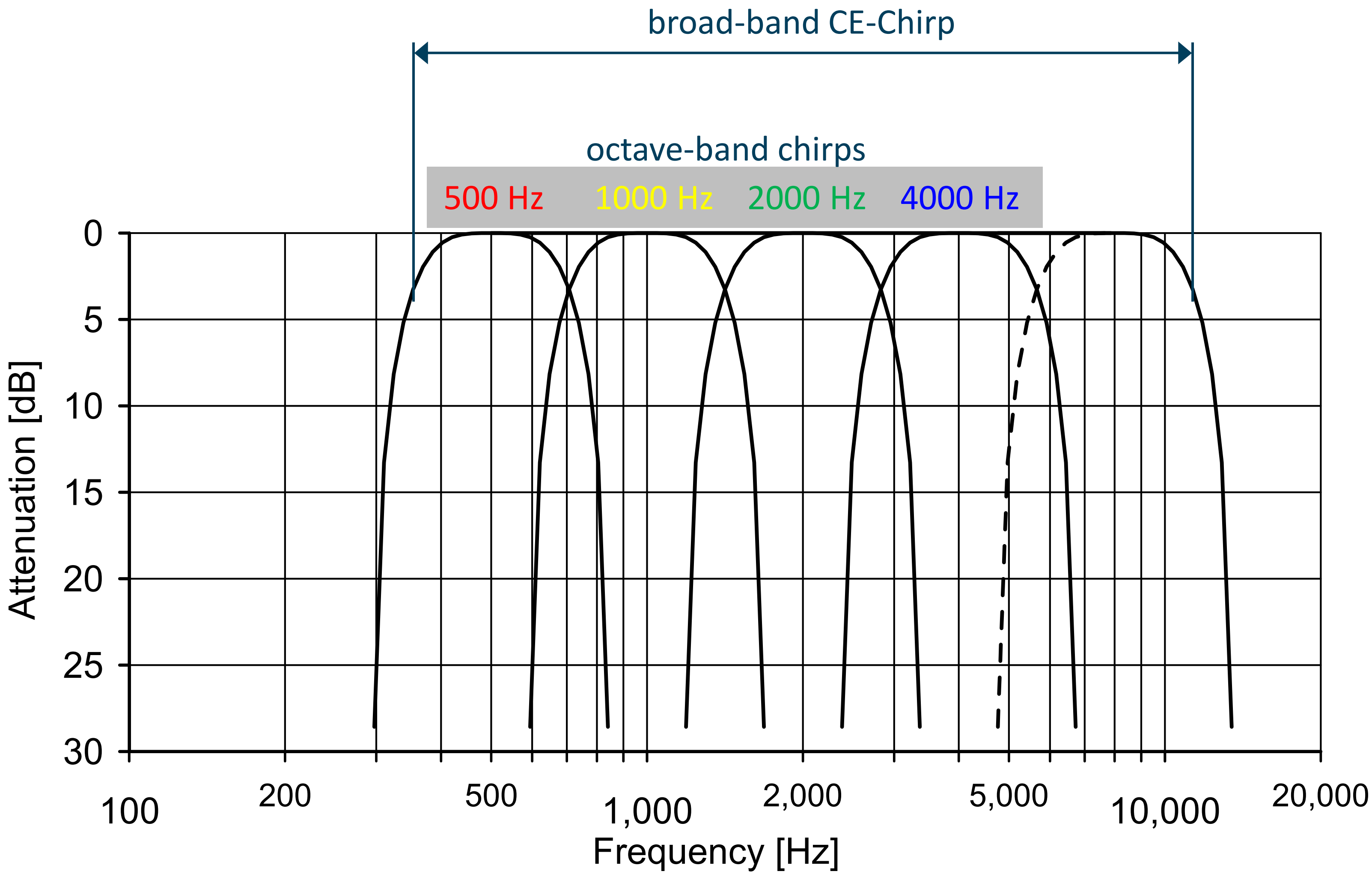
PACS number(s): 43.64.Qh, 43.64.Bt, 43.64.Ri [BLM] Pages: 2955–2964

