

# Music and Hearing Aids

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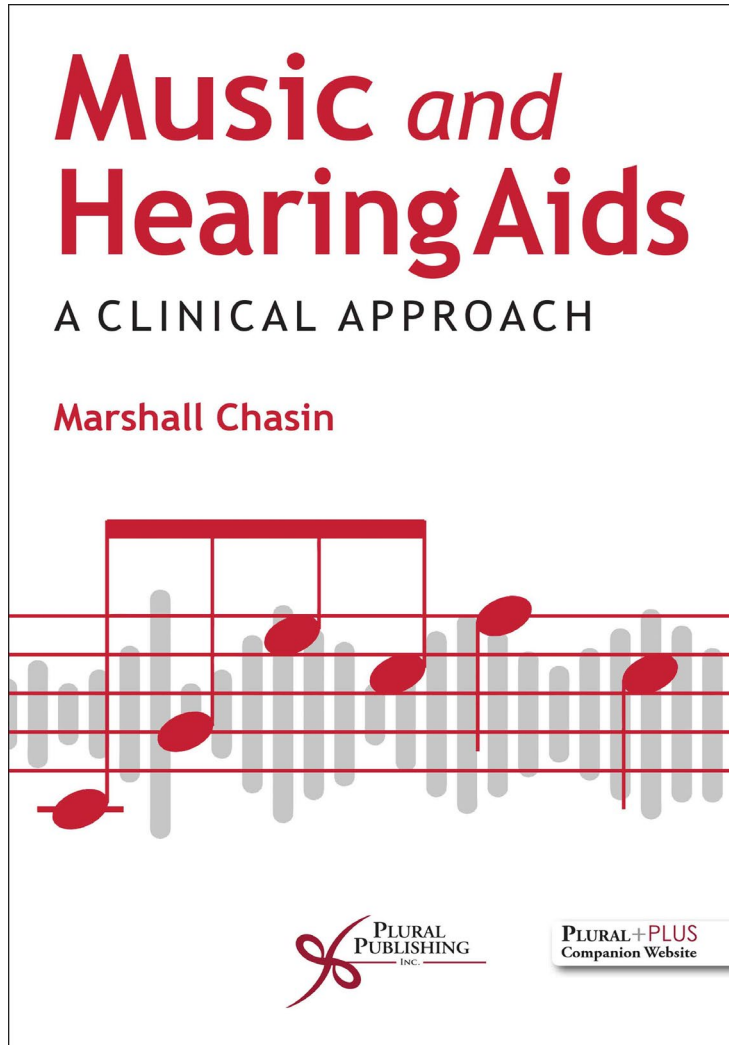
# Three music programs

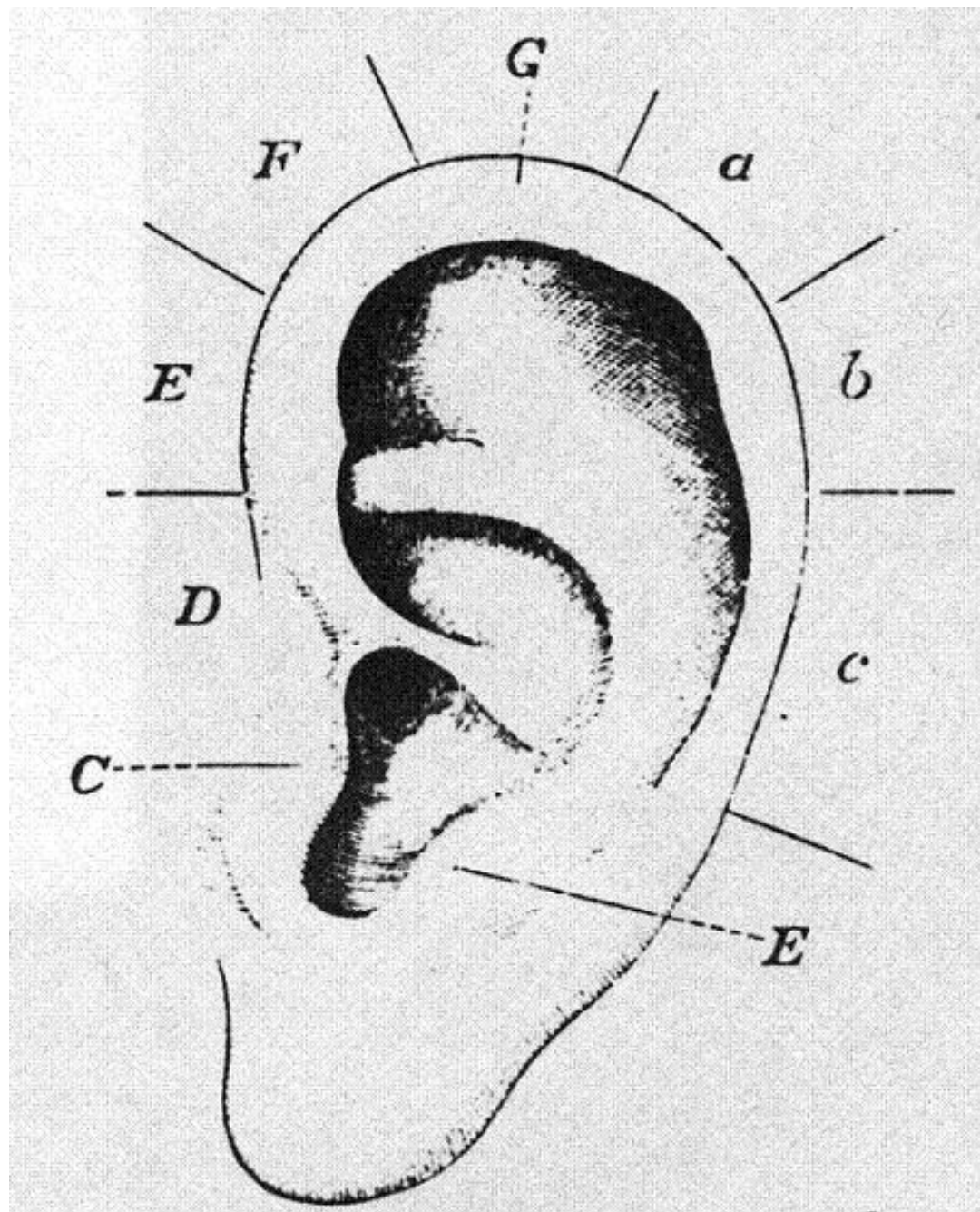
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# Conflict of Interest declaration...





# Three Differences ...

- Speech vs. Music Spectra
- Differing sound levels
- Crest factors



# Three Differences ...

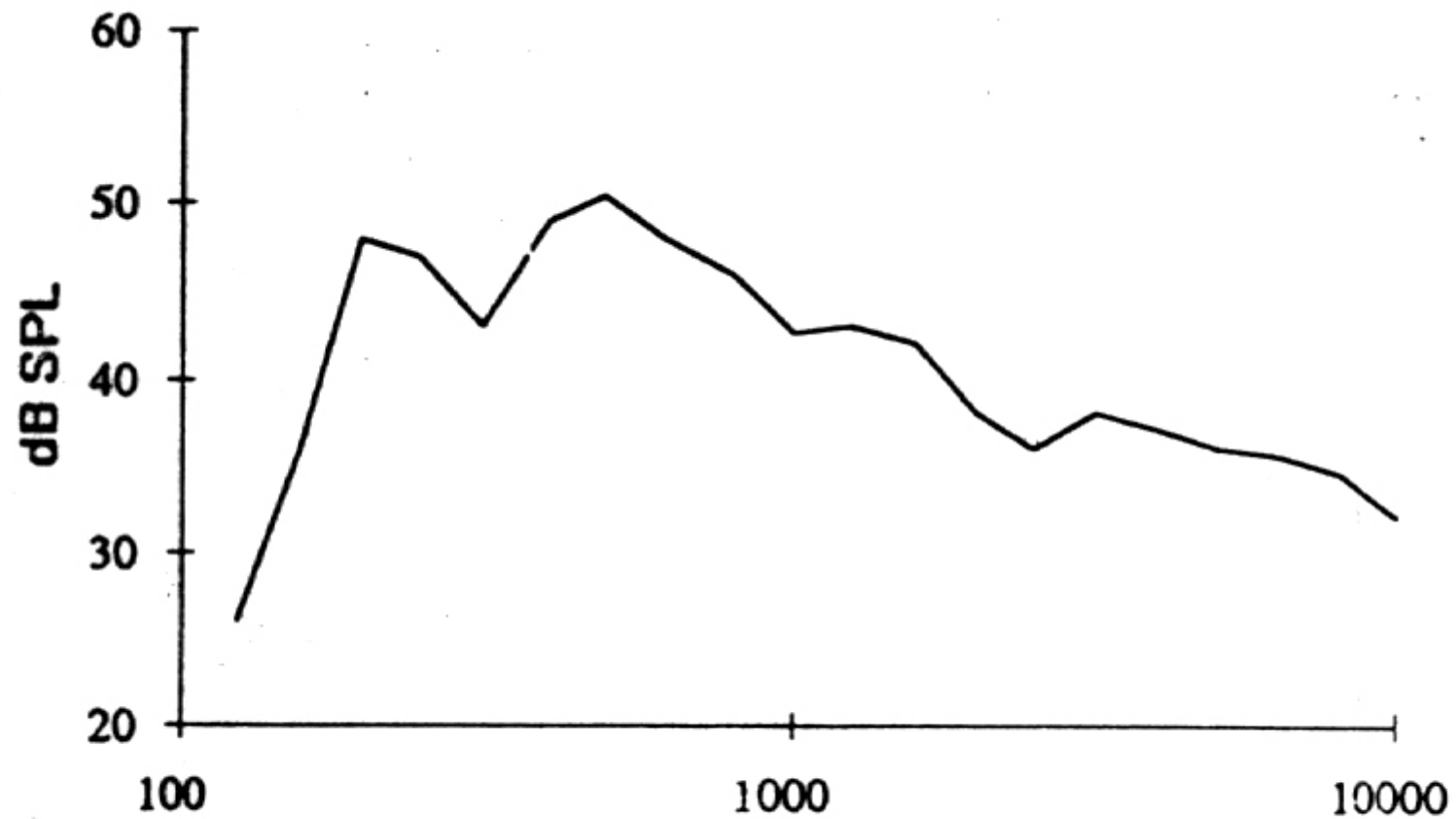
## (1) Speech vs. Music Spectra:

*Speech has a relatively uniform spectrum*

- Human vocal tract source
- Long-term speech spectrum “target”

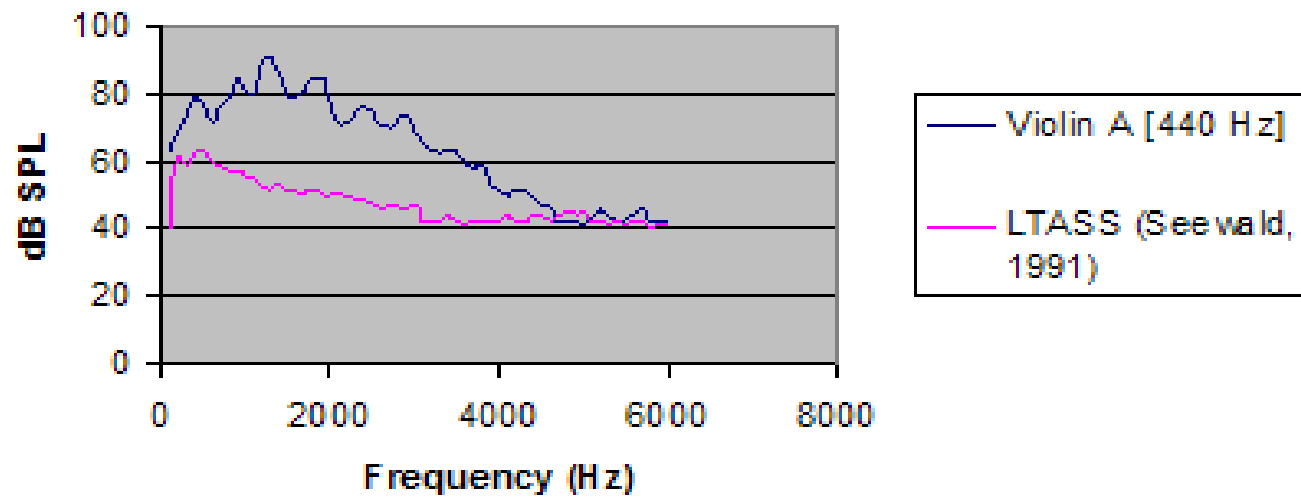
*Music has many sources*

- Highly variable
- No “music target”



