The VTuning™ Model for Hearing Damage

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Abstract

When audiology of sensioneural impairment is plotted in Bark frequency space, the indicated threshold elevations in dBHL fall roughly along a straight line. On the basis of Bekesy's position theory for pitch perception, this corresponds to an exponential decline in cochlear damage as one proceeds from the oval window, where high frequencies are sensed, toward the apical end where bass frequencies are discerned. Intuitively, this is a sensible first-order model, as one would expect the damage to decrease exponentially along the length of the cochlea due to power dissipation. VTuning takes advantage of that model to predict effective threshold elevations that are more in line with actual hearing experience than can be obtained from standard audiological examinations.

1 Discussion

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

By plotting measured threshold elevations in dBHL against Bark frequency, these are found to lie along a straight line (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.

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. VTuning presents a more accurate estimate of hearing damage, as assessed by listener studies in realistic listening environments.

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 musical spectrum at loud, but comfortable, levels. Where the indicated audiology threshold elevations are below the musical spectrum, the listener can presumably hear that portion of spectrum.

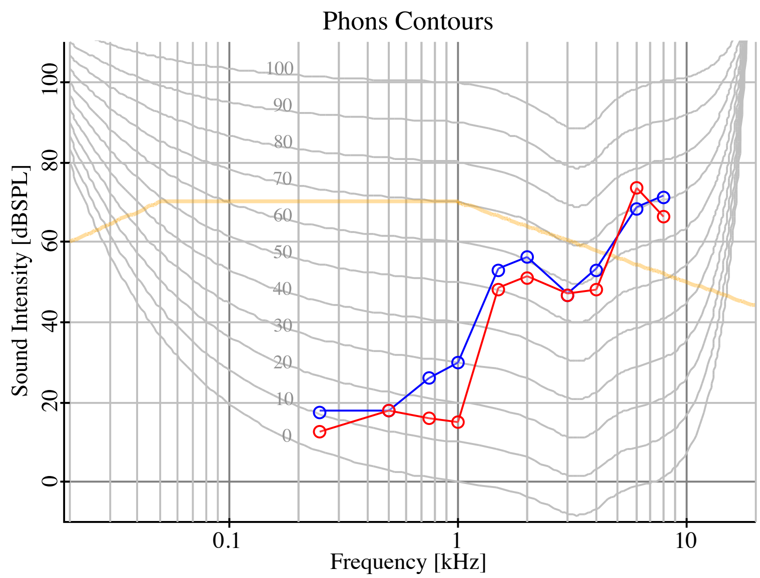

Figure 1: *Example audiology for sensioneural hearing impairment as a function of frequency in kHz.*

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.

Our VTuning is simply a measure of the slope of this straight line, dB Phon vs Frequency in Bark, starting at 250 Hz, or 2.5 Bark. We make the assumption that frequencies below 250 Hz are largely unaffected by typical sensioneural impairment. Effectively, VTuning is a measure of how severe the damage is in the region of the cochlea near the oval window, and describes the rate at which damaging power was dissipated along the length of the cochlea.

