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Evaluating the Efficacy of Music Programs in Hearing Aids

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Purdue University

Joshua M. Alexander, PhD, CCC-A

Joshua Alexander is an associate professor at Purdue University in West Lafayette, Indiana. At the University of Wisconsin-Madison, he received a BS, MS, and PhD in Audiology (psychoacoustics) and researched speech perception as a post-doctoral scientist. He also completed clinical and post- doctoral fellowships at Boys Town National Research Hospital in Omaha, Nebraska. The central goal of Dr. Alexander's research is to improve speech understanding and decrease listening effort in hearing aid users. To assist in these efforts, he has developed a PC-based hearing aid simulator that is capable of replicating key features of commercial hearing aids. This tool combined with laboratory measures and models of processing at the sensory, neural, and cognitive levels allows him and his collaborators to explore how and why certain features of hearing aids affect perception and to explore factors that might explain individual differences in hearing aid benefit.

Emily Sandgren, BS

Emily Sandgren is a third year graduate student in the audiology program at Purdue University. She received her BS in Communication Sciences and Disorders with minors in Music and Spanish from Samford University as a member of the University Fellows Honors Program. She has an extensive background as a musician and has played piano, cello, percussion, trumpet, and mellophone in numerous ensembles. She will complete her fourth year clinical placement at UW Health in Madison, WI.

Disclosures

- **Presenter Disclosure**: Financial: Joshua Alexander is an employee of Purdue University and has past research support from: The National Institutes of Health; The Indiana Clinical and Translational Sciences Institute; The William Demant Holding Group; Sonova Holding AG. He is the holder of two patents on a method of frequency lowering and has a recent invention disclosure on another method. He is a paid consultant for Creare, LLC on an NIH SBIR project to develop an open-source, master hearing aid. Dr. Alexander is the recipient of speaker honoraria from Signia, Oticon, Phonak, Starkey, and ReSound hearing aid companies, and received an honorarium for presenting this course. Non-financial: Joshua Alexander has no relevant non-financial relationships to disclose. Financial: Emily Sandgren is a student of Purdue University. Non-financial: Emily Sandgren has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
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Learning Outcomes

After this course, participants will be able to

1. Describe how hearing aids may negatively impact music perception.
2. Describe key features of real or hypothetical music programs for hearing aids.
3. Describe the efficacy of current music programs in hearing aids.

Music Enjoyment

- **Significant source of entertainment**
  - Americans aged 16 to 65+ years listen to music more than 2 hours per day (Delmonte 2018)
  - 73% of the use of smart home speakers is for listening to music (Delmonte 2018)
- **Directly related to quality of life**
  - Hearing aid users report negative emotional consequences when they disengage from music due to the sound quality of music with hearing aids (Greasley *et al.* 2020)

Hearing Aids and Music Listening

- Greasley (2022) online survey of 1,406 hearing aid users
  - 84% reported listening to recorded music with their hearing aids
  - 70% listened for ≥ 3 hours/week

Dissatisfaction with Hearing Aids

- Greasley (2022)
  - **75%** hearing aid users reported **distortion** is at least an occasional problem when listening to recorded music
  - **25%** reported **distortion** is a problem often or all the time
- Greasley *et al.* (2020)
  - 67% of hearing aid users reported difficulty with music
- Madsen & Moore (2014)
  - >50% reported hearing aids made music sound **distorted**

Hearing aids are optimized for speech, Music is different than speech

1. Listening levels are higher
   - Croghan *et al.* (2016): preferred levels for recorded music ≈ **80 dBA** at the tympanic membrane for aided and unaided
2. Higher crest factors (*peak dB — average dB*)
   - **18-25 dB** for live music; 12-15 dB for speech
3. At a given time instant, music tends to be wideband while speech is narrowband (**Chasin 2022**)
   - Speech: lower-freq. formants (e.g., vowels) or higher freq. frication (e.g., “s”), but not at same time
   - Music: low-freq. fundamental and all higher freq. harmonics

Features may be Problematic for Music

- Wide dynamic range compression (WDRC)
  - Recorded music is already compressed; may alter spectral balance
- Directional microphones
  - May distort temporal envelope; low-freq. roll-off will **reduce bass**
- Noise reduction
  - May distort temporal envelope
- Impulse/transient reduction
  - Music has a lot of transients!
- Feedback suppression
  - Entrainment, may work against intense tonal music elements
- Frequency lowering
  - If low freq. are altered, will distort harmonic relationships

What do hearing aid users prefer?

- **Compression distorts temporal envelope: <u>less is more</u>**
- Linear usually preferred over WDRC
  - Madsen *et al.* (2015), Kirshberger & Russo (2016)
- Slow acting compression preferred over fast acting
  - Davies-Venn et al. (2007), Moore (2012), Croghan et al. (2014)

What do hearing aid users prefer?

- **Extended ultra-high-frequency response**
  - Benefit is usually limited by hearing loss
- **Extended ultra-low-frequency response (<200 Hz)**
  - Vaisberg *et al.* (2020, 2021), Franks (1982), Punch (1978)
  - Benefits for filter cutoffs as low as 50-55 Hz
    - Moore & Tan (2003); Vaisberg et al., (2017)
    - *Why?* According to Olive (2022): Recorded music is designed for loudspeakers in a semi-reflective room → reflections increase energy < 200 Hz by 5-6 dB → spaciousness, naturalness, fullness, volume

Music Program Use

- **1 out of 3 to 4** users report having a music program
  - Greasley (2022), Looi et al. (2019), Madsen & Moore (2014)
- Greasley et al. (2020): For 58% of hearing aid users, music was not discussed in clinic
- Greasley (2022): **86% of these users utilize the music program at least occasionally**

