Hearing Aids and Music

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Or...

Music and Hearing Aids
Or...

Music and Hearing Aids is not a software issue...
Hear the Music

www.MusiciansClinics.com

www.HearingHealthMatters.org/HearTheMusic
Four Differences ...

• Speech vs. Music Spectra
• Phonemic vs. phonetic requirements
• Differing sound levels
• Crest factors
Four 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”
Spectral comparison between LTASS and violin playing A [440 Hz]

- Violin A [440 Hz]
- LTASS (Seewald, 1991)
Spectral comparison between LTASS and violin playing A [440 Hz]

- Violin A [440 Hz]
- LTASS (Seewald, 1991)
Different Spectra of Music

Classical Music

Flute & Guitar

Four differences ...

(2) Phonemic vs. phonetic requirements:

*Speech is mostly low-frequency energy and high frequency clarity (SII).*

*Music perceptual requirements depends on the instrument.... Highly variable.*
  - Violins need to hear the balance between low and high frequencies.
  - Clarinets only need to hear the lower frequencies.
Four differences ...

(3) Differing sound levels:

*Speech is 65 dB SPL ± 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*
Four differences ...

(4) Crest factor: (peak – RMS)

*Speech has a crest factor of 12 dB*

*Music has a crest factor -up to 18 dB*
  • Less damping.
Crest factor

- Peak Level
- RMS Level
Speech

- 65 dB SPL RMS
- 12 dB crest factor
- -6 dB / octave
- Well defined SII and target
- Context and conversation

Music

- >100 dB SPL RMS
- 18 dB crest factor
- Variable slopes
- No “MII” and no target
- No context
What about hard of hearing musicians ... 

... or non-musicians who like to listen to music?
Hearing Aids and Musicians

Peak input limiting level of most hearing aids limits sound above 85 dB SPL.

... 1980s: set to about 100 dB SPL.

.... shouted [a] is about 82 dB SPL peak
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.
Max Headroom
The overpass analogy

80 dB dynamic range
Intense music and low "ceiling"
If we don’t have enough Headroom
The Fallacy of ANSI S 3.22

ANSI S 3.22 is a REPORTING standard and not a PERFORMANCE standard.

Mentions how to measure gain, output, distortion, equivalent internal noise....

Newest version doesn’t measure attack or release time.

And it never has measured “peak input limiting level”
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 96 dB SPL to 92 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 105 dB SPL
... better since no A/D...
even better since wider bandwidth
Software changes?

Many manufacturers have tried frequency response changes. This may take the effect of a low cut, a low frequency boost, a high cut, a high frequency boost, or alterations to the mid-frequencies.

None work well, and are (probably) of minimal use in real life situations.
Four strategies...

1. Lower volume on stereo or other input and increase gain on aid.
2. You can use an FM (or ALD) system as input.
3. 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).
4. Take off the hearing aids
1. Lower the volume of the input (and raise the volume control if necessary)...
... turn down the input...
2. You can use an FM system as input.

And turn down the volume on the FM or other assistive listening device. (“10 kohm resistor in series and 1 kohm to ground”... and this will give 20 dB reduction)
3. Use microphone attenuators such as Scotch tape.

3-4 layers of Scotch tape will attenuate the input by 10-12 decibels...
Reducing output by reducing input (not gain)
4. Take off the hearing aids

Since music has a higher sound level than speech, maybe removing the hearing aids may be the best thing?
4. Take off the hearing aids

<table>
<thead>
<tr>
<th>dB HL at 1000 Hz</th>
<th>65 dB input</th>
<th>80 dB input</th>
<th>95 dB input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>35</td>
<td>8</td>
<td>4</td>
<td>0</td>
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<tr>
<td>45</td>
<td>14</td>
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<td>55</td>
<td>20</td>
<td>10</td>
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<tr>
<td>65</td>
<td>28</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>75</td>
<td>36</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>85</td>
<td>44</td>
<td>24</td>
<td>4</td>
</tr>
</tbody>
</table>
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.

Fooling the stimulus level...
(can also use tape over the reference microphone...)

Artificially increasing stimulus level by 10 dB

- **Test mic half way to speaker**
Let’s re-examine the crest factor for speech ...

<table>
<thead>
<tr>
<th>Analysis window (msec)</th>
<th>500</th>
<th>400</th>
<th>300</th>
<th>200</th>
<th>125</th>
<th>100</th>
<th>50</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crest factor (dB)</td>
<td>12.46</td>
<td>12.48</td>
<td>12.46</td>
<td>12.45</td>
<td>12.46</td>
<td>13.22</td>
<td>16.68</td>
<td>16.68</td>
</tr>
</tbody>
</table>
Let’s re-examine the crest factor for speech ...

Sivian and White (1933) and Cox et al. (1988)

Assumed the analyzing window should be 125 msec.
... but we are not talking about our auditory systems, .... only the front end.
What the crest factor can tell us about speech...

If the crest factor is actually a function of the window of analysis, then a hard of hearing person’s own voice can overdrive their own hearing aid!

84 dB input + 16 dB crest factor > 96 dB
Benefit even for high level speech...
Opn and the DOSO (Cox et al., 2014)

Device-Oriented Subjective Outcome (DOSO) scale.

As shown by Cox and her colleagues, “...compared with wearer-oriented outcomes, device-oriented outcomes were more independent of personality variables.” (p. 727).

DOSO- good test for determining differences among devices - “relatively” independent of personalities.
Opn and the DOSO (Cox et al., 2014)

7 point scale answering the question “How good are the hearing aids at...”