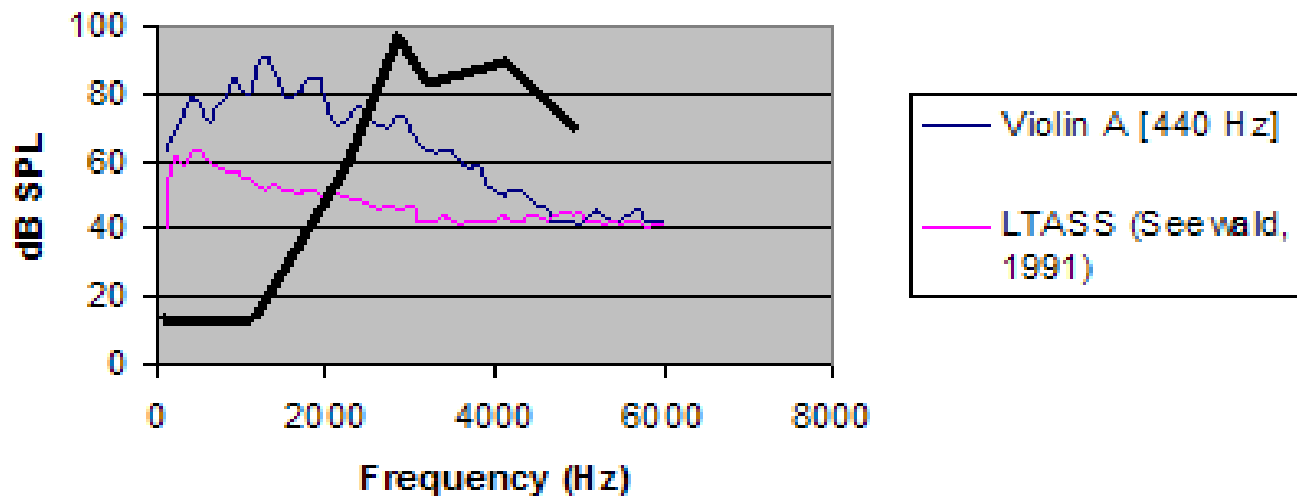
**1/3 Octave Band Center Frequencies (Hz)**

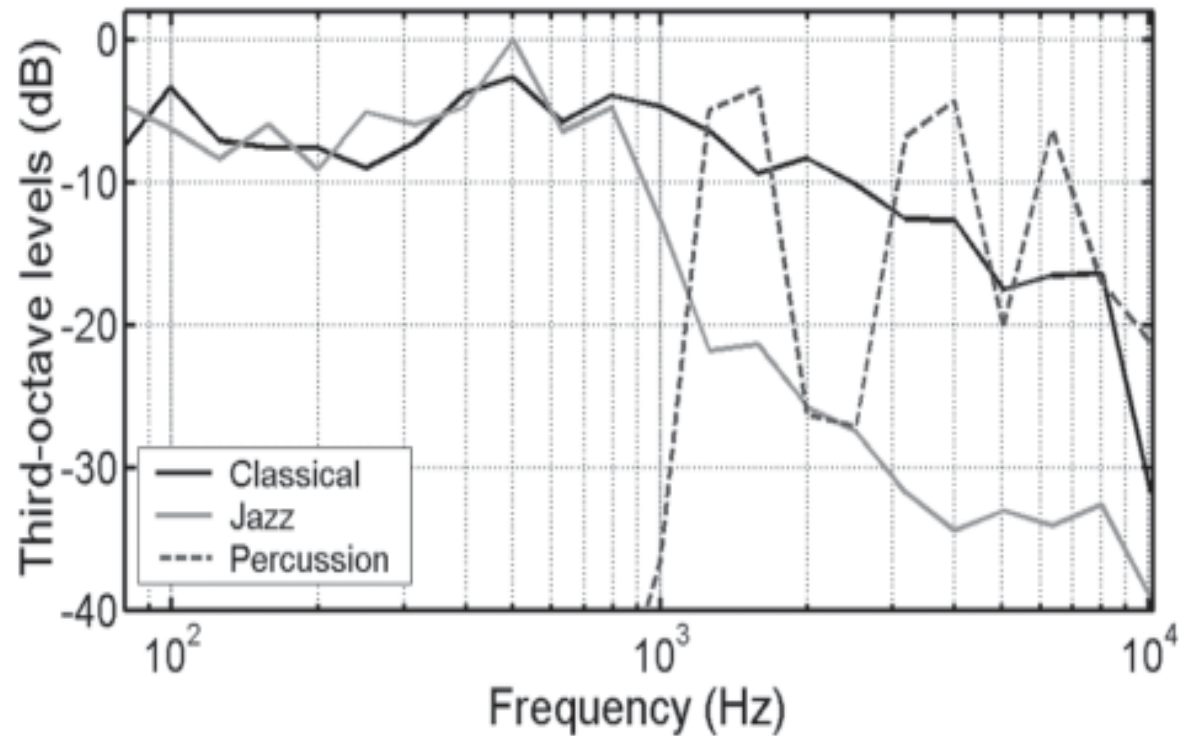
### Spectral comparison between LTASS and violin playing A [440 Hz]





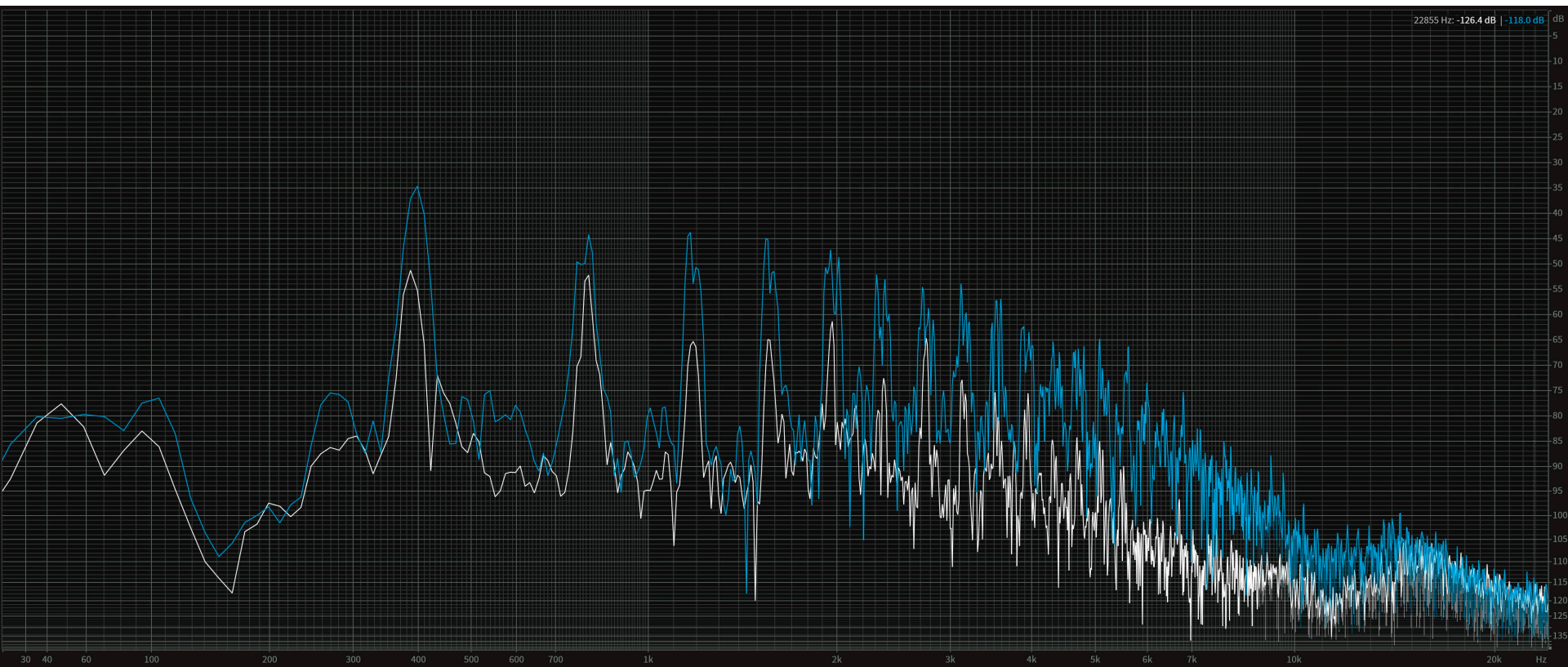
### Spectral comparison between LTASS and violin playing A [440 Hz]





Moore, B. C. J. (2012). *Effects of bandwidth, compression speed, and gain at high frequencies on preferences for amplified music. Trends in Amplification, 16(3), 159–172.*

# Violin (soft and loud)



# French horn (soft and loud)



# Spectral shapes differences (soft to loud)

	<i>Low Frequency Region</i>	<i>High Frequency Region</i>
<b><i>Vocals</i></b>	11-15 dB	0-10 dB
<b><i>Stringed Instruments</i></b>	11-15 dB	11-15 dB
<b><i>Brass Instruments</i></b>	< 10 dB	> 30 dB
<b><i>Reeded Woodwinds</i></b>	< 10 dB	> 30 dB

# Three Differences ...

(2) Differing sound levels:

*Speech is 65 dB SPL  $\pm$  12 dB*

- (53 dB SPL to 77 dB SPL)
- Shouted speech can be 82 dB SPL

*Music can reach 105 dBA; peaks of 120 dBA*

Table 2-1. Average sound levels of a number of musical instruments (from over 300 musicians) measured from 3 meters on the horizontal plane. \*Also given is the sound level for the violin measured near the left ear of the player. (Chasin, 2006).