Music Program Performance

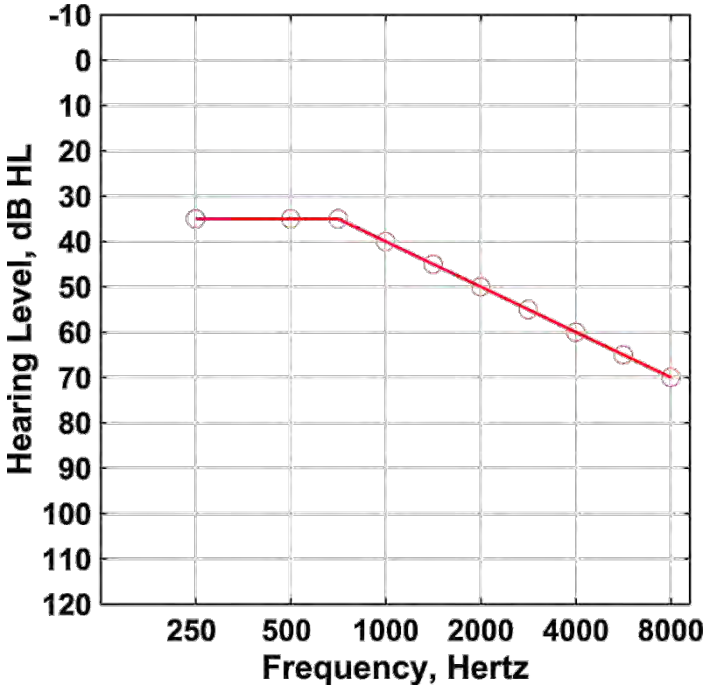
- Madsen & Moore (2014) reported **little differences** in music listening experiences between users with and without music programs
- Vaisberg et al 2019
  - Musician participants reported that music programs in their hearing aids did not provide benefit
- Vaisberg et al. (2022) reported **mixed results**
  - Music program = Universal program for 2 brands
  - Music program > Universal program for 2 brands
    - Music program had **more low-frequency output** than Universal
  - A bigger difference between the best and worst brands than between programs

Study Purpose

Evaluate the efficacy of hearing aid manufacturers' default programs for music compared to their default programs for speech

Hearing Aids

All programmed to NAL-NL2 targets for the same audiogram



MODEL	BRAND
Audéo Paradise	Phonak
Evolv AI 2400	Starkey
Moment 440 RC	Widex
MORE 1	Oticon
Moxi B-R Flex:Trial	Unitron
One 961	ReSound
Pure Charge & Go AX	Signia

Randomly assigned A - G

Music Program Features

Brand	Bit Depth	Microphone	Feedback Suppression	Noise Reduction	Impulse Reduction	Wind Reduction	Expansion
A	24	Omni	Less	Off	Off	--	--
B	24	Virtual Pinna	Off	Off	Off	Off	Off
C	20/24	Omni	Automatic	Off	Off	Off	Off
D	24	Virtual Pinna	Slow	Off	Off	Off	--
E	16	Omni	Slow	Off	Off	Off	On
F	24	Virtual Pinna	On	Off	Moderate-High	Off	--
G	18	Omni	On	Off	Off	Off	Off

Music Samples: 80 dBA in Verifit 2

Title	Artist
“High Hopes”	Panic! At The Disco
“Love Talk”	WayV
“One Dance”	Drake, Wizkid, and Kyla
“DDU DDU DU”	BlackPink
“Don’t Be Shy”	Tiesto and KAROL G
“It’s Only A Paper Moon”	by Nat King Cole
“Lay Your Head on Me”	Crush
“No Problem”	Chance the Rapper, Lil Wayne, and 2 Chainz
“Nunca Es Suficiente”	Los Ángeles Azules and Natalia Lafourcade
“Remember Me”	Fawn Wood, Randy Wood, and R. Carlos Nakai
“Royals”	Lorde
“Sing Sang Sung”	Gordon Goodwin’s Big Phat Band
“Symphony No. 9 in E Minor”	Antonin Dvorak as performed by the Wiener Philharmonic Orchestra

Study Participants

- 59 normal-hearing listeners
- 18-25 years old
- 30 “musicians”
- 29 “non-musicians”

“Rate the Quality”