Chirps - one octave wide



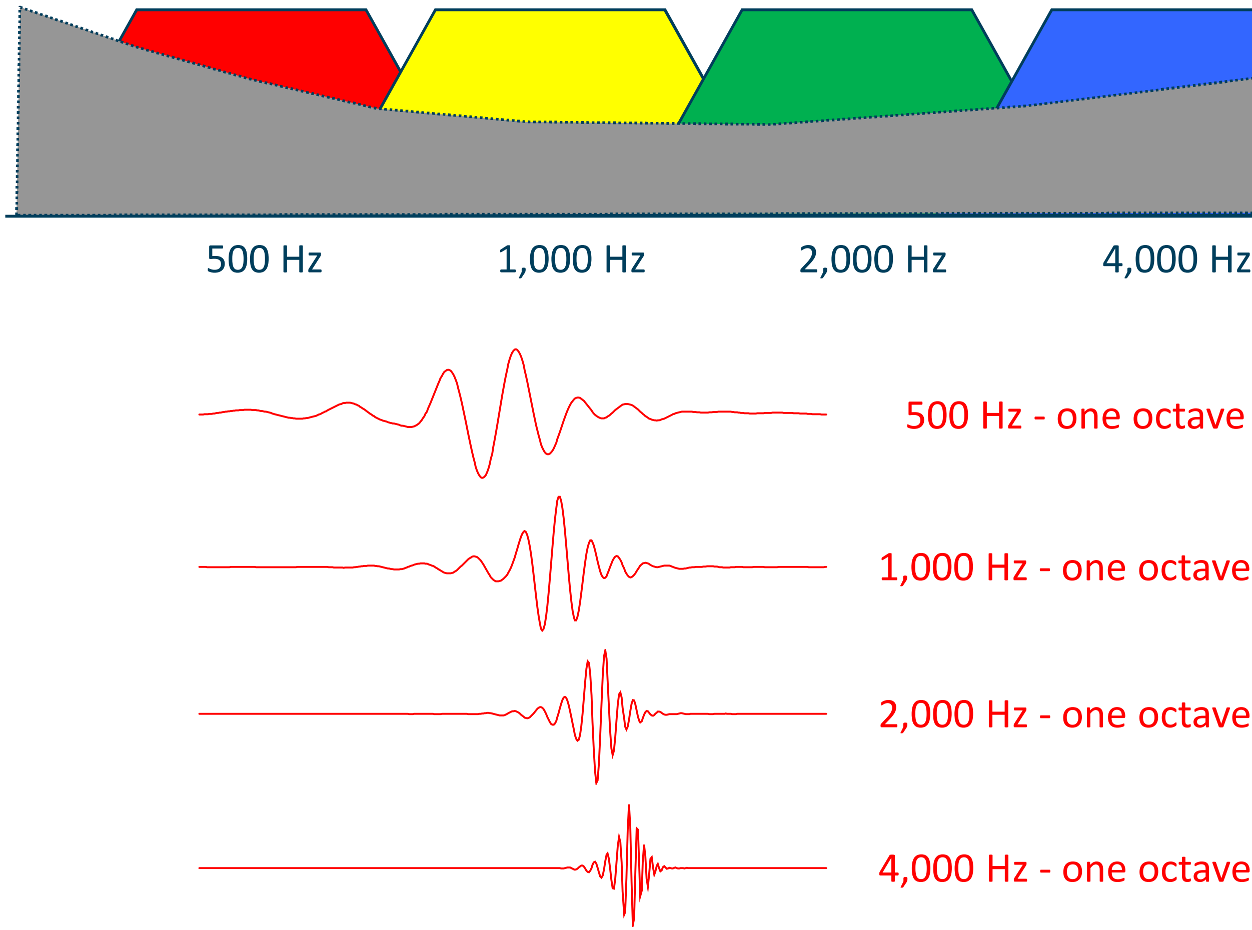
William Demant

Octave-band chirps