<b>Musical Instrument</b>	<b>dB(A) ranges measured from 3 meters</b>
Cello	80-104
Clarinet	68-82
Flute	92-105
Trombone	90-106
Violin	80-90
Violin (near left ear)*	85-105
Trumpet	88-108

# Three Differences ...

(3) Crest factor: (instantaneous peak – long term RMS)

*(Used in hearing aid testing... OSPL90 – 77 dB = Ref. Test Gain)*

*Speech has a crest factor of 12 dB- 16 dB*

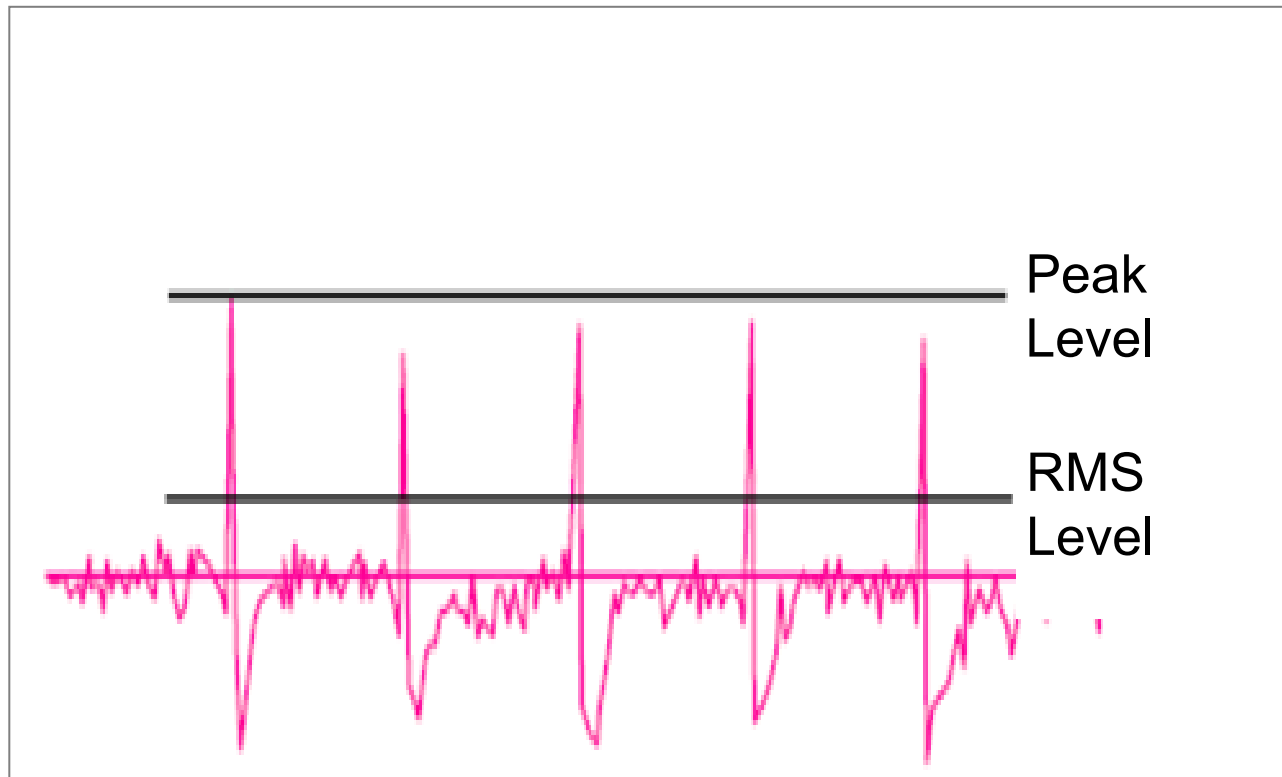
*Music has a crest factor of 18 dB-22 dB*

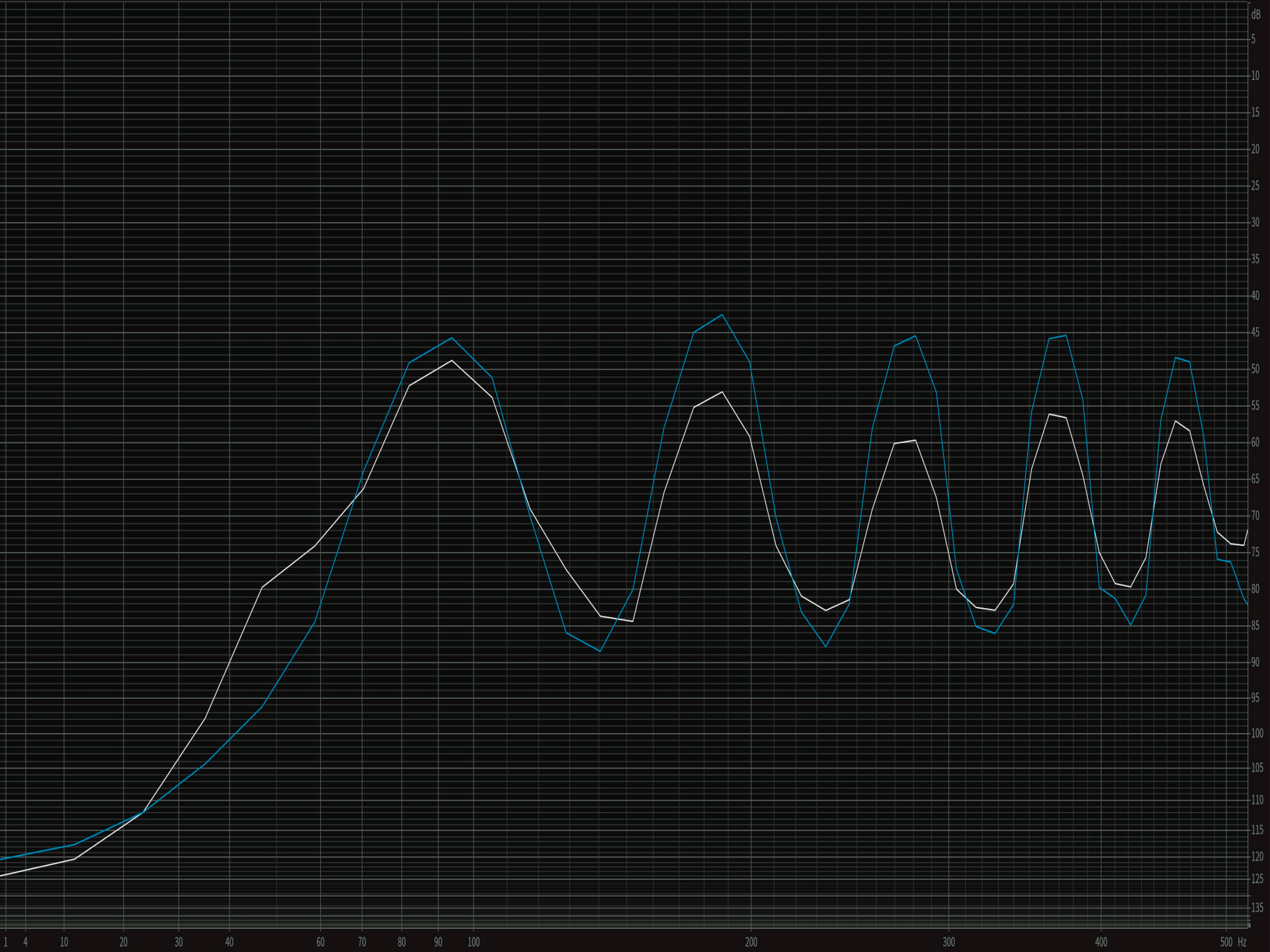
- Less damping.





# Crest factor





# Speech

65 dB SPL RMS

12-16 dB crest factor

-6 dB / octave

Well defined SII  
and target

Low frequency boost  
for louder speech

# Music

>100 dB SPL RMS

18-22 dB crest factor

Variable slopes

No “MII” and no  
target

Variable boosts for  
louder music

What about hard of hearing musicians ...  
... or non-musicians who like  
to listen to music?



# Peak input limiting level

Peak input limiting level of many hearing aids (up until very recently) limits sound above 90 dB SPL.

(...Only 1 analog aid of the 1980s had 115 dB)

.... shouted [a] is about  
82 dB SPL



# Peak input limiting level

This occurs just after the microphone, and is related to the A/D converter.

- Overloading the “front end”.

If distortion occurs this early in the circuitry, then nothing later (e.g. software adjustments) can improve things.

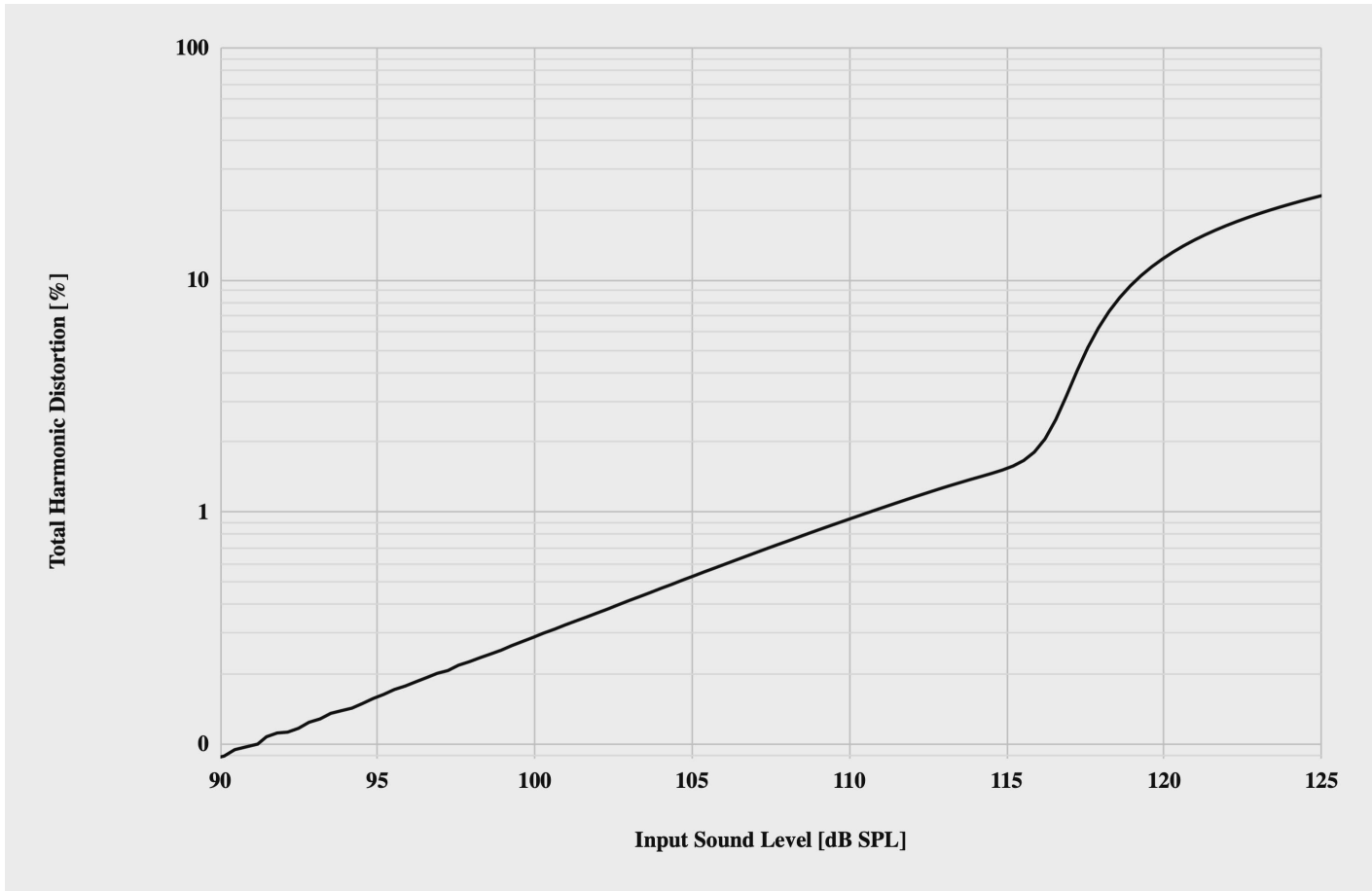
*Chasin, M., & Russo, F. (2004). Hearing aids and music. Trends in Amplification, 8(2), 35–48.*

*Oeding, K., & Valente, M. (2015). The effect of a high upper input limiting level on word recognition in noise, sound quality preferences, and subjective ratings of real-world performance. Journal of the American Academy of Audiology, 26(6), 547–562.*

*Plyler, P., Easterday, M., & Behrens, T. (2019). The effect of extended input dynamic range on laboratory and field-trial evaluations in adult hearing aid users. Journal of the American Academy of Audiology, 30(7), 634–648.*

Before we get to the 3 programs, we need to take care of the “front end”...