7. Excellent

6. Very Good

5. Good

4. Fair

3. Poor

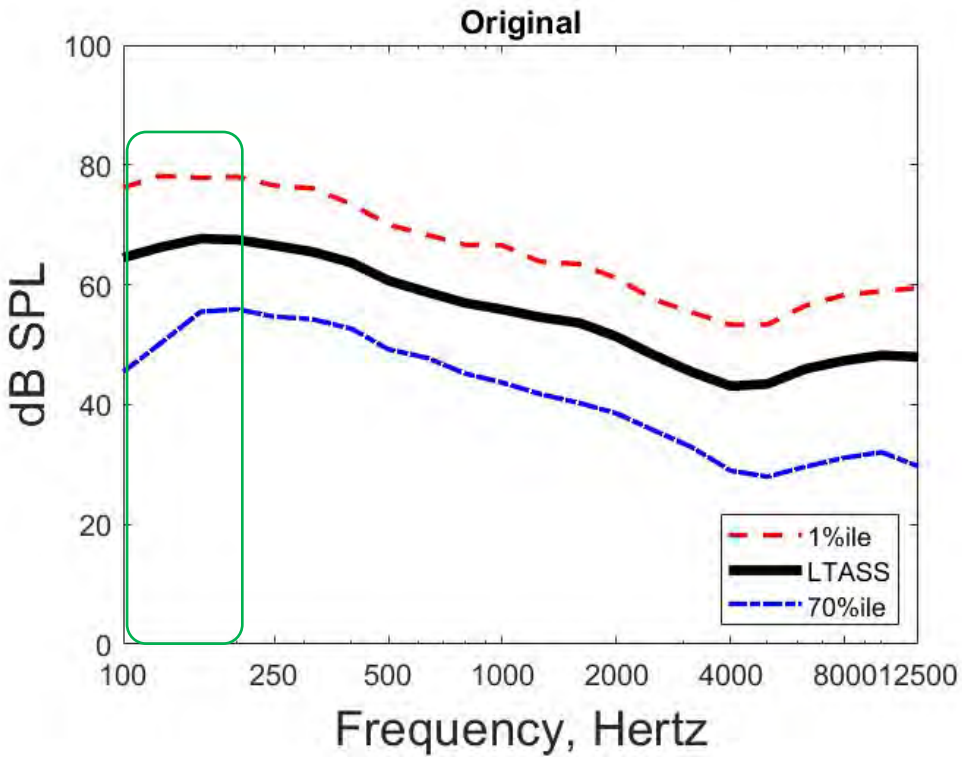
2. Very Poor

1. Unacceptable

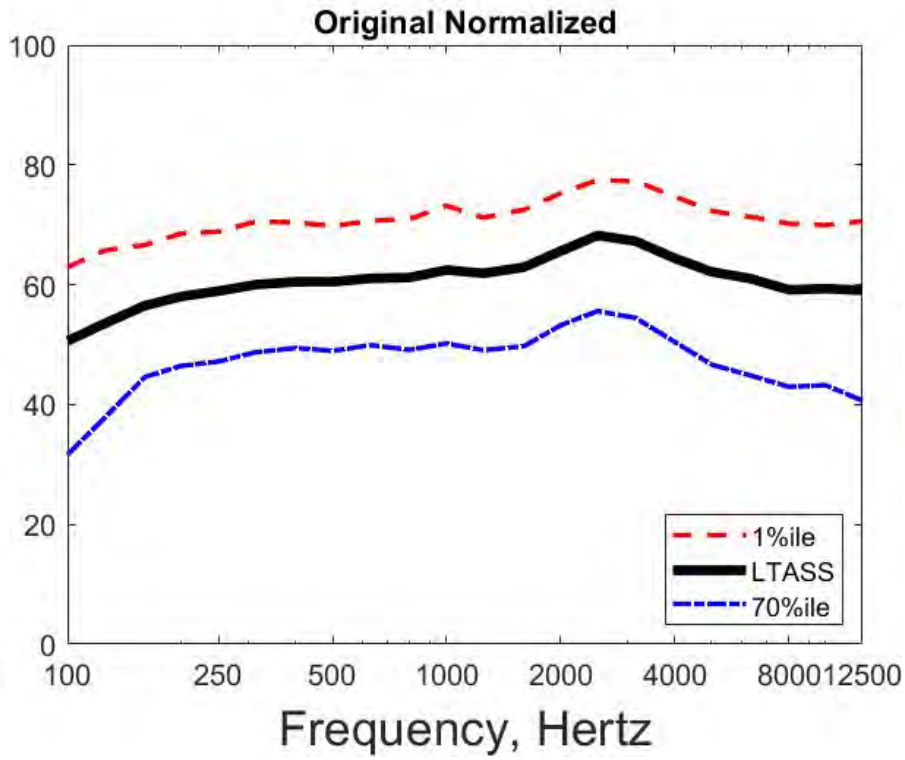
Results

Control Stimuli