Categories:

• Speech cues
• Listening effort
• Quiet
• Pleasant
• (Convenience and Use)
Opn and the DOSO (Cox et al., 2004)

Statistical averages:

Box = inner two quartiles (50%)
Stems = 80 percentile range
Musician averages for old and new (opn) technology
Non-musicians averages for the old and new (opn) technology
Musicians vs. non-musicians for the old technology
Musicians vs. non-musicians with the new (opn) technology
Preferences for musicians with auto wave "on" (gray) and "off" (orange)

Preference differences for musicians for auto wave "on" and auto wave "off"
Preferences for non-musicians with auto wave (on (gray) and off (orange))

Preference differences for non-musicians for auto wave "on" and auto wave "off"
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. (Unitron has done this).
Microphone noise... you will need expansion...
Expansion comes to the rescue

\[ \text{FREQUENCY kHz} \]

- violet = high frequency emphasis microphone system
- red = broadband microphone system
- black = high frequency emphasis microphone system + adjusted LLE thresholds for noise compensation

\[ \text{Pout dB SPL} \]
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

- 95 dBSPL = Yellow
- 100 dBSPL = Blue
- 105 dBSPL = Grey
- 110 dBSPL = Black

![Graph showing THD results with HF Mic for 95, 100, 105 & 110 dB SPL inputs. The graph displays distortion (%) against frequency (Hz) with different lines representing each SPL level.]
2. Shifting the dynamic range upwards

Bernafon Live Music Plus (111 dB SPL) has shifted the dynamic range up from 0-96 dB SPL to 15 dB – 111 dB SPL.
2a. Low gain/high output test  
(105 dB SPL input)

Live Music Plus function turned on:  
<3% distortion

Live Music Plus function turned off:  
20-24% distortion
2b. Shifting the dynamic range upwards

Another approach
(Widex Dream/Beyond/Evoke, 113 dB SPL)

Transformer effect by doubling the voltage

Different than amplification because it increases top end while keeping the noise floor low
Paired Comparisons for All stimuli: Visit 1

Number of subjects = 10

Stimulus Level

Preference (%)
3. Front end compression prior to the A/D converter

Almost all hearing aid companies (the first was Resound, 106 dB SPL) are now using an analog compressor prior to the A/D converter ...

... and then digitally re-establish gain after...
20 and 24 bit architecture A/D converters that have > 96 dB dynamic range.
- Sound Design Wolverine,
- ON Semi-Conductor Ezairo 5900/7000
- Motorolla 24 bit system
- For each bit \( n \) add 6 dB to dynamic range
  \[
  (20n)\log_2 = 20n \times 0.3
  \]
HIT OF THE PARTY

OH, Marshall
YOU’RE WONDERFUL!

Did he say 20nlog2!!
Some new “24 bit” systems:

Unitron North (119 dB SPL max)
Phonak Venture (119 dB SPL max)
Oticon Opn
Widex Evoke
Bernafon Zarena

………..
... and everything else...

1. Frequency response
2. One channel is better than multi-channel
3. Similar compression characteristics as speech. (Davies, Souza & Fabry, 2009)
4. Disable noise reduction and feedback management systems.
5. No frequency transposition
6. 6 dB lower OSPL90 and gain than the speech-in-quiet program.
7. Number of receivers? (a temporal issue)
1. Frequency response

Frequency response...

... based more on limitations of auditory system and not input stimulus

Based on the work of Brian Moore and Todd Ricketts:

*If mild loss then broadest possible bandwidth*

*If steeply sloping loss then narrower may be better (dead regions)*

*If >60 dB HL then narrower may be better (dead regions)*
2. One channel is best...

The lower frequency fundamental energy is treated in the same way as the higher frequency harmonic energy

The balance of music is maintained
.... the shape of the spectrum is maintained.
.... At least for classical music...
3. Similar compression

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).
4. Disable advanced features

Disable the noise and feedback management systems.

The signal (music) is so intense that any microphone noise would be inaudible.

The gain is so low (due to intense inputs) that may not need feedback control. Chirping due to uncancelled feedback signal?
5. No frequency transposition

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

EXCEPT if a child has successfully adapted to transposition for speech then...???
5. No frequency transposition

Music: line spectrum (except percussion).

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

1. Low frequency line spectra Sonorants
2. High frequency continuous spectra Obstruents

Music:

All frequencies have line spectra
6. 6 dB lower OSPL90 and gain

Given similar compression characteristics between speech and music, and given a 6 dB greater crest factor for instrumental music….

-6 dB OSPL90 than speech-in-quiet program

and...

-6 dB gain than speech-in-quiet program
7. One or more hearing aid receivers?
7. One or more hearing aid receivers?

Speech is low frequency OR high frequency but at any one point in time is never both...

Music is always both low AND high frequency at any one point in time. Low frequency fundamental and high frequency harmonics...
Speech is narrowband and Music is wideband

<table>
<thead>
<tr>
<th></th>
<th>SPEECH</th>
<th>MUSIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long term bandwidth</td>
<td>wide</td>
<td>wide</td>
</tr>
<tr>
<td>Short term (at one point in time)</td>
<td>narrow</td>
<td>wide</td>
</tr>
<tr>
<td>Low frequency energy</td>
<td>narrow band harmonics</td>
<td>narrow band harmonics</td>
</tr>
<tr>
<td>High frequency energy</td>
<td>Continuous spectral smear</td>
<td>narrow band harmonics</td>
</tr>
<tr>
<td>Frequency transposition</td>
<td>Useful for high frequencies</td>
<td>Never useful</td>
</tr>
</tbody>
</table>
7. One or more hearing aid receivers?

Speech should have two receivers
    - one for lows and another for highs

Music should have one receiver (opposite of many in-ear monitors).
Musicians and Hearing Aids

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www.MusiciansClinics.com

www.HearingHealthMatters.org/HearTheMusic