# Its not the microphone...





# Max Headroom







# The overpass analogy



80 dB  
dynamic  
range

High level music and low “ceiling”



# An Experiment:

A hearing aid was constructed where the peak input limiting level can be successively reduced from 115 dB SPL, to 105 dB SPL, to 95 dB SPL ... and back to 115 dB SPL.

Acknowledgments: Mead Killion, Russ Tomas, Norm Matzen, Mark Schmidt, Steve Aiken.

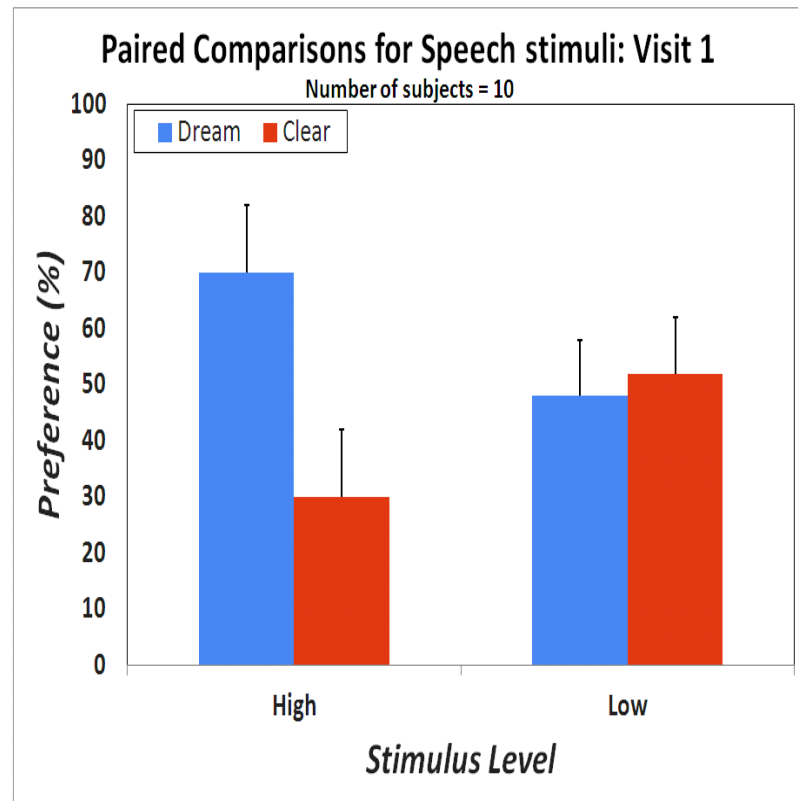
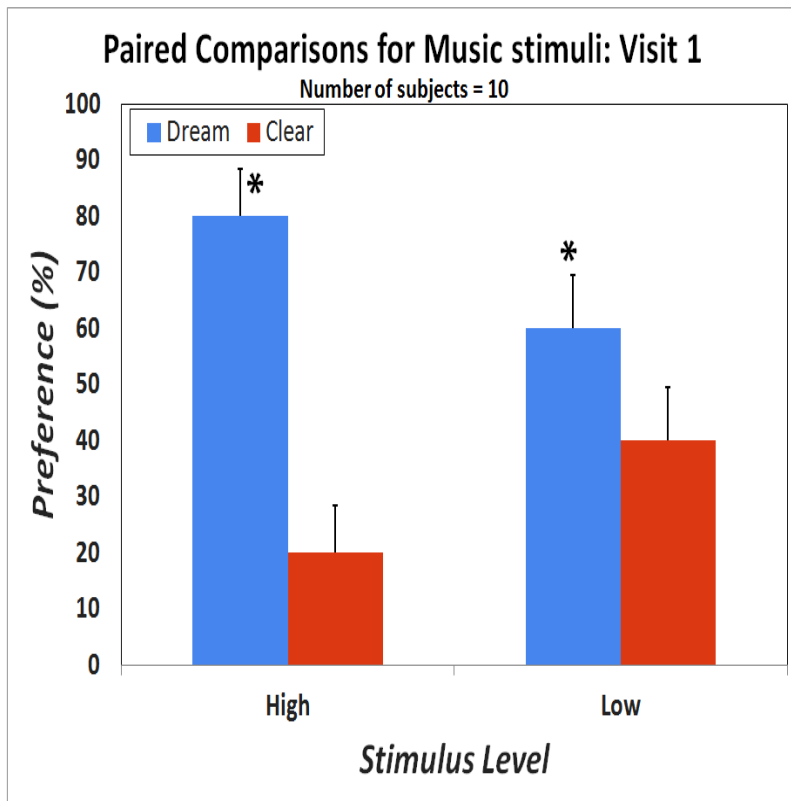


# Therefore ....

Peak Input Limiting Level should be at least 115 dB SPL .... Or maybe even up to the limit of modern hearing aid microphones ?

... And it's not just for music. What about the level of a hard of hearing person's own voice at their hearing aid?

# Benefit even for high level speech...





# What the crest factor can tell us about speech...

A hard of hearing person's own voice can overdrive their own hearing aid!

84 dB input + 16 dB crest factor = 100 dB ish

# Four clinical strategies...

- \* Lower volume on stereo or other input and increase gain on aid.
- \* You can use an ALD (WITH A VOLUME) as input.
- \* Use (creative) microphone attenuators such as Scotch tape. (3-4 layers of tape will provide 10-12 dB of flat attenuation up to 4000 Hz).
- \* Take off the hearing aids

Use microphone attenuators such as Scotch tape.

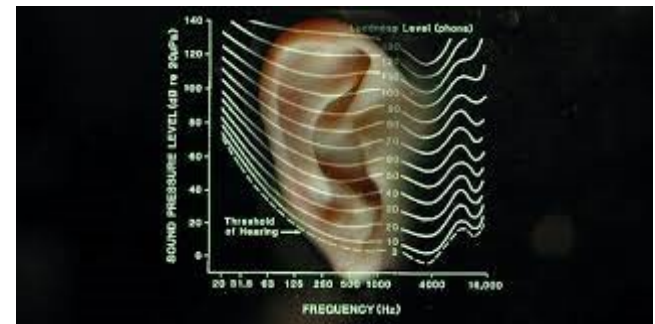
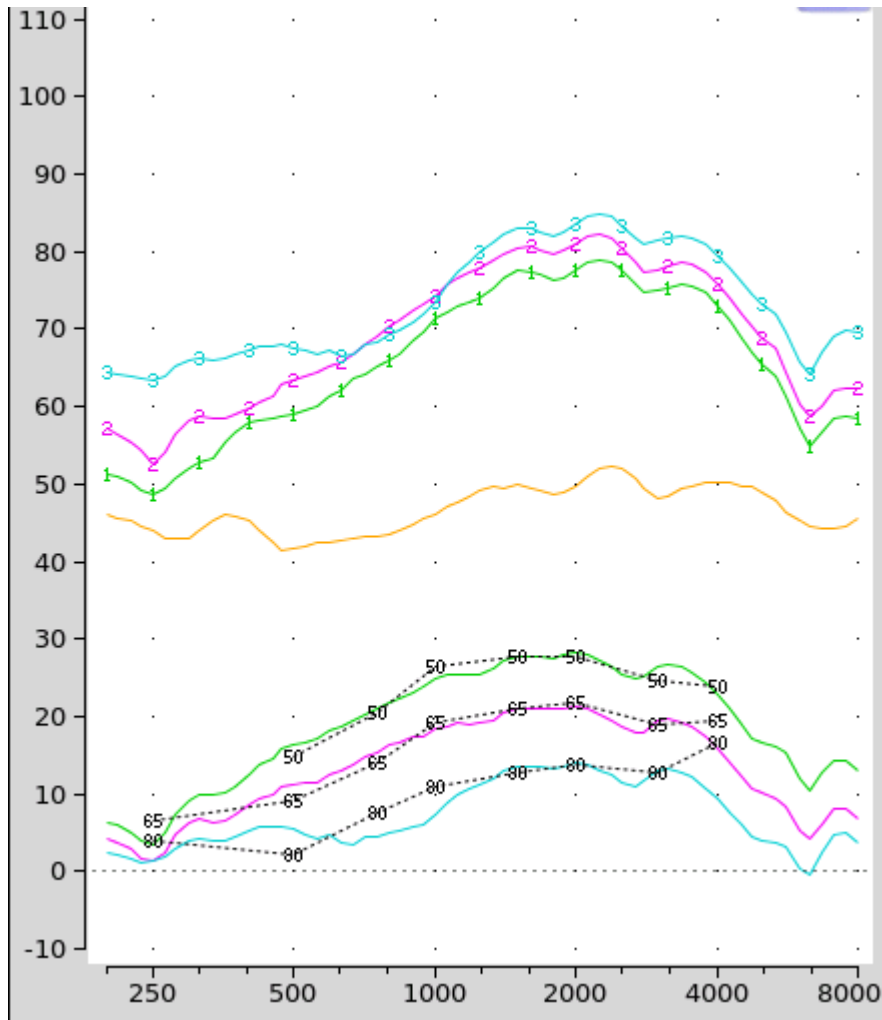
3-4 layers of Scotch tape will attenuate the input by 10-12 decibels...



# Take off the hearing aids

<i>dB HL at 1000 Hz</i>	<i>65 dB input</i>	<i>80 dB input</i>	<i>95 dB input</i>
15	0	0	0
25	2	1	0
35	8	4	0
45	14	7	0
55	20	10	1
65	28	15	2
75	36	20	3
85	44	24	4

# Higher inputs require lower gains...



# Low gain/high output test

Set an aid for 5-10 dB of gain, but maximum OSPL90 with a 105 dB SPL input and if distortion (>20%) then cannot handle loud (live) music.

Input + gain << Output

# Four technical innovations...

1. -6 dB/octave low cut microphone
2. Shifting the dynamic range upwards
3. Front end compression prior to the A/D converter
4. Post 16 bit architecture

# 1. -6 dB/octave low cut microphone

Non-occluding BTE provide gain above 1000 Hz and do not occlude the ear canal.

Useful for those with a high frequency loss

BUT still has a front end limiting problem...



# 1. -6 dB/octave low cut microphone

SO.... We can use a desensitized microphone.