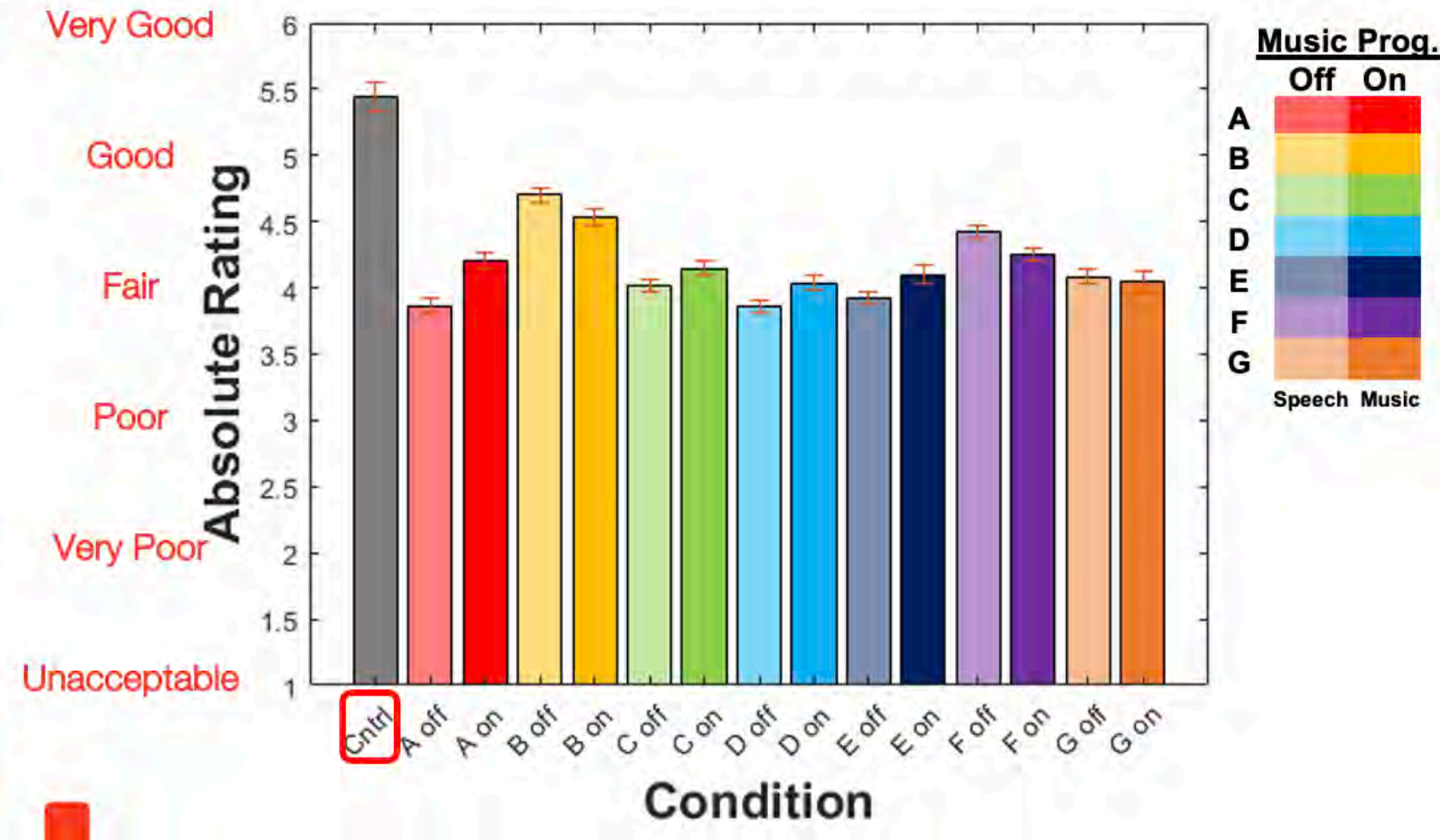
This was the input to the hearing aid



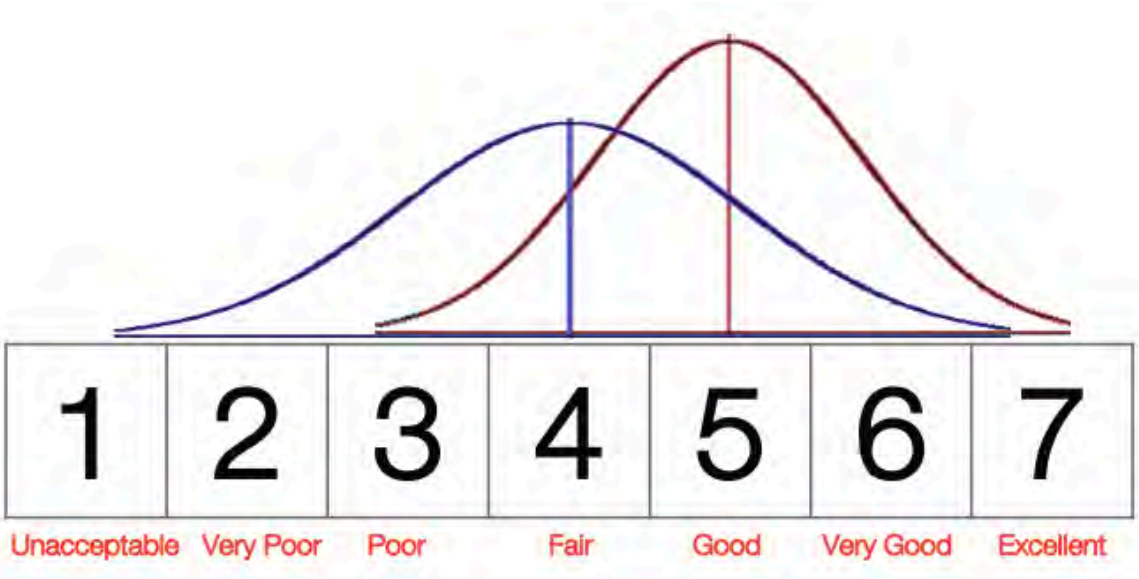
This is what the listeners heard
(Shaped to match the avg. hearing aid output)



