# Why Most Hearing Models are Incorrect

David McClain, Acudora, Inc.

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**Abstract**

For listeners with typical noise-induced sensioneural hearing impairment, a shaped noise field at normal loudness levels can be used to estimate the degree of threshold elevation at all frequencies from just one listening. Hearing aids fitted at these estimated elevations can produce greater satisfaction for the listener since the degree of extrapolation of manufacturer's (possibly incorrect) loudness models is minimized.

Moore, B. C. J., B. R. Glasberg and T. Baer (1997). "A Model for the Prediction of Thresholds, Loudness, and Partial Loudness." Journal of the Audio Engineering Society 45(4): 224-240.

## 1 Discussion

Iso-loudness contours are most often displayed in terms of dB intensity versus log frequency. The log frequency axis provides excessive emphasis to the lower frequencies and less emphasis of high frequencies where audiological damage most often occurs in noise-induced sensioneural hearing loss.

By plotting measured threshold elevations in dBHL against Bark frequency, these are found to lie along a low order polynomial, to within experimental errors. The Bark frequency axis gives more prominence to the mid-range frequencies, and less to the deep bass frequencies. Bark frequency also corresponds more closely to the nature of human hearing. Bands of constant Bark-bandwidth widen approximately logarithmically toward higher frequencies, while remaining nearly constant bandwidth below 500 Hz.

A low order polynomial fit is intuitively satisfying as it corresponds to a physics model of hearing damage, which should decline exponentially as a simple function of linear distance along the basilar membrane. Highest frequencies are sensed nearest to the oval window of the cochlea, and lowest frequencies are sensed at the apex. As per Bekesey's position

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theory for pitch perception, Bark frequencies better model the linear distance along the basilar membrane than log frequencies.

As we will show, standard audiology is highly inaccurate as a means to assess the actual degree of hearing damage, most often overestimating the effective working threshold elevations for persons in normal loudness range environments. Coupled with a poor understanding of the loudness response, the use of threshold measurements to extrapolate to the degree of compression needed for normal loudness levels exaggerates the errors of both measurements and loudness response model failures.

Fitting at loudness levels that correspond more closely to everyday experience minimizes the exaggerations of measurement errors and model failures since the degree of extrapolation is minimized. A shaped noise field, with approximately equal power per unit of Bark frequency, can be used to perform a test that requires only one listening, as the audiologist adjusts the coefficients of the low-degree polynomial that best approximates the listener's impairment curve.

Figure 1 shows an example of audiology for a typical case of sensioneural hearing loss, plotted against the usual logarithmic frequency in kHz. The background gray curves indicate iso-loudness contours. The orange curve shows a typical ambient spectrum at loud, but comfortable, levels. Where the indicated audiology threshold elevations are below the ambient spectrum, the listener can presumably hear that portion of spectrum without assistance.

Figure 2 shows the same audiology when plotted against Bark frequency. The straight green line shows the approximate line along which the audiology appear to fall. Corresponding frequencies in kHz are shown along the top of the graph. Deviations of audiology from that straight line can be largely attributed to inherent innaccuracies of standard audiological threshold measurements.

Weighted fitting of the audiology measurements in these graphs might be deemed appropriate. However, the need for corrective compression is greatest where the threshold elevations are greatest, while measurement uncertainties are also greatest at those same frequencies. Hence the importance weighting is cancelled by the uncertainty weighting, making a simple unweighted best-fitting wholly appropriate.

Figure 3 shows why typical audiology can become so inaccurate. The thick green curve represents normal human hearing, from threshold levels at the left, to extremely loud levels at the right. The axes represent Phon presentation loudness levels along the horizontal axis, and perceptual log-Sone loudness levels along the vertical axis. By presenting these curves in loudness space, we can represent the behavior of human hearing in a frequency independent manner.

At very loud levels most hearing becomes asymptotically compressive with a slope of about

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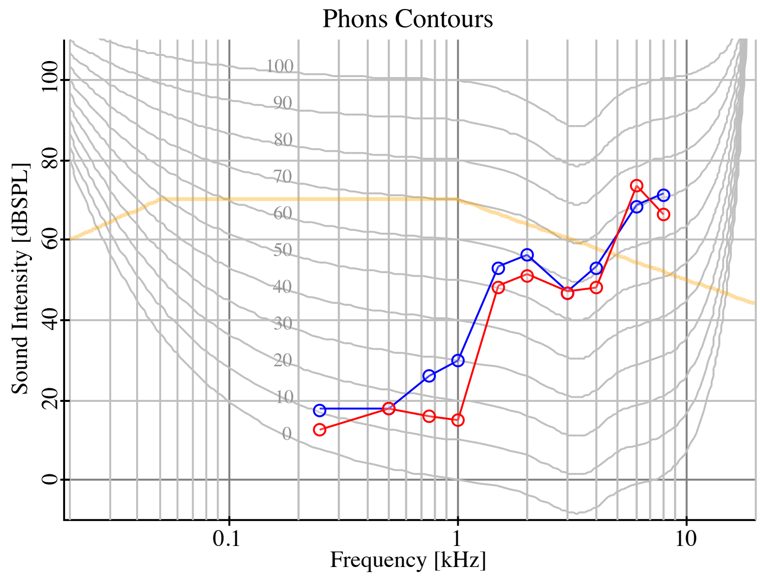


Figure 1: *Example audiology for sensioneural hearing impairment as a function of frequency in kHz.*

0.34. For normal hearing, below 20 dB Phon, the hearing curve bends downward, ultimately becoming linear with loudness at threshold levels.