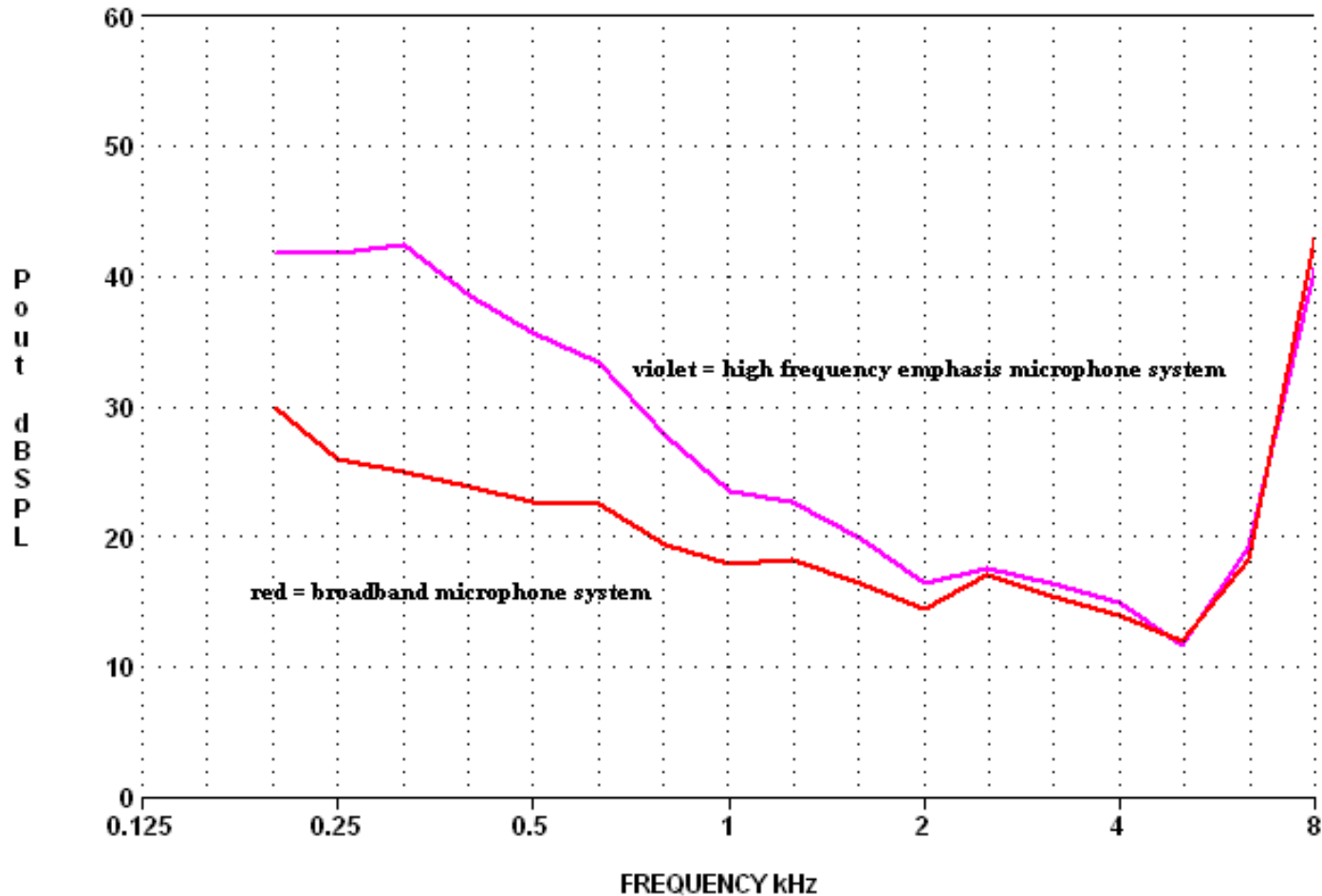
Use a high frequency emphasis (-6 dB low frequency roll-off) microphone.

Same frequency response but less front end distortion.

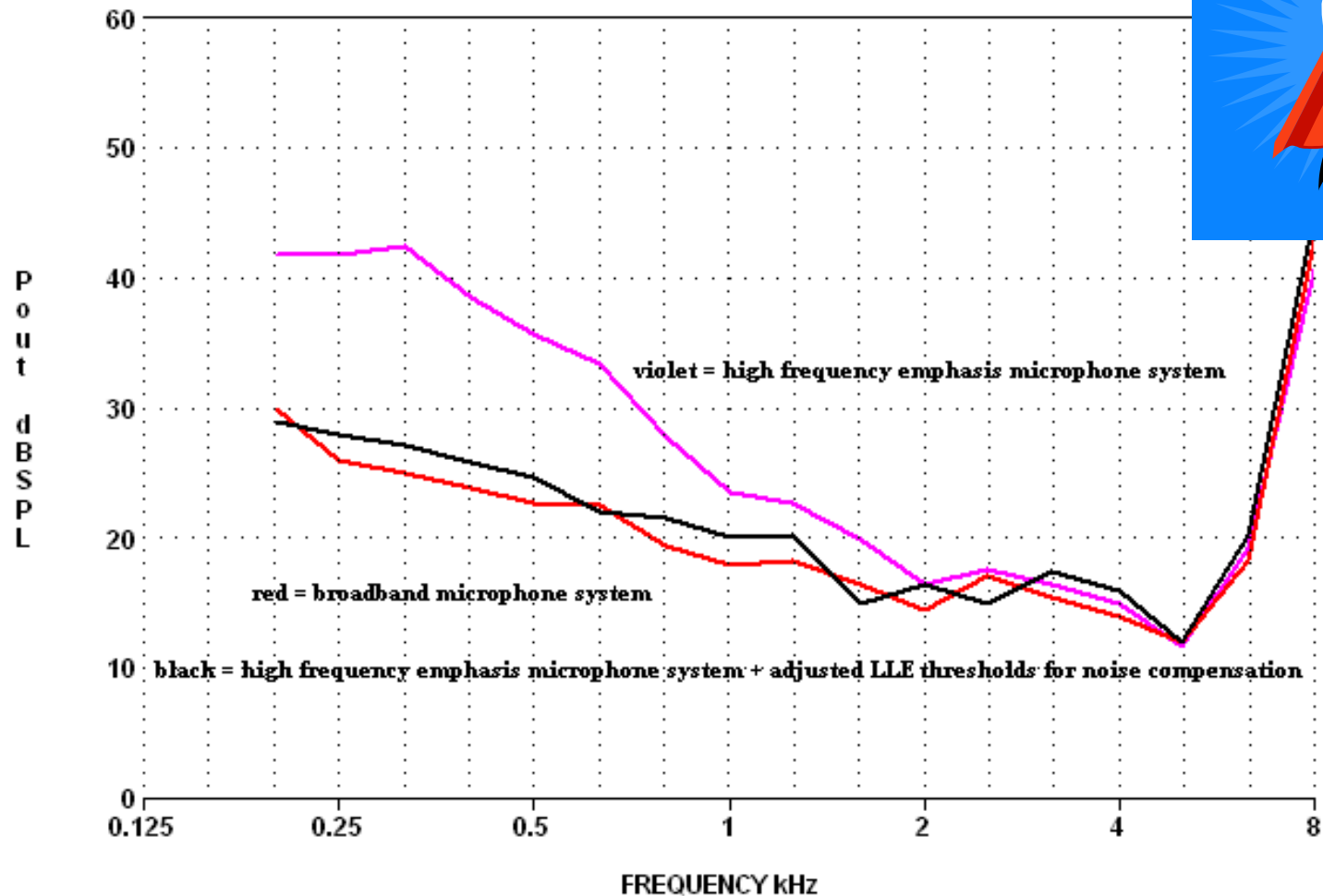
*Chasin, M., & Schmidt, M. (2009). The use of a high frequency emphasis microphone for musicians, Hearing Review, 16(2), 32–37.*

*Schmidt, M. (2012). Musicians and hearing-aid design—Is your hearing instrument being overworked? Trends in Amplification, 16(3), 140–145.*

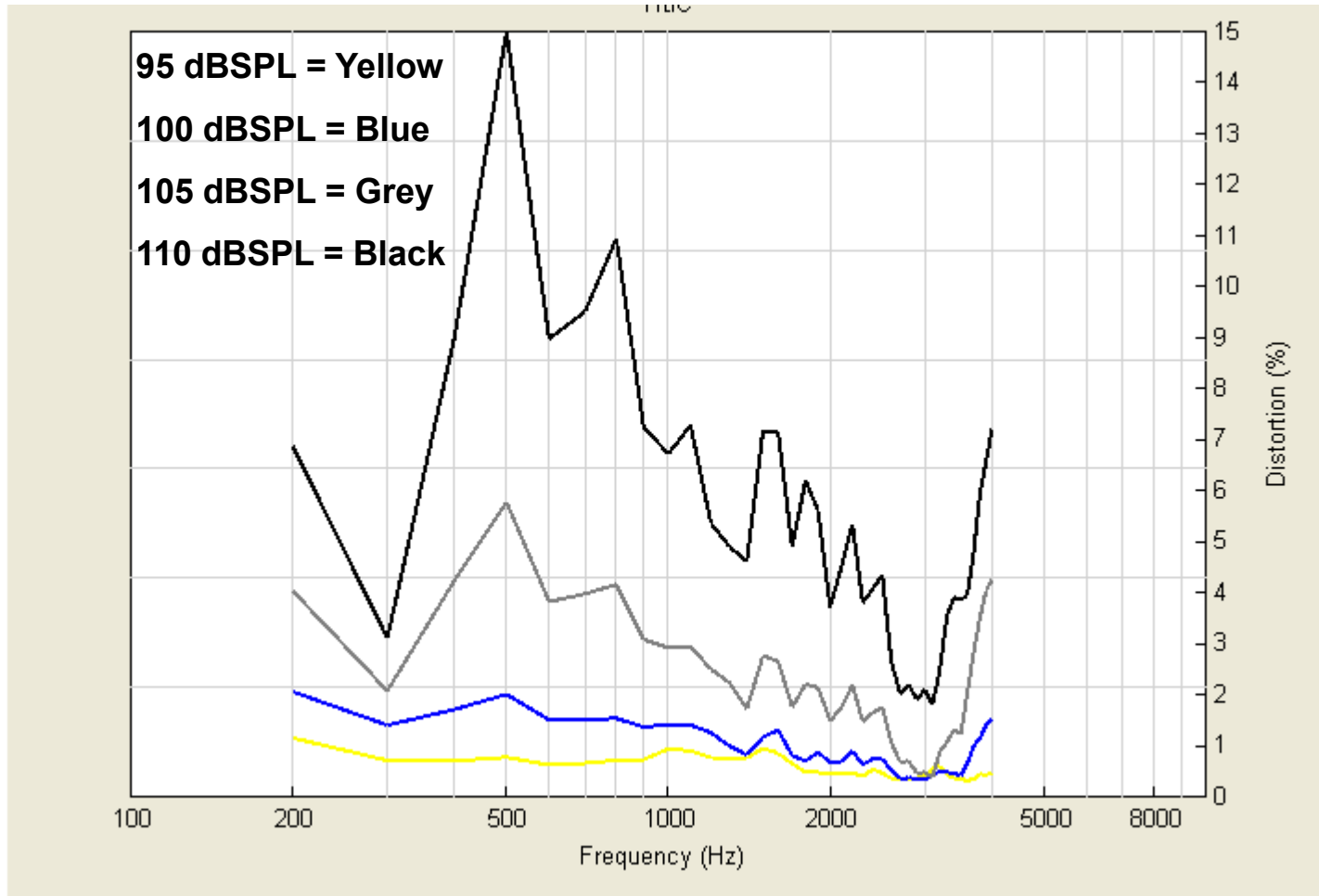
# Microphone noise... you will need expansion...