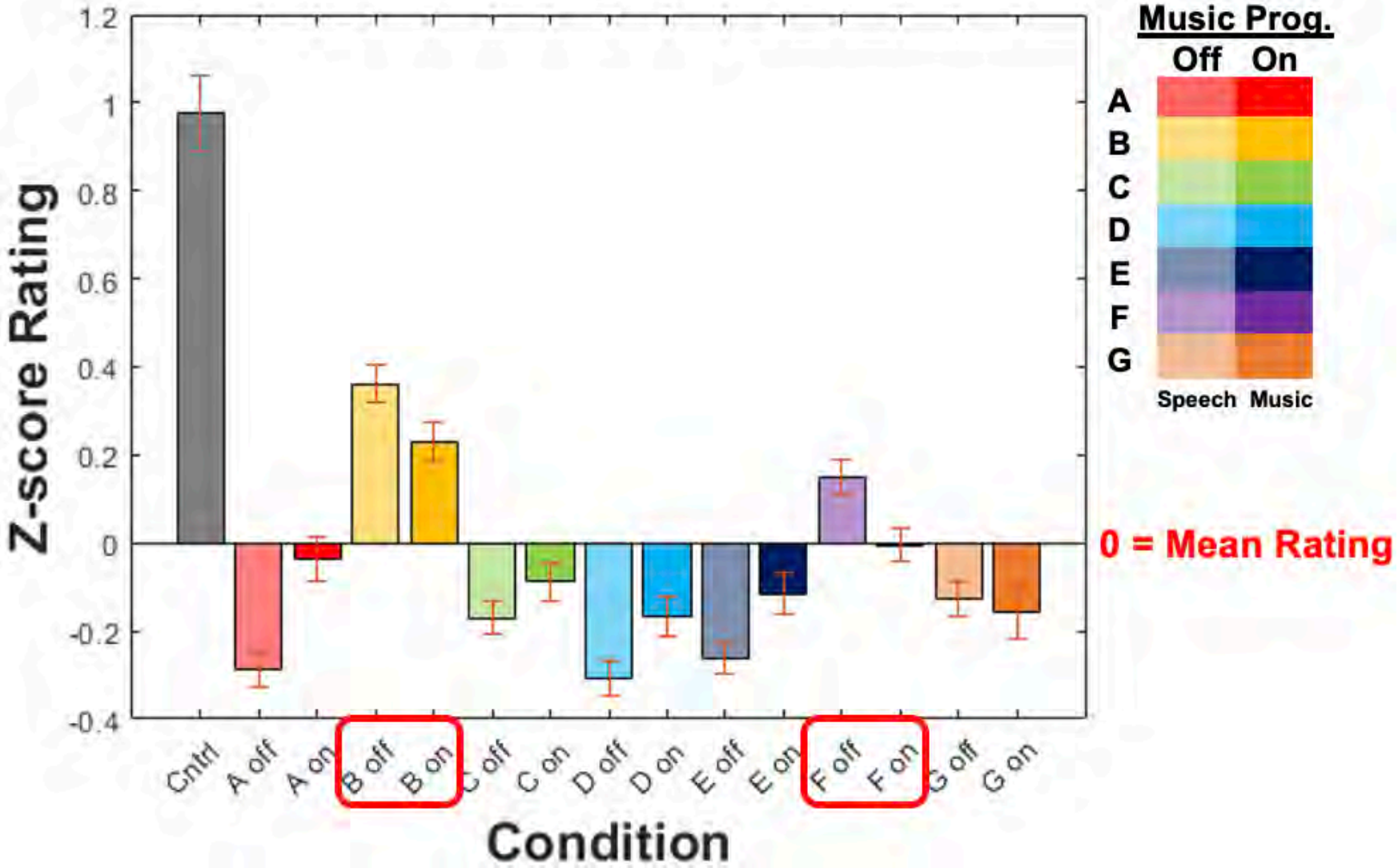
Absolute Ratings



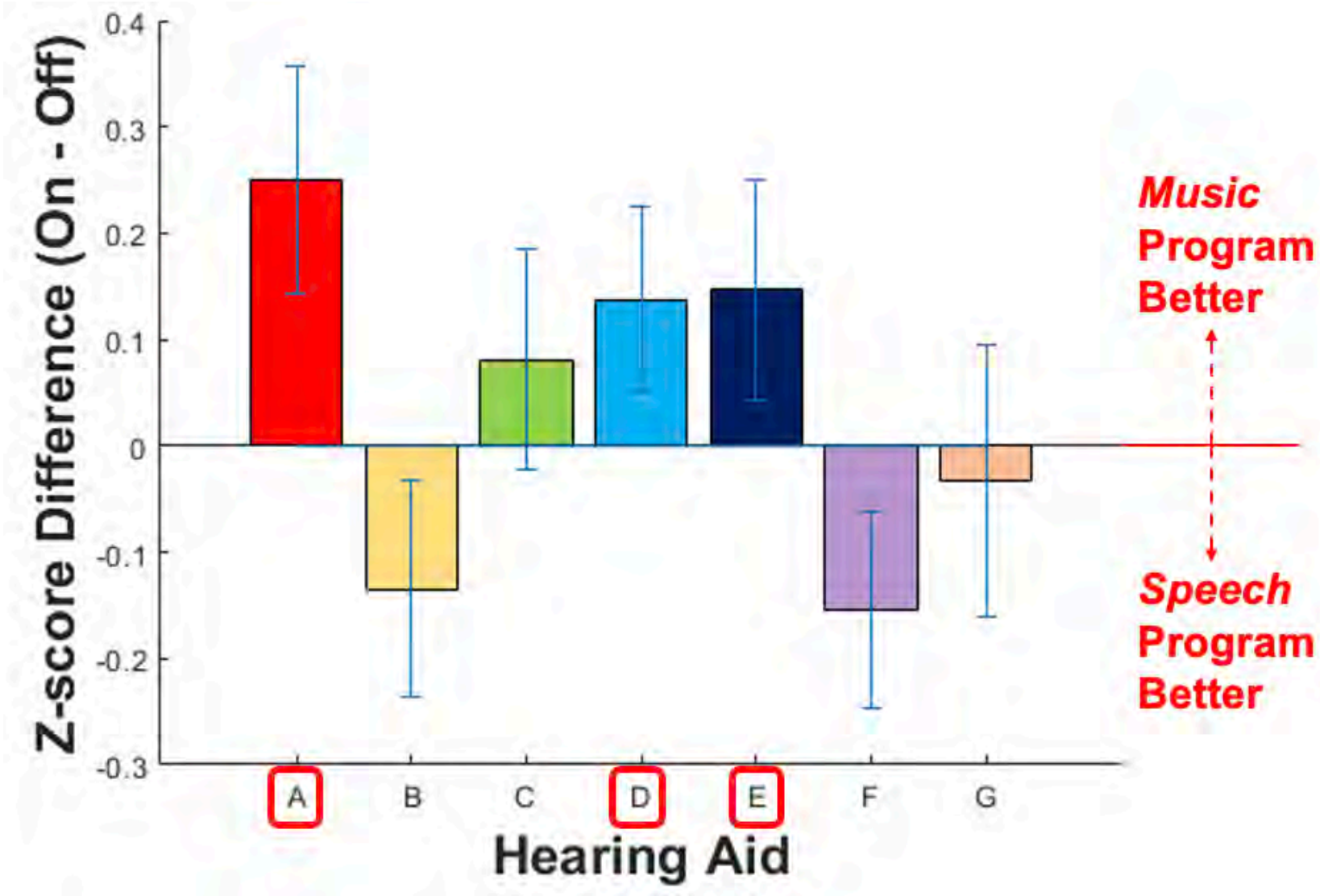
Normalized Ratings



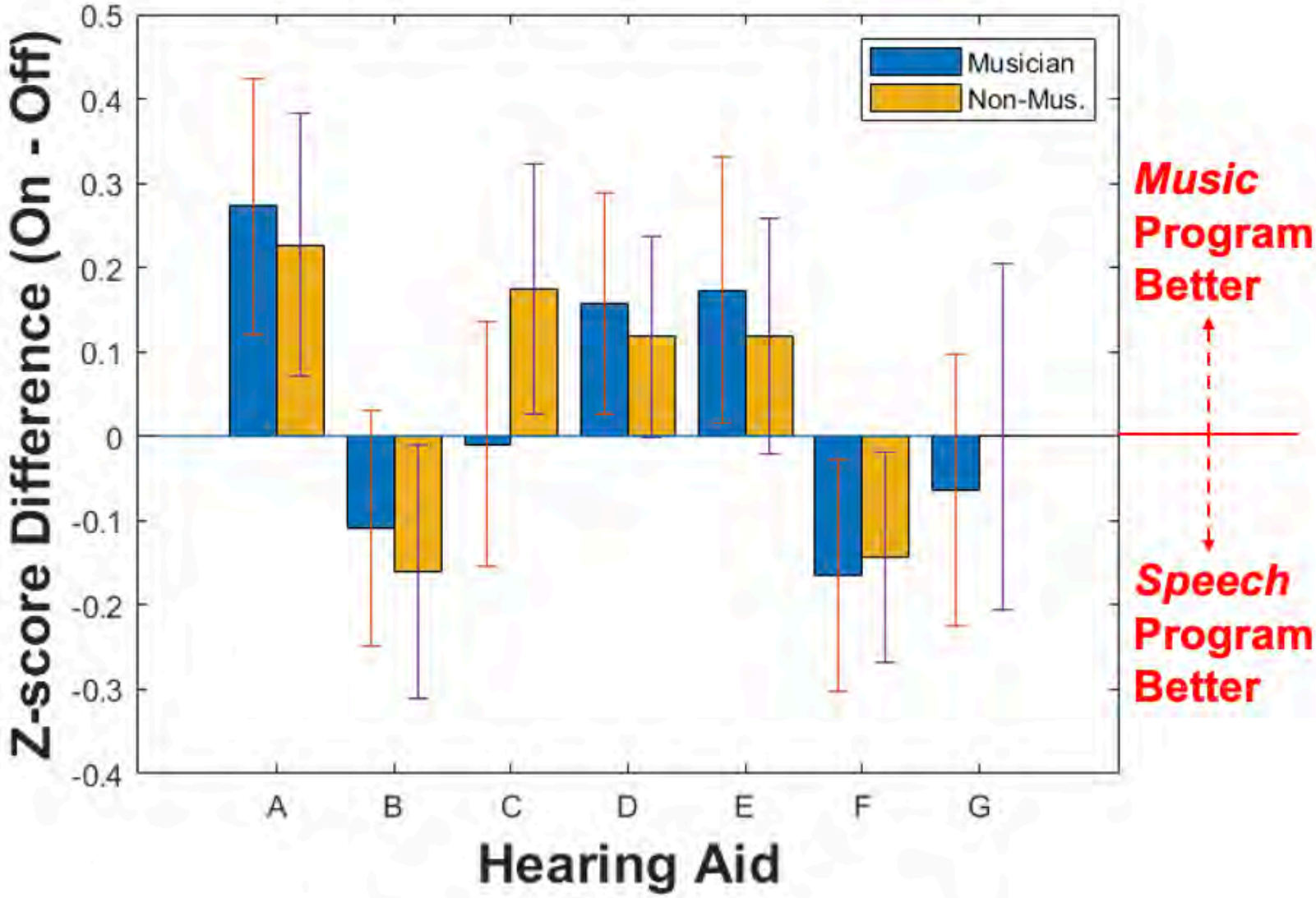