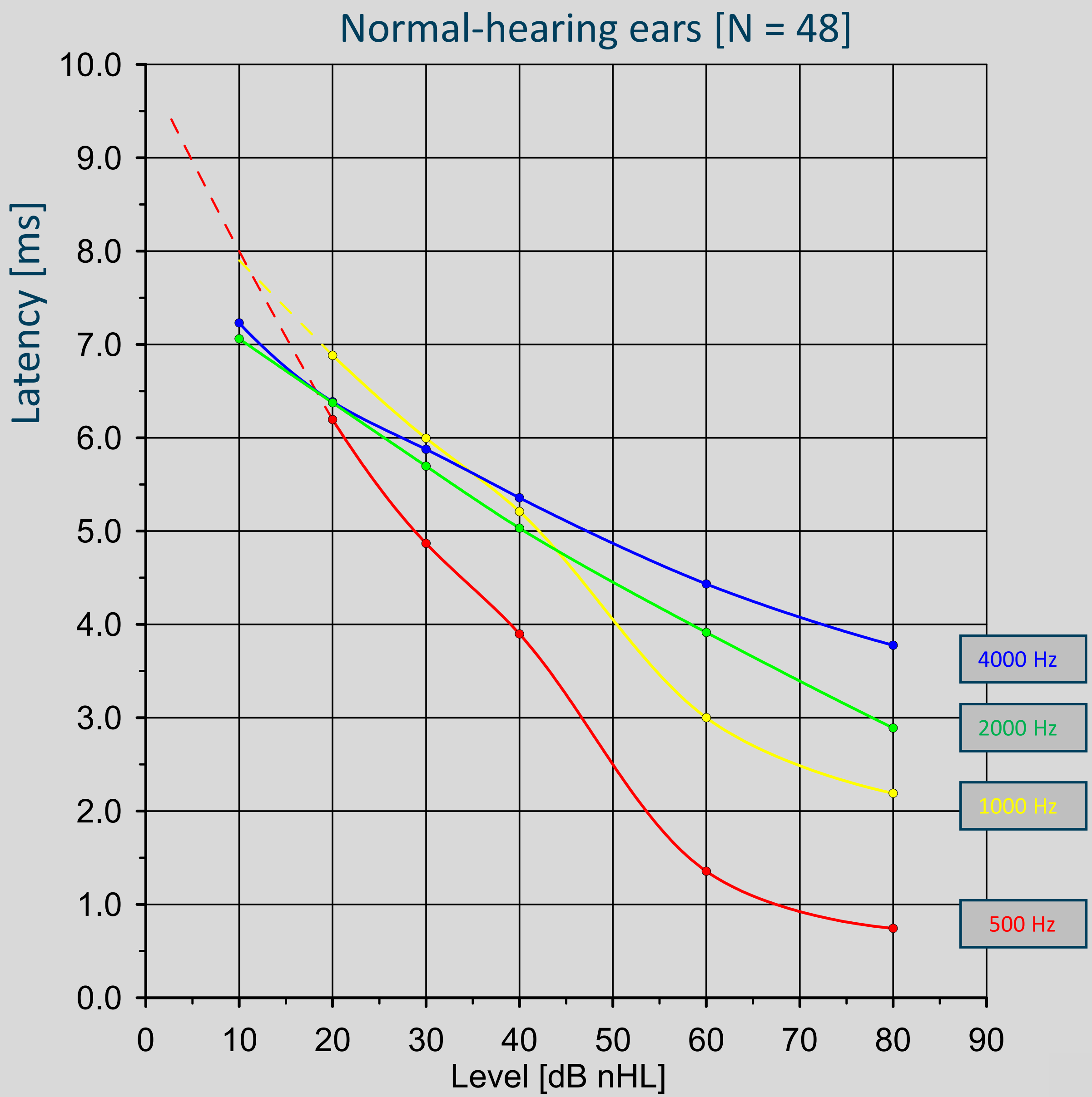


William Demant

Octave-band chirps

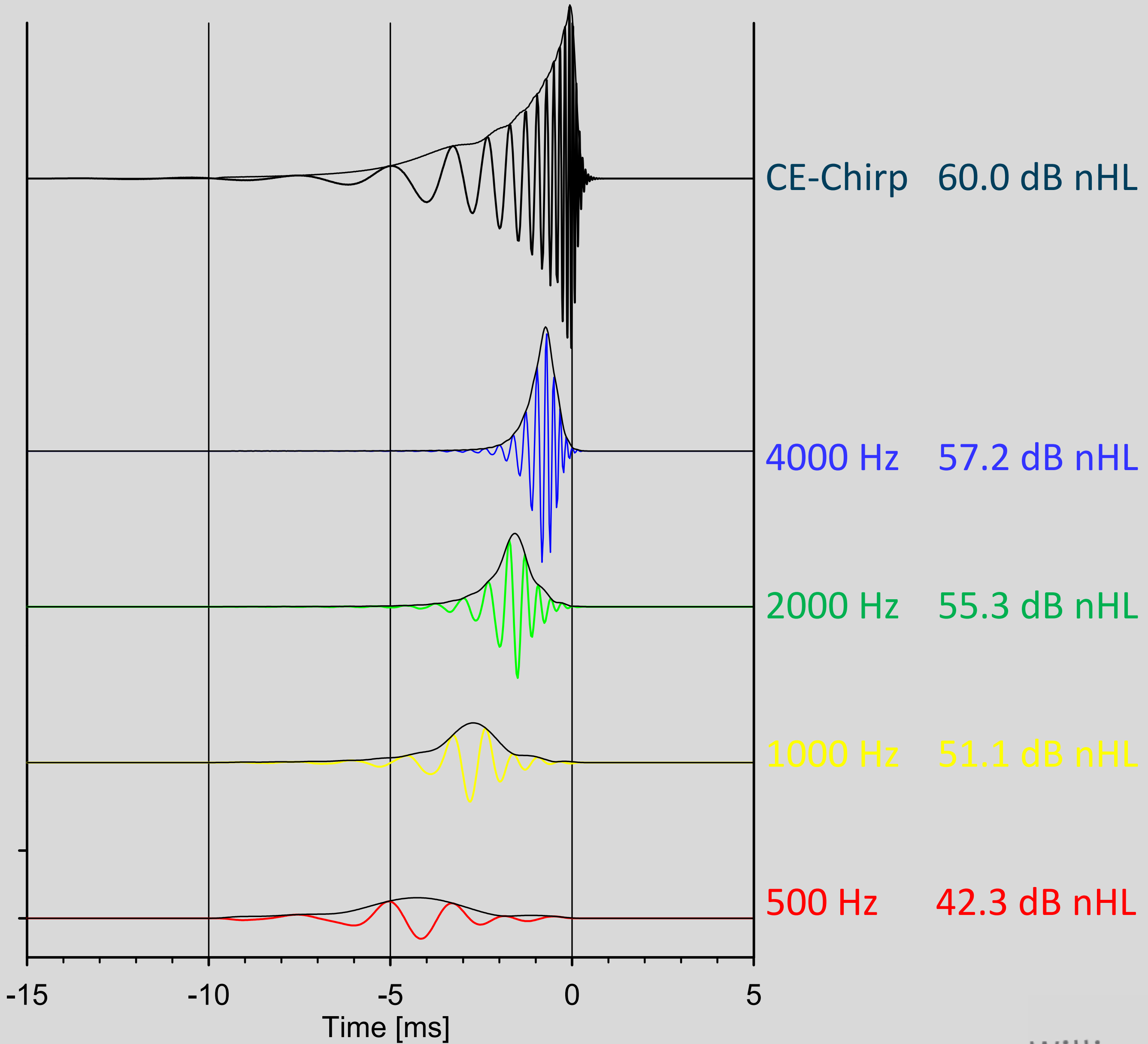