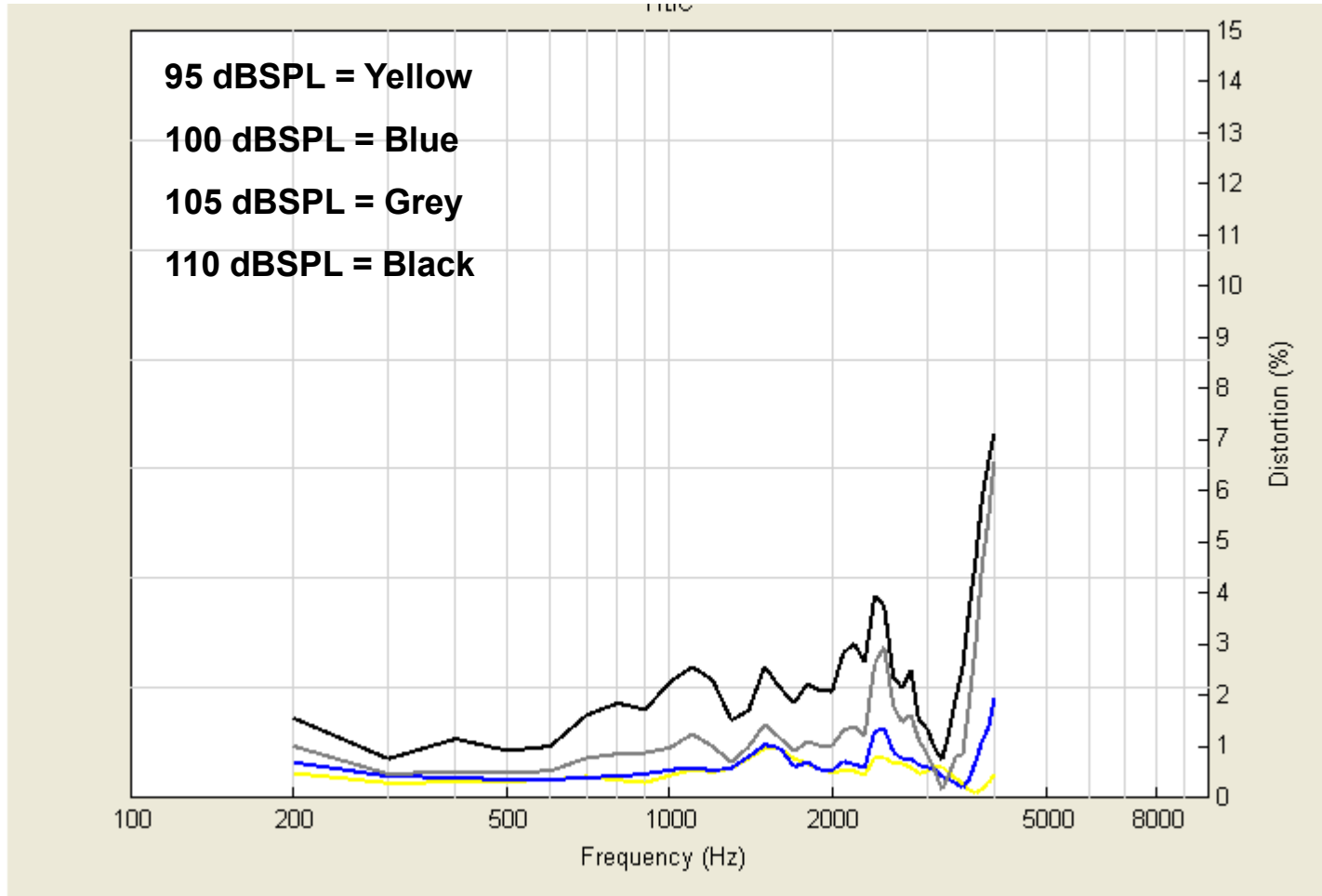
# Expansion comes to the rescue



# THD Results with BB Mic for 95, 100, 105 & 110 dB SPL inputs



# THD Results with HF Mic for 95, 100, 105 & 110 dB SPL inputs



## 2a. Shifting the dynamic range upwards

Based on the definition of “dynamic range”

“90 dB dynamic range”

0 dB SPL to 90 dB SPL	15 dB SPL to 105 dB SPL
24% distortion	< 3% distortion

## 2b. Shifting the dynamic range upwards

Another approach ...

Transformer effect by doubling the voltage

Increases the high end of the dynamic range by up to 6 dB (can be accomplished off-IC chip)

## 2b. Shifting the dynamic range upwards

And other approaches ...

Auto-ranging of the A/D converter that detects the input and ensures that the input is within the optimal operating range. (e.g. HRX)

“Stacked A/D converters”, while still commercially available, aren’t widely used.



### 3. Front end compression prior to the A/D converter

Some hearing aid manufacturers are now using an analog compressor prior to the A/D converter ...

... and then digitally re-establish gain after...  
after...



## 4. Post 16 bit architecture

20 and 24 bit architecture A/D converters that have > 96 dB dynamic range.

- For each bit (n) add 6 dB to dynamic range  
 $(20n)\log_2 = 20n \times 0.3 = 6n$



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## 4. Post 16 bit architecture

Some “19 or 20 bit” systems

..... (As reported by manufacturers):

Unitron Discover Next™/Blu (119 dB SPL)

Phonak Paradise™ (119 dB SPL max)

Oticon More™ (119 dB SPL auto-range)

Widex Moment™ (115 and 119 dB SPL)

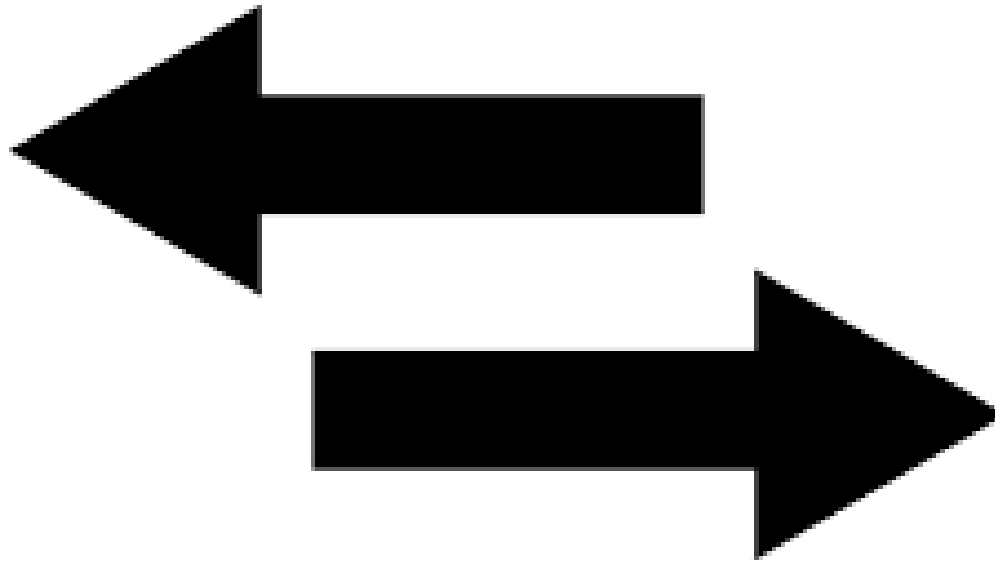
Bernafon Alpha™ (119 dB SPL auto-range)

Resound LiNX Quattro™/Key (116 dB SPL)

Starkey Evolve AI™ (116 dB SPL)

.....

Frequency response... the two ends...



# Frequency response... the low end

Low frequency end (down to 55 Hz):

- affected by earmold/eartip venting

- Hirsch and Bowman (1953)

  - distortion occurred for low frequency inputs >80 dB SPL

- High level, low frequency sounds rarely would be seen by speech but commonly seen even by unamplified music.

Moore, B. C. J., & Tan, C-T. (2003). Perceived naturalness of spectrally distorted speech and music. *Journal of the Acoustical Society of America*, 114(1), 408–419

Hirsch, I. J., & Bowman, W. D. (1953). Masking of speech by bands of noise. *Journal of the Acoustical Association of America*, 25, 1175–1180.

# Frequency response... the high end

- Hallowell Davis et. al (1950):

- American servicemen (and Davis himself) volunteered to have TTS created unilaterally.
- They were given two unmarked knobs; one controlled frequency and the other, sound level. Asked to match the sound in the good ear with that of the TTS affected ear.
- Low frequencies = good correspondence
- High frequencies = heard as louder, but not higher pitched  
.... Subjects heard the sound as flat relative to good ear.

Diagnostic clue = if a client hears sounds as flat...

(opposite study has yet to be done...)

# Frequency response... the high end

In the early 1990s Brian Moore and his colleagues noted that sometimes if the hearing was very severe, then cochlear dead regions may exist.

TEN test which takes around 10 minutes for 4 frequencies

1. Reduce the amplification in this region
2. Frequency shift to a lower frequency (healthier) region

*Moore, B. C. J. (2004). Dead regions in the cochlea: Conceptual foundations, diagnosis, and clinical applications. Ear and Hearing, 25(2), 98–116. 3.*

*Moore, B. C. J., Glasberg, B. R., & Stone, M. A. (2004). New version of the TEN Test with calibrations in dB HL. Ear and Hearing, 25, 478–487.*





A clinical trick to assess  
dead regions...



*Chasin M. "Testing for cochlear dead regions using a piano". Hearing Review. 2019;26(9):12.*

# Quick check if asymmetrical loss

Pairs of puretones (left channel and right channel) for a range of frequencies.

If different pitch (comparing right ear and left ear) then cochlear dead regions; else no cochlear dead regions



# Summary of limitations of the high frequencies... (based on speech, but...)

Mild hearing loss	>55 dB hearing loss	Steeply sloping audiogram
Broad bandwidth	Narrow bandwidth	Narrow bandwidth

Aazh, H., & Moore, B. C. (2007). Dead regions in the cochlea at 4kHz in elderly adults: Relation to absolute threshold, steepness of audiogram, and pure-tone average. *Journal of the American Academy of Audiology*, 18(2), 97–106.

Ricketts, T. A., Dittberner, A. B., & Johnson, E. E. (2008). High frequency amplification and sound quality in listeners with normal through moderate hearing loss. *Journal of Speech-Language-Hearing Research*, 51, 160–172.

## Sometimes we can just change the input...

A client came in with a high frequency hearing loss as a result of chemotherapy as a child. Great mezzo soprano but was having difficulty passing an ear training class (intervals, chords,...)

Was able to convince the administration to perform the test one octave lower...

.... She passed!

## But Skinner and Miller (1983)...

For each increase in high frequency gain, there must be an associated low frequency gain increase as well in order to maintain or improve speech discrimination.

Based on speech but an hypothesis is that this will also apply for music.



One cannot specify a high frequency figure without also specifying an associated low frequency limit as well.

*Skinner, M. W., & Miller, J. D. (1983) Amplification bandwidth and intelligibility of speech in quiet and noise for listeners with sensorineural hearing loss. Audiology, 22(3), 253–279.*

# No frequency lowering for music



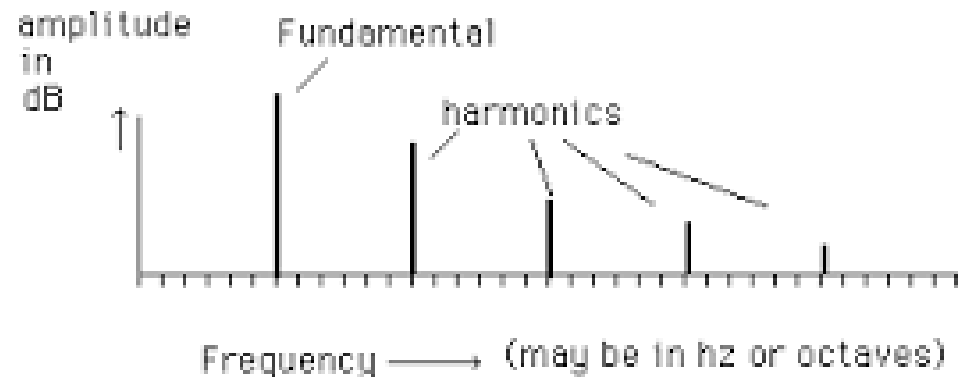
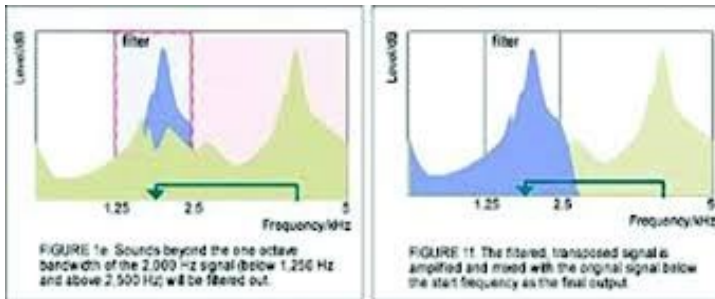
# No frequency lowering

Any change in frequency will be disastrous- may improve things after a lengthy training period?? but doubtful if any musician will tolerate this.

# No Frequency Lowering

Music: line spectrum (except percussion).