Normalized Ratings



Music vs. Speech Program

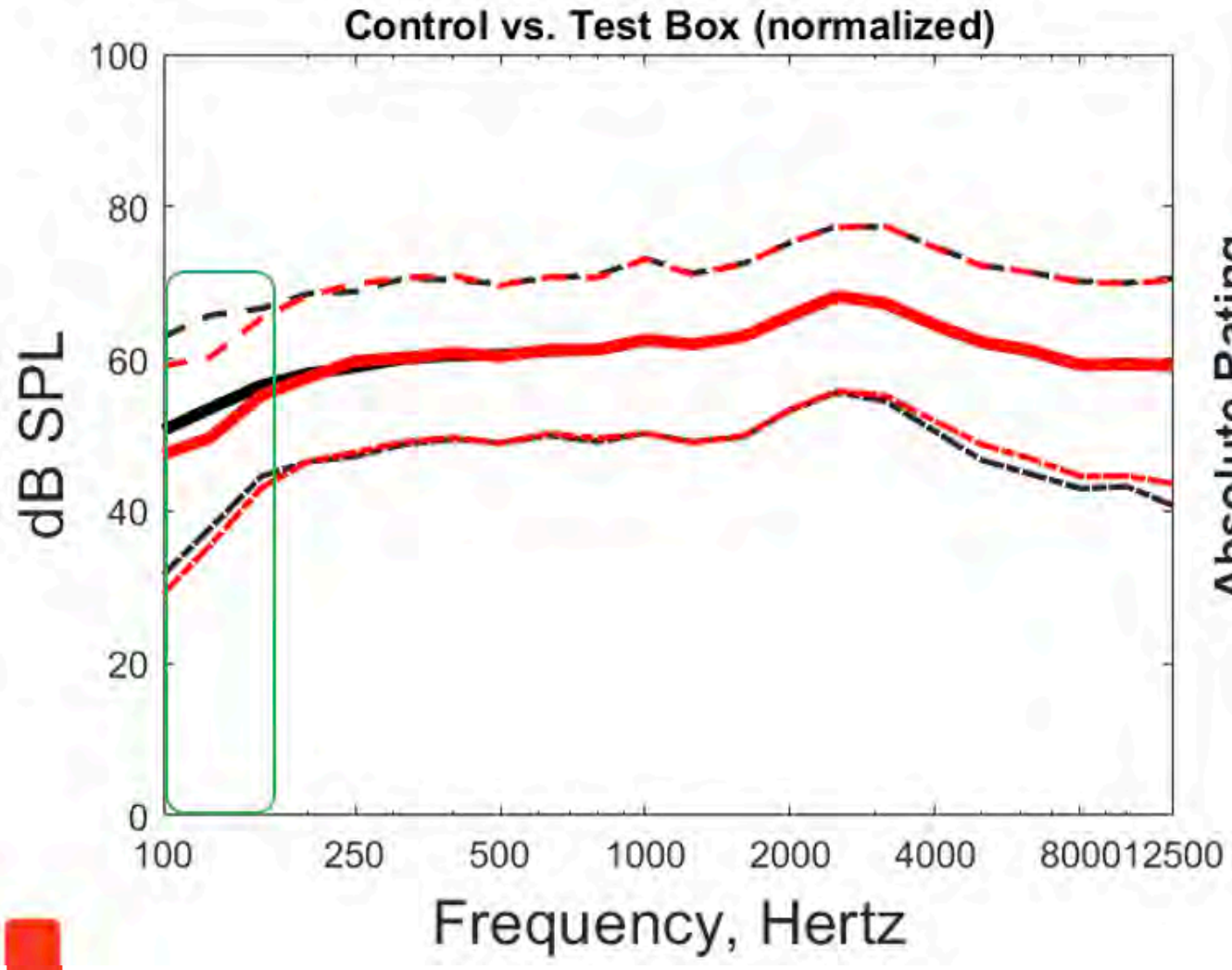


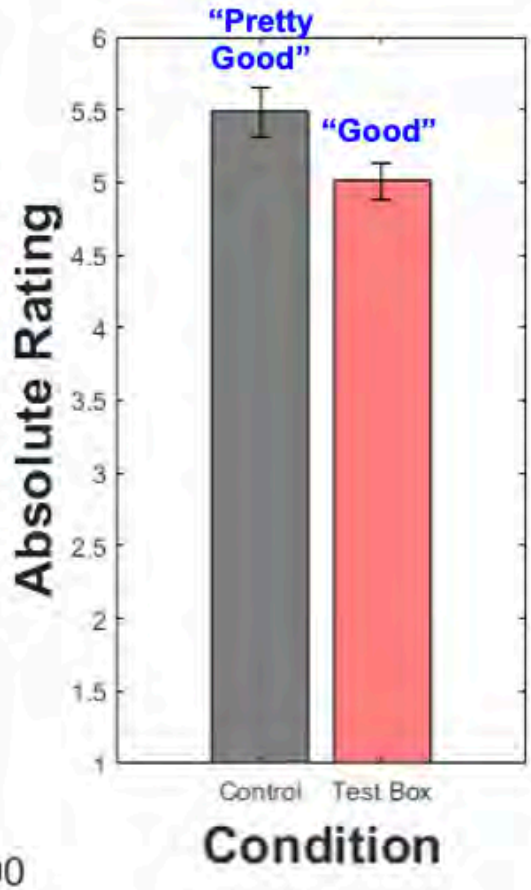
