# Modelling Of Outer Hair Cell Damage And Implications For Hearing Aid Signal Processing

**Christian Giguère**
Programme d'audiologie et d'orthophonie, Université d'Ottawa, Ottawa (ON), K1N 6N5

## 1.0 INTRODUCTION

Sensorineural hearing loss is associated with a variety of auditory disabilities such as elevated detection threshold, reduced frequency selectivity and temporal resolution, abnormal growth of loudness, and poor speech perception. Outer hair cell (OHC) damage is the underlying cause in many cases. Yet, despite rapid advances in hearing aid technology, the optimal solution to combat OHC damage is still a matter of debate and research. The success of future amplification strategies depends on our detailed knowledge of the effects of OHC loss, and on our understanding of what hearing aids can and cannot do to restore normal hearing.

## 2.0 GENERAL APPROACH

A mathematical model of the cochlea was used to assess the theoretical benefits of hearing aids to compensate for outer hair cell (OHC) damage (Giguère and Woodland, 1994; Giguère and Smoorenburg, 1999).

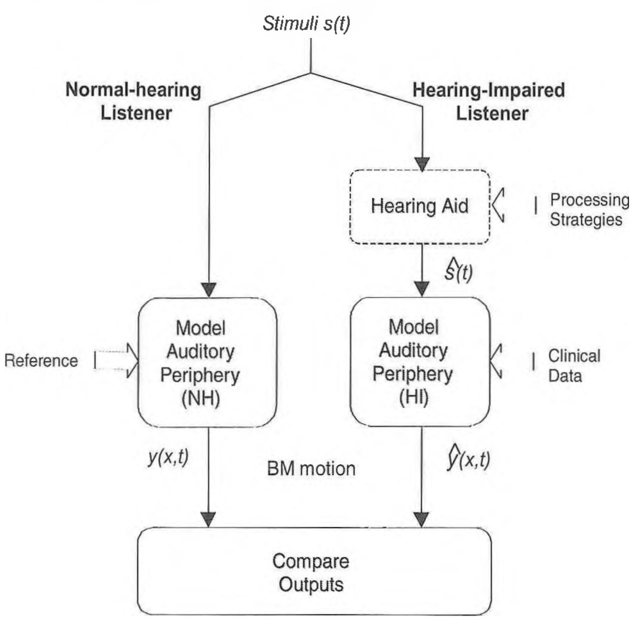


**Figure 1: Modelling framework**

*Question* — To which extent the BM response from a cochlea with damaged OHCs can be restored to that of a normal cochlea by processing the input signal as in a hearing aid?

*Tool* — A computational model of the auditory periphery (external ear, middle ear, cochlea) with OHC elements.

*Stimuli* — Pure tones, speech.

*Method* — Compare the BM excitation pattern of a normal-cochlea model against that of a model configured for different degrees of the OHC damage in conjunction with different hearing aid processing strategies (see Figure 1).

*Hearing aid processing* — Multi-band amplitude compression, spectral sharpening.

## 3.0 SIMULATIONS

Figure 2a illustrates the basilar membrane excitation patterns at the output of the model with intact OHCs (N) and for different degrees of OHC damage (D) for a synthetic vowel /ae/. With increasing hearing loss: (1) the gain gradually decreases throughout the cochlea, (2) the spectral resolution decreases and the formants (F1 to F3) broaden, and (3) the basalward (upward) spread of masking increases (F2 on F3).

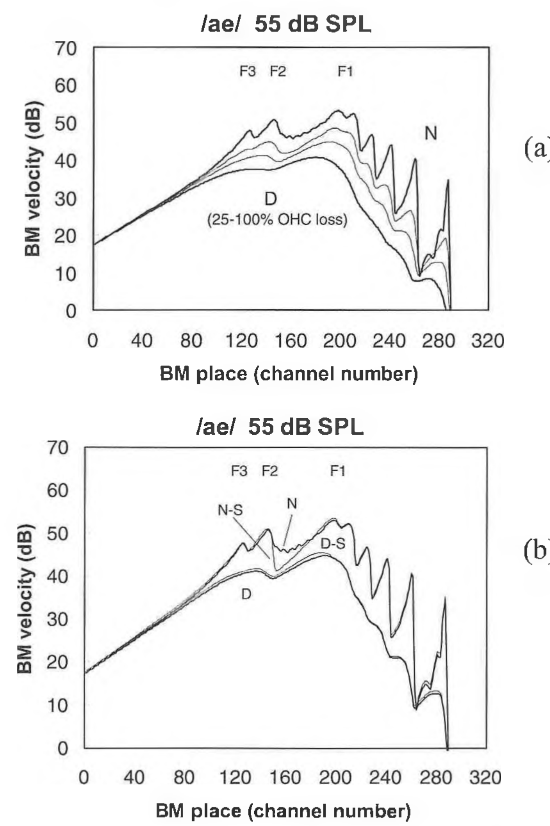


**Figure 2: Basilar membrane excitation patterns at the output of the cochlea model from base (channel 0) to apex (channel 320). N = normal cochlea, D = damaged cochlea, N-S: normal cochlea with spectral sharpening, D-S: damaged cochlea with spectral sharpening, F1 to F3: vowel formants.**

Figure 2b illustrates the effects of spectral sharpening (S) on the basilar membrane excitation patterns. The benefits of spectral sharpening is only evident in the case of the normal cochlea (N vs N-S), where there is an increase in the peak-to-valley ratio between formants F1 and F2. There are no benefits of spectral sharpening when the basilar membrane excitation patterns have been degraded due to OHC damage (D vs D-S).

## 4.0 CONCLUSIONS

- The effects of OHC loss on BM vibration depend on both frequency and place;

- OHC loss leads to:
  (1) a basalward shift of the place of maximum vibration,
  (2) a decreased gain near the characteristic place,
  (3) a broadening of the tuning curves,
  (4) an altered summation of activity across frequency components, and
  (5) an altered temporal waveform.

- From a hearing aid point of view, only the frequency dimension is accessible, not the place dimension. The main consequence of this mismatch is that hearing aids cannot, in general, compensate for the exact damage caused by OHC loss;

- Hearing aids can compensate for the general loss of sensitivity and reduced dynamic range, but they cannot compensate completely for the reduced frequency selectivity associated with OHC damage.

- BM vibration cannot be completely restored for pure tones, complex tones, vowels, and in general for sounds where the BM excitation pattern is dominated by narrow-band energy.

- A broadening of the BM excitation curves by a factor 2 to 3 would severely limit the choice of signal processing strategies available.

## REFERENCES

[1] Giguère C. and Woodland P.C. (1994). "A Computational model of the auditory periphery for speech and hearing research. I. Ascending path," J. Acoust. Soc. Am. 95: 331-342.

[2] Giguère, C. and Smoorenburg, G.F. (1999). "Computational modeling of outer hair cell damage: Implications for hearing aid signal processing," in: Psychoacoustics, Physiology and Models of Hearing, edited by T. Dau, V. Hohmann and B. Kollmeier (World Scientific, Singapore), pp. 155-164.