ABR-latency to octave-band chirps



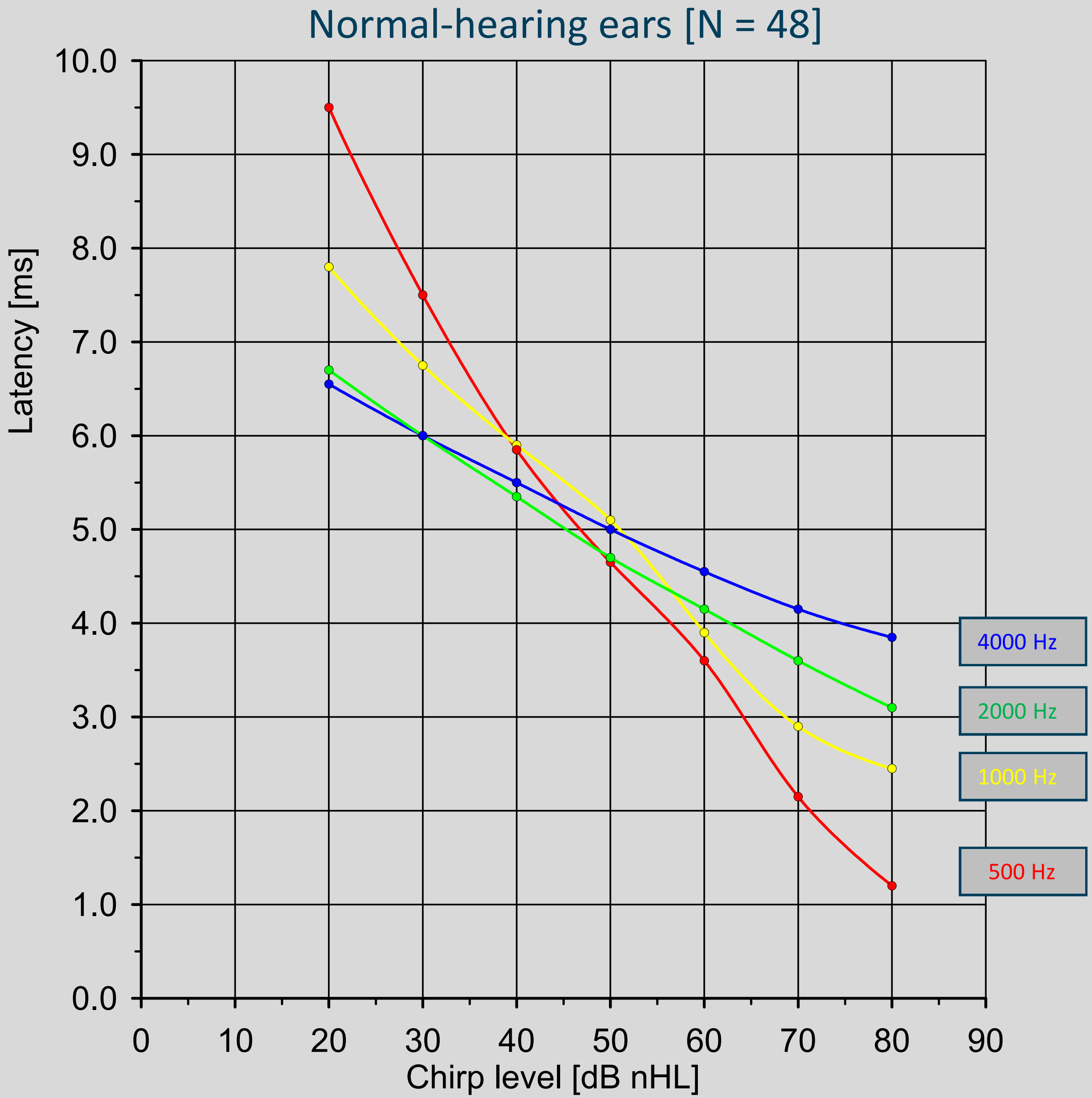