Musicians vs. Non-Musicians



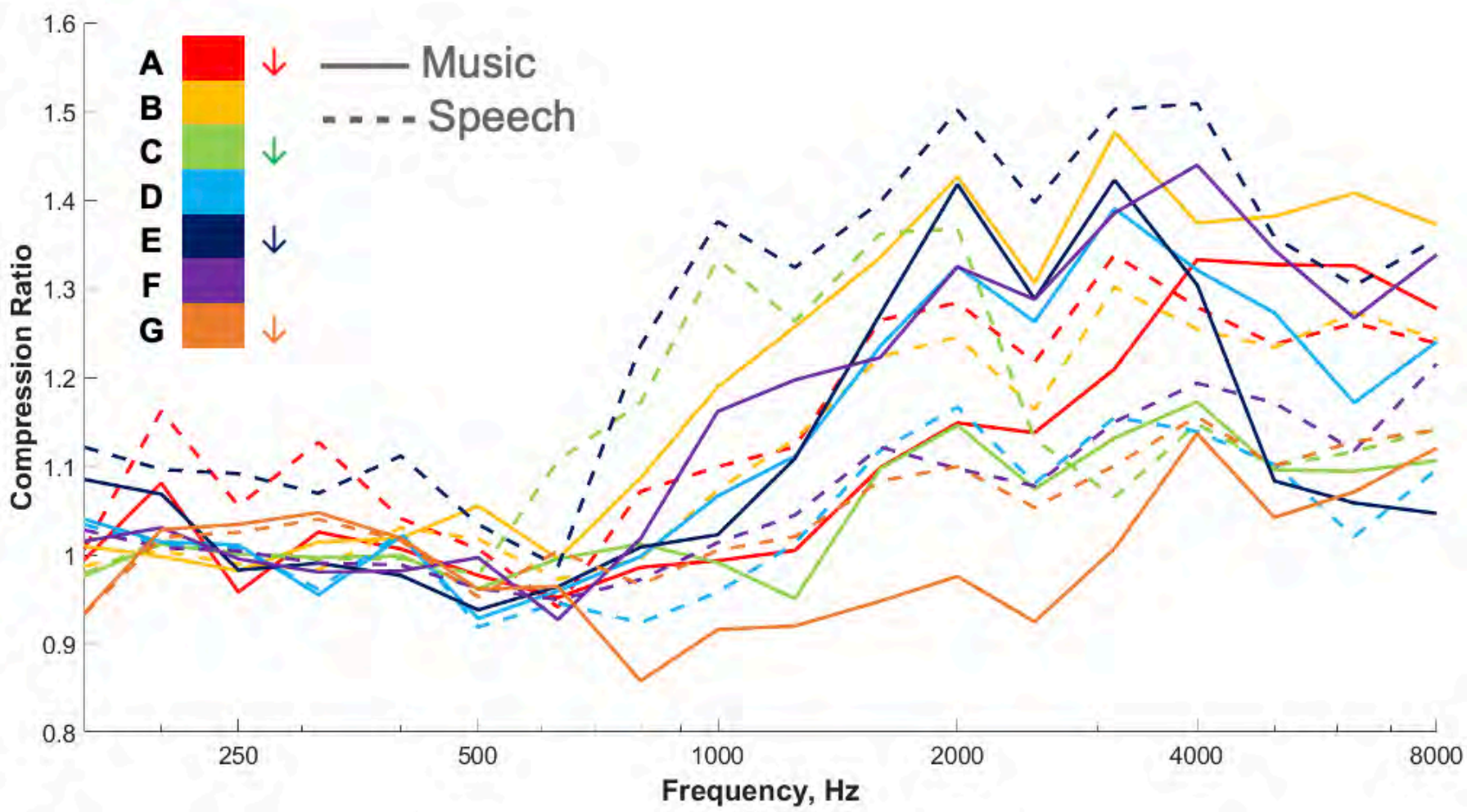
Search for Explanatory Factors

Pilot: Effects of the test box (n=11)