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

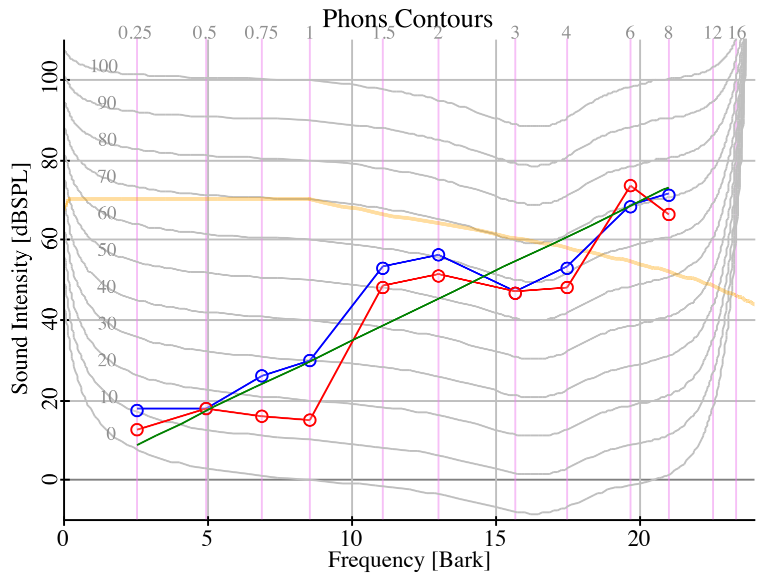

Figure 2: *Example audiology for sensioneural hearing impairment as a function of frequency in Bark.*

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 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. Our recent discoveries of the equations that describe human hearing provide us with detailed information about the transition region between these two asymptotic behaviors.

As one can see, the recruited hearing 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 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.

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-

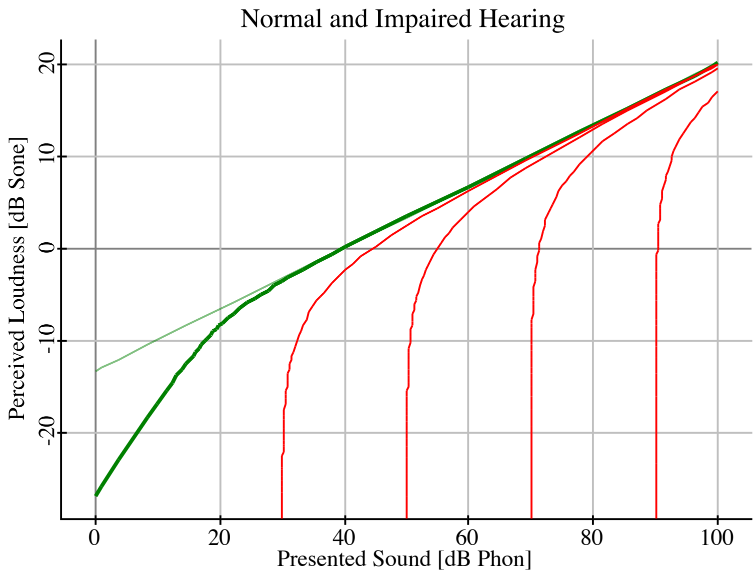

Figure 3: *Curves of normal (green) and recruited hearing (red) for varying degrees of threshold elevation.*

derstood by audiology practitioners. Invariably, the threshold elevations are overestimated and lead to too much correction at normal listening loudness levels.

What we have found in listening tests with a wide range of individuals is that the use of VTuning settings instead of audiology measurements produces a much more pleasing listening experience.

Furthermore, when offered the opportunity to listen through our corrective systems, based on our hearing equations, people with normal hearing uniformly prefer some amount of VTuning corrections. The reason for this is quite simple to understand. The green curve representing normal hearing in Figure 3 shows a recruitment-like behavior near threshold, where human hearing becomes linear.

Going back to the iso-loudness contours, it can be seen that everyone is "impaired" at higher frequencies unless the music is very loud. Most of the spice of music is found in the high frequency region – sibilant speech, breathiness, cymbals, etc. Nearly everyone enjoys music more when it is played loudly. That gives them the opportunity to hear this musical spice. But by using one of our corrective systems, they gain that sense of enjoyment without needing to raise the volume to potentially damaging levels.

Using our equations for recruitment correction, we find that most people with normal hearing prefer a VTuning setting of around 2.5 dB / Bark, when listening at 77 dB SPL through headphones. That corresponds to a working threshold elevation of 50 dB at the highest frequencies. But since we don't live in a world of threshold level sounds, the actual gain needed for a 50 dB threshold elevation, when the sound is at 60 dBSPL and 10 kHz, is only on the order of 5 dB or so. The gains applied are nonlinear compression to overcome the "recruitment" gain expansion produced by ear physics.