These asymptotic relationships have long been known. What hasn't been well established is the exact nature of the transition region between compressive hearing at louder levels and linear response at threshold levels, in the green curve for normal hearing. Hence, the zero point calibration of most audiological test stations is quite a bit in doubt.

Furthermore, as one can see, the recruited hearing (red) curves become very steep in the vicinity of the elevated thresholds. Audiology seeks to determine the loudness location of these steep segments, relative to the green normal hearing curve at threshold levels. A small error in either the zero point of the measuring device, or its gain, produces large swings in perceived amplitude for hearing impaired persons.

Taken together, these measurement and calibration errors, along with inexact understanding of the shapes of these recruitment curves, means that errors at threshold levels will become magnified as we extrapolate to the necessary gain and compression ratios at typical normal loudness levels.

Based on the widely reported dislike of hearing aid settings, I would suggest that both the zero point setting and the gains of standard audiology measuring devices are poorly un-

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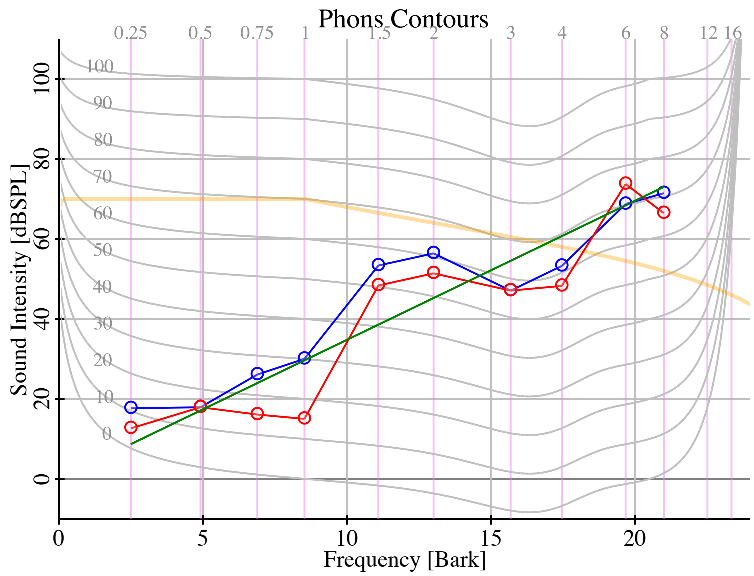


Figure 2: *Example audiology for sensioneural hearing impairment as a function of frequency in Bark.*

derstood by audiology practitioners. Invariably, the threshold elevations are overestimated and lead to too much correction at normal listening loudness levels. The experience of hearing aid wearers is that frequencies around 1 kHz are grossly overcorrected, and this happens to be at a frequency where many still have substantial discernment.

An audiology test station could be designed with simple potentiometer adjustments for each of the low-order polynomial coefficients that control the underlying best fitting curve. The audiologist would present the shaped noise field, and perform coefficient adjustments until the unassisted listener can just discern the highest possible frequency. At that point, the coefficients can be used to estimate threshold elevations at all frequencies that best correspond to these normal loudness level sounds. Those estimated threshold elevations can be fed to the manufacturer's hearing aid adjustment process to make a more satisfactory hearing aid setting for the subject.

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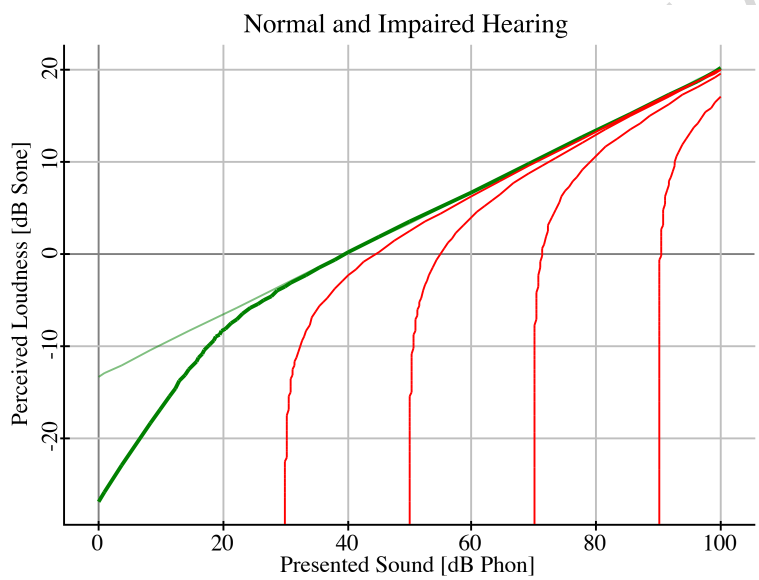


Figure 3: *Curves of normal (green) and recruited hearing (red) for varying degrees of threshold elevation.*

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