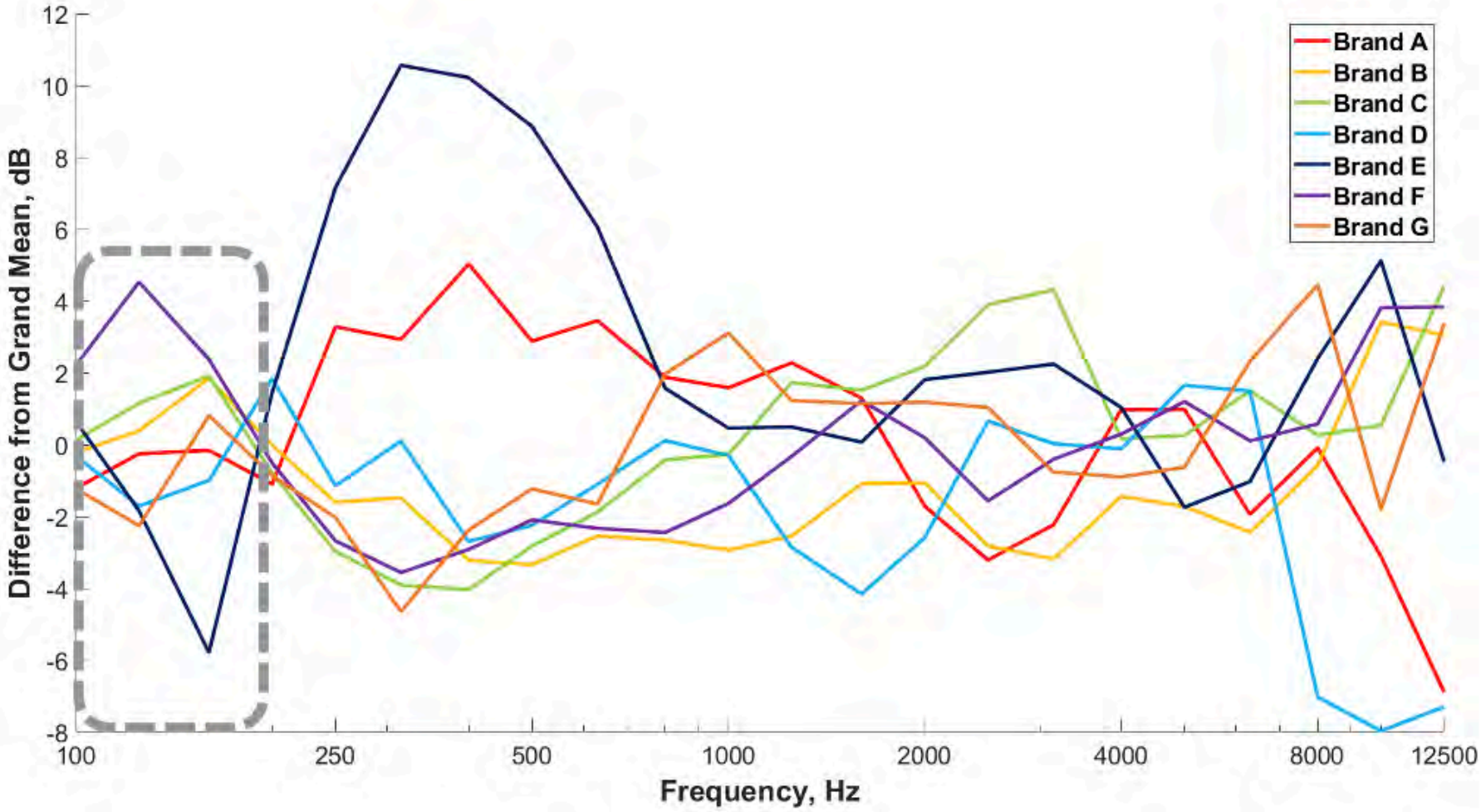




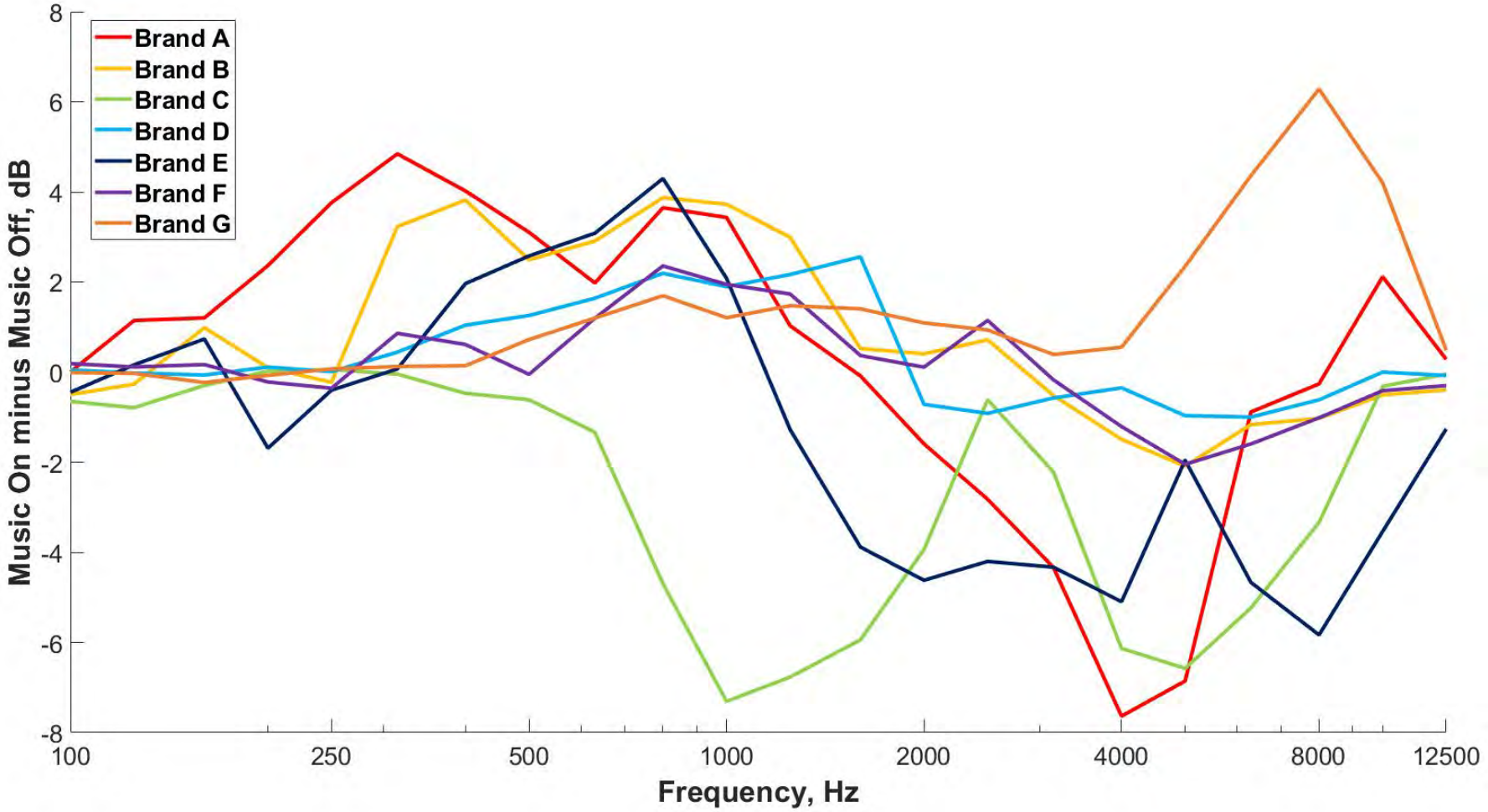
Compression Ratios