Speech: line spectrum for low frequencies  
continuous spectrum for high frequencies





# Frequency lowering is for speech; not for music

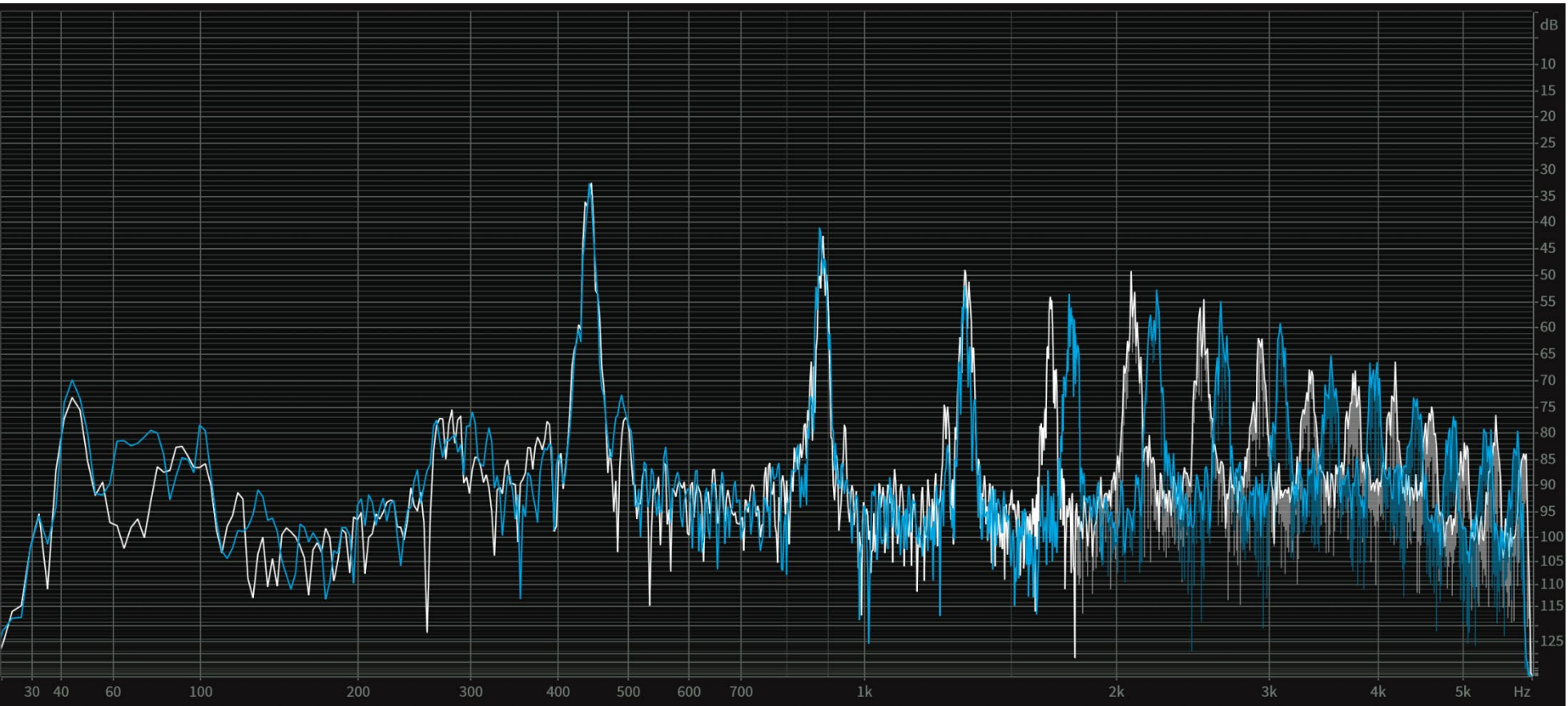
## Speech:

1. Low frequency line spectra Sonorants
2. High frequency continuous spectra  
Obstruents (e.g., 's, sh, th, f,...')

## Music:

All frequencies have line spectra

½ of one semi-tone decrease above 1500 Hz



# No Frequency Lowering



$\frac{1}{2}$  of one semi-tone  
decrease above 1500 Hz  
with one note ( $1.059/2$ )

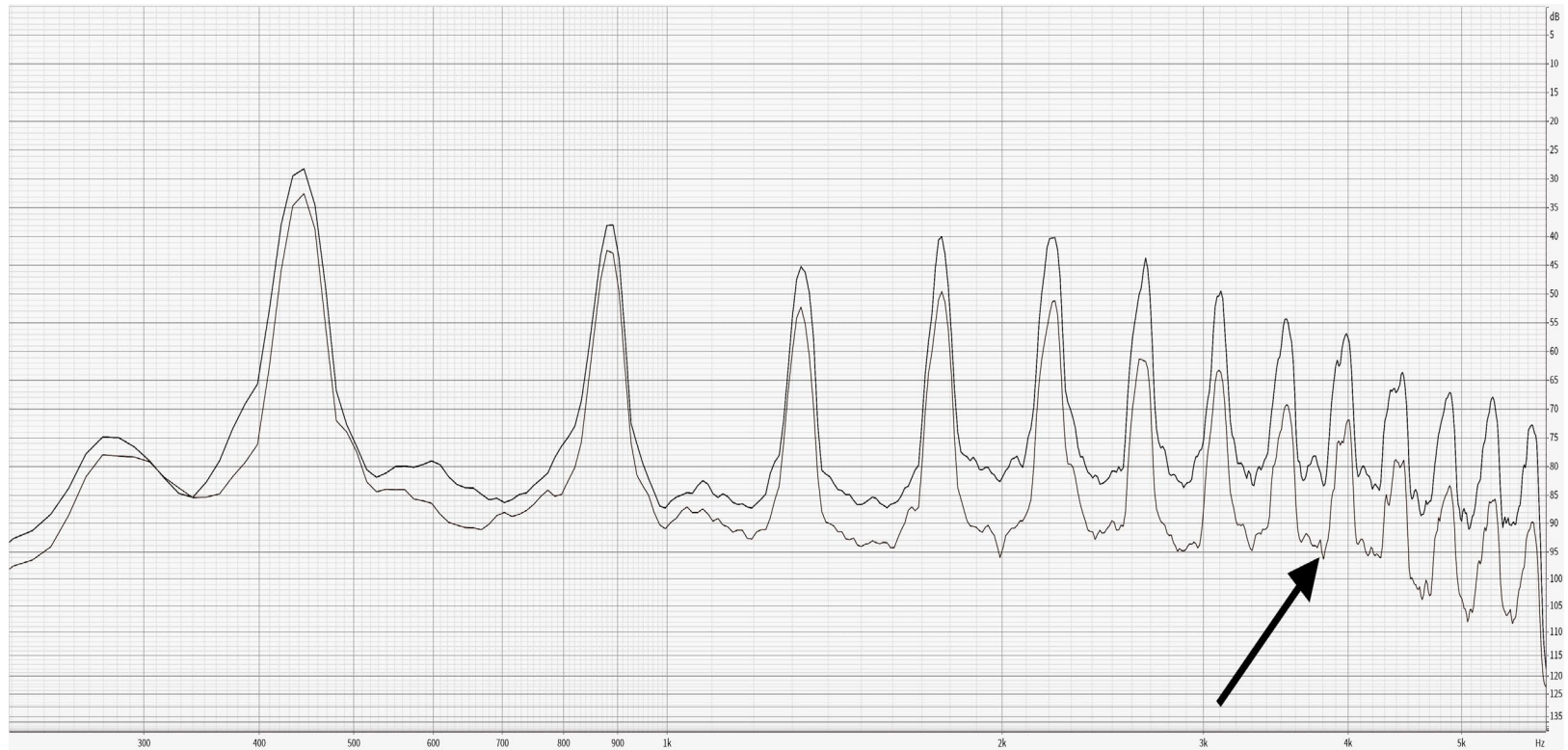


Same thing with full music  
score



But OK for speech

# -6 dB/oct roll-off above 1500 Hz



# -6 dB/oct roll-off above 1500 Hz



Do not change the frequencies of the harmonics, but instead gradually reduce the amplitudes slightly

# Similar compression...

## ... A cochlear issue

Compression is implemented in order to re-establish the loudness growth function of the damaged cochlea and not the characteristics of the input signal.

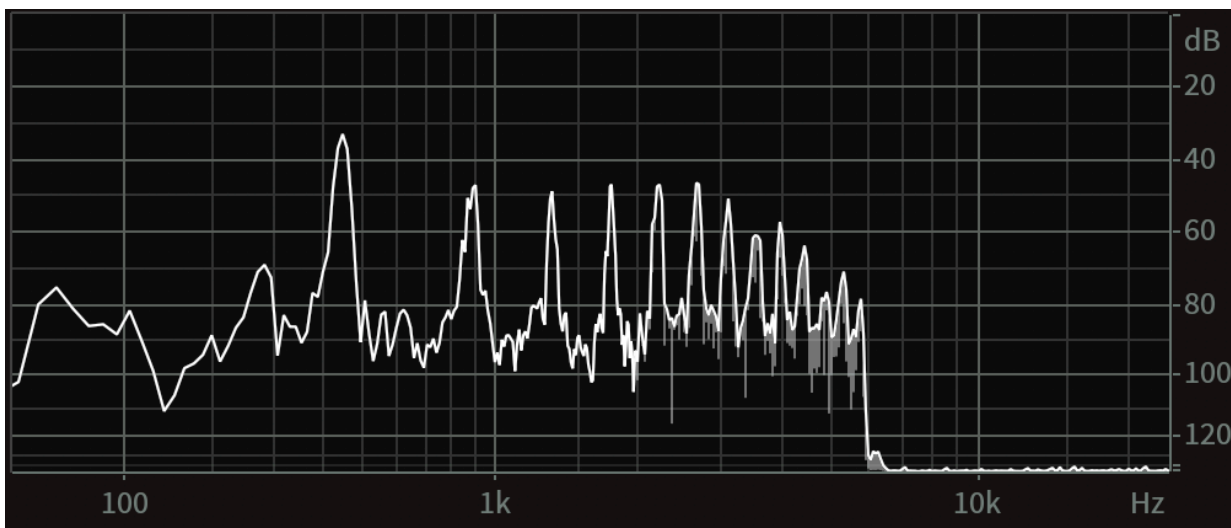
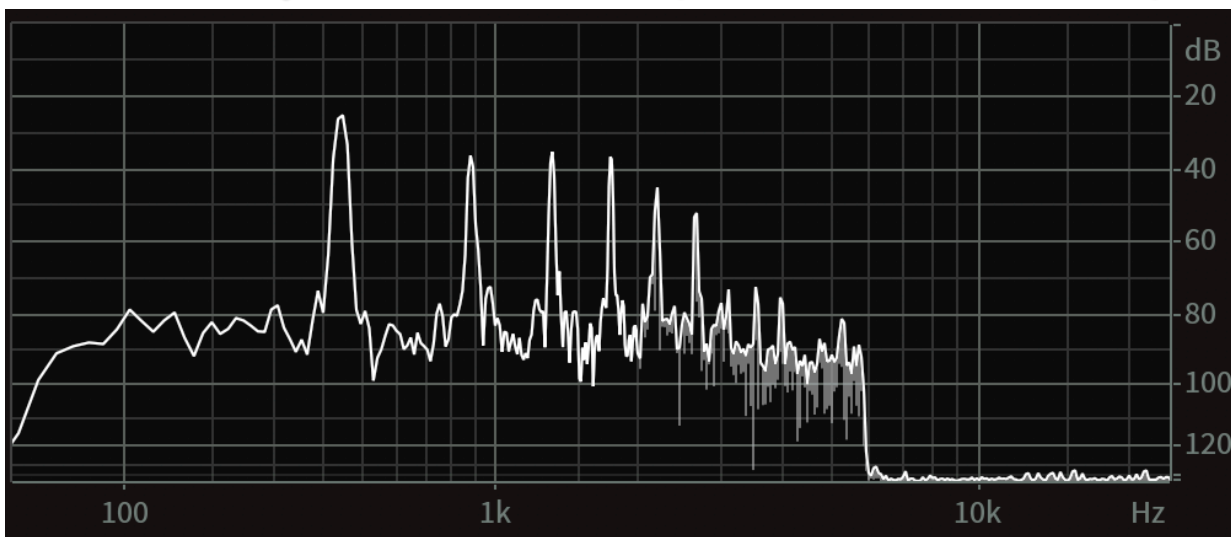
Davies et al. (2009)... “Chasin and Russo (2004) suggested that WDRC ... may be better for music.... That hypothesis was supported by the present data.” (p. 696).