William Demant

Broad-band and octave-band Chirps



William Demant

ABR-latency to octave-band chirps



William Demant

New delay model

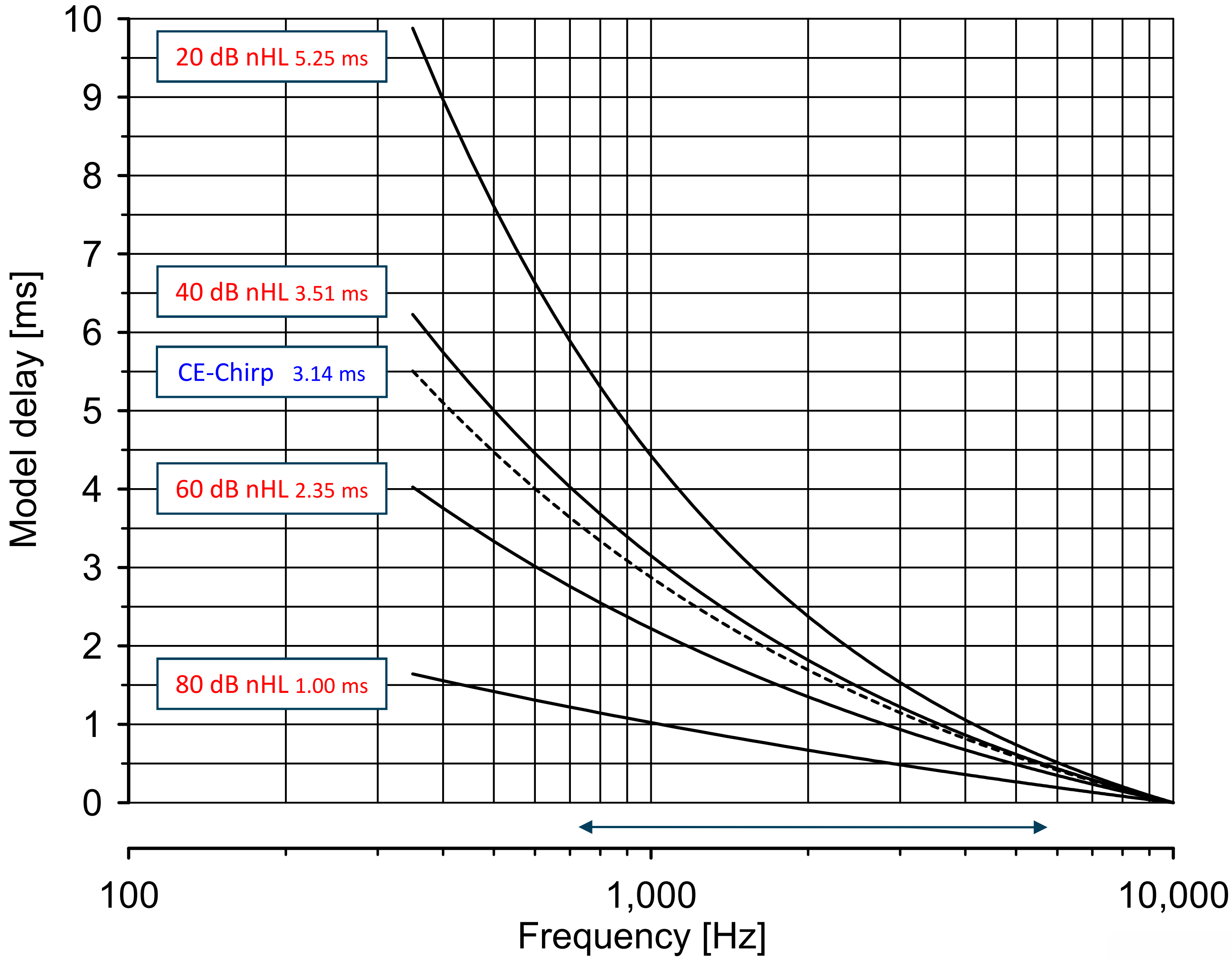
Formula for the new delay model:

$$\tau = k \cdot f^{-d}$$

$$\tau = k_1 \cdot e^{-k_2 \cdot L} \cdot f^{-(d_1 \cdot L + d_2)}$$

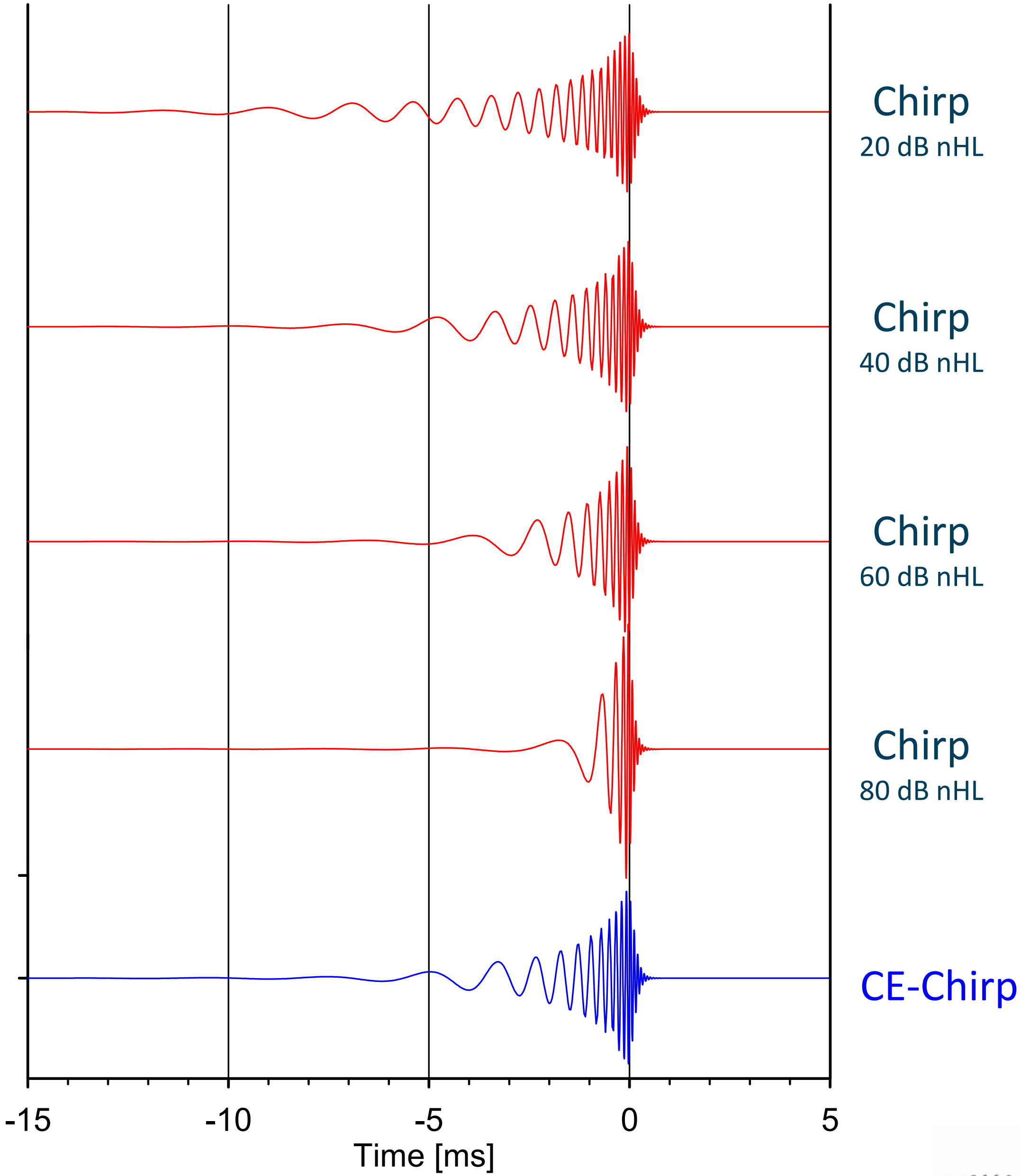
L = Chirp level [dB nHL]

New delay model



William Demant

Level-specific CE-Chirps => LS-Chirp



William Demant

Summary and Conclusion

- Summary
  - The cochlea and the traveling wave delay
  - Input and output compensation (the Chirp and the Stacked ABR)
  - Different delay models
  - Level effects of chirp-ABRs
  - The direct approach model
- Conclusion (for normal hearing subjects)
  - The Chirp generates much higher response amplitudes than the click – both of the ABR and of the ASSR
  - The efficiency of the Chirp is dependent on stimulus level
  - The Chirp needs to be shorter at higher levels
  - The Chirp needs to be longer at lower levels

END