# The (potential) problem with multi-band compression

Many musical instruments vary by only the amplitude of the harmonics (and not the frequency of the harmonics).

Examples: violin, piano, flute, guitar, saxophone,... only are all  $\frac{1}{2}$  wavelength resonator instruments and all have integer multiples of their fundamental (or tonic)- they only differ in the amplitude of the harmonics.

# The (potential) problem with multi-band compression (flute/oboe)





**#1**

# Music Program #1- Live Music

1. The “front end” has been taken care of
2. The frequency bandwidth has been optimized for that client
3. Frequency lowering has been disabled
4. Similar compression characteristics to a speech-in-quiet program
5. Advanced features such as feedback management has been “managed”

**#2**

# What about streamed music?

Thank you to:

Crogan, N., Arehart, K, and Kates, J. (2012). Quality and loudness judgments for music subjected to compression limiting. *JASA*, 132(2), 1177-1188.

Music has been compression limited once already during the creation of the MP3/MP4 process. This is a relatively benign form of compression but does reduce the volume. (Some radio stations tend to use this as well).

Should not “doubly” compress this streamed music, so the music program should be close to linear.

# Music Program #2- Streamed Music

1. The “front end” has been taken care of
2. The frequency bandwidth has been optimized for that client
3. Frequency lowering has been disabled
4. Linear, or only slight WDRC compression for this program
5. Advanced features such as feedback management has been “managed”

**#3**

# What about “instrumental only” music?

..... An island of refuge...

# An island of refuge...

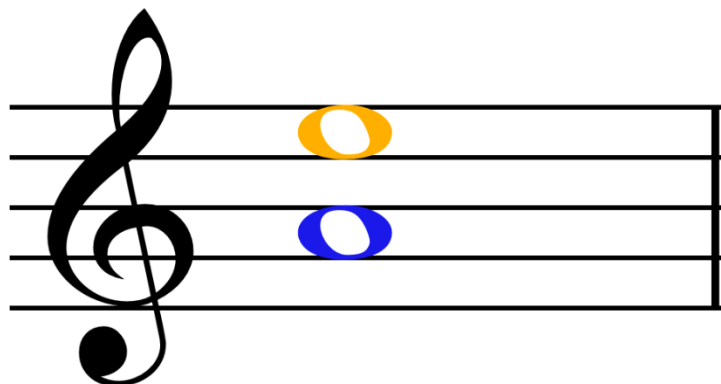
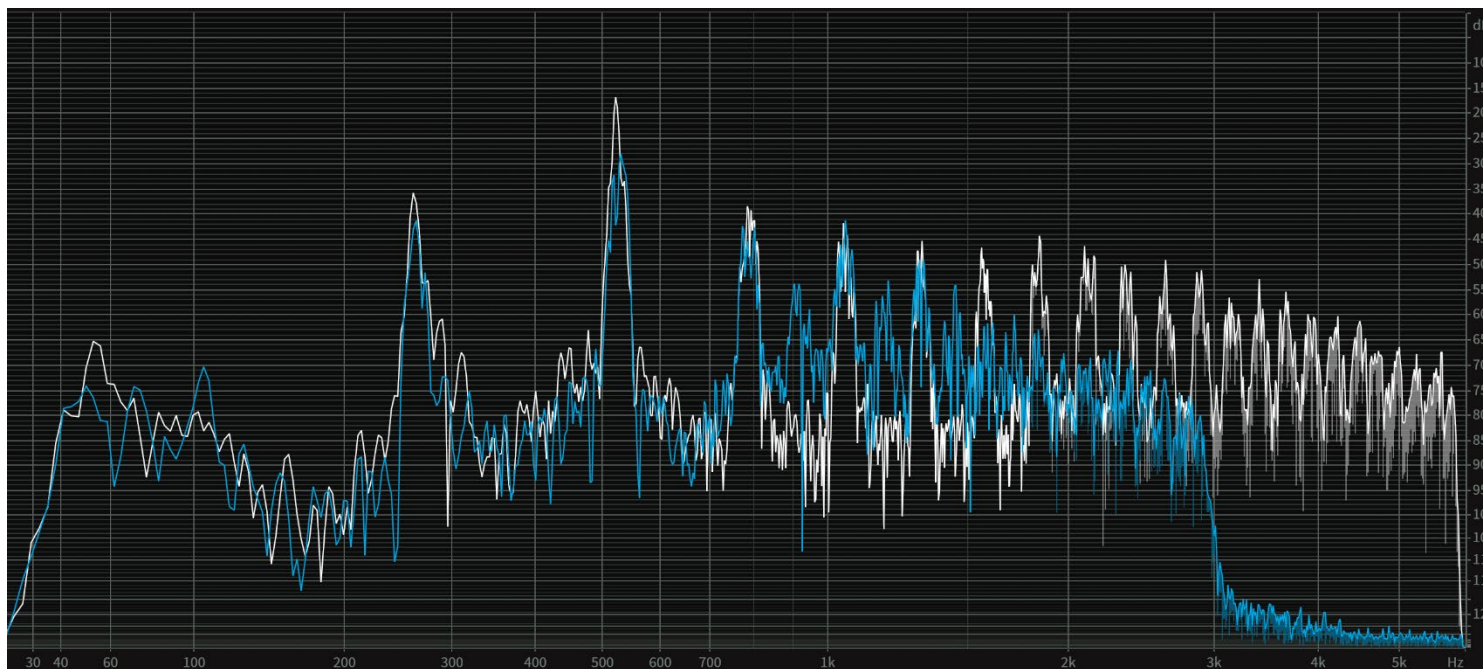
## .... The one octave counter-example

If all frequencies (e.g. above 1500 Hz) are decreased linearly by exactly one octave, the odd numbered harmonics will line up perfectly with already existing harmonics.

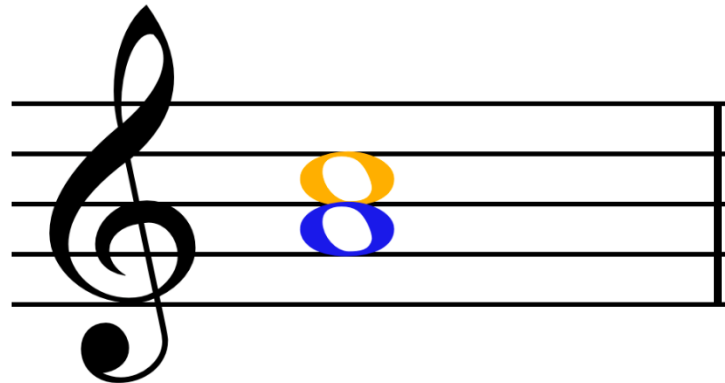
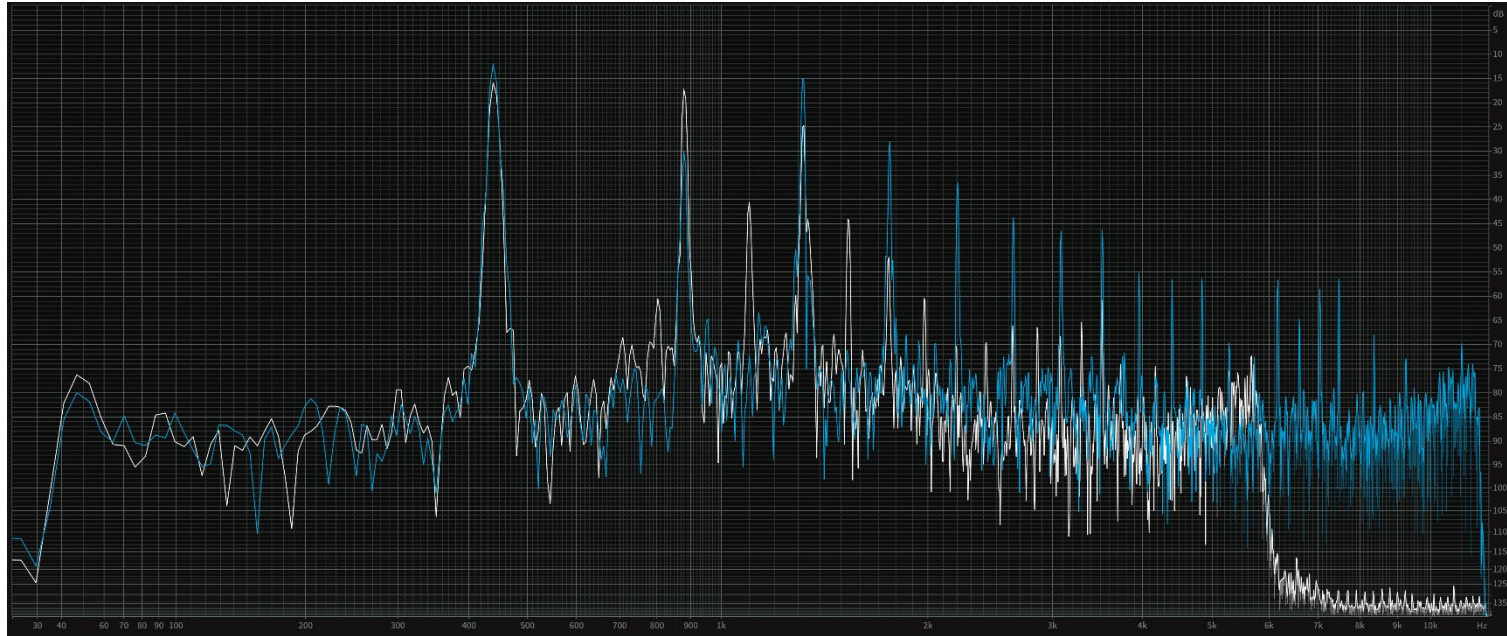
Depending on the acoustics of the musical instrument, either a perfect fifth will be created (for  $\frac{1}{2}$  wavelength resonator instruments) or a third will be created (for  $\frac{1}{4}$  wavelength resonator instruments).



# Perfect Fifth (violin, guitar, flute,...)



# Third - clarinet, trumpet, French horn ...



But.... the one-octave “island of refuge” is not useful for speech/vocals



Marina Salorio-Corbetto, Thomas Baer & Brian C. J. Moore (2016): Quality ratings of frequency-compressed speech by participants with extensive high-frequency dead regions in the cochlea, *International Journal of Audiology*, DOI: [10.1080/14992027.2016.1234071](https://doi.org/10.1080/14992027.2016.1234071)

# Music Program #3- Instrumental Only Music

1. The “front end” has been taken care of
2. The frequency bandwidth has been optimized for that client
3. One octave linear frequency lowering
4. Similar compression characteristics to a speech-in-quiet program
5. Advanced features such as feedback management has been “managed”

# Some hardware and after-fit tech desired by professional musicians

[www.HearingReview.com](http://www.HearingReview.com) (October 2018)

A series of hard of hearing professional musicians give a “wish list” of what they would like to see provided alongside hearing aids:

- \* a series of patch cords (from streamers to amplifiers)
- \* a method to connect digital audio work stations (DAW) with their hearing aids
- \* more control over their hearing aids “on the run”
- \* fewer knobs (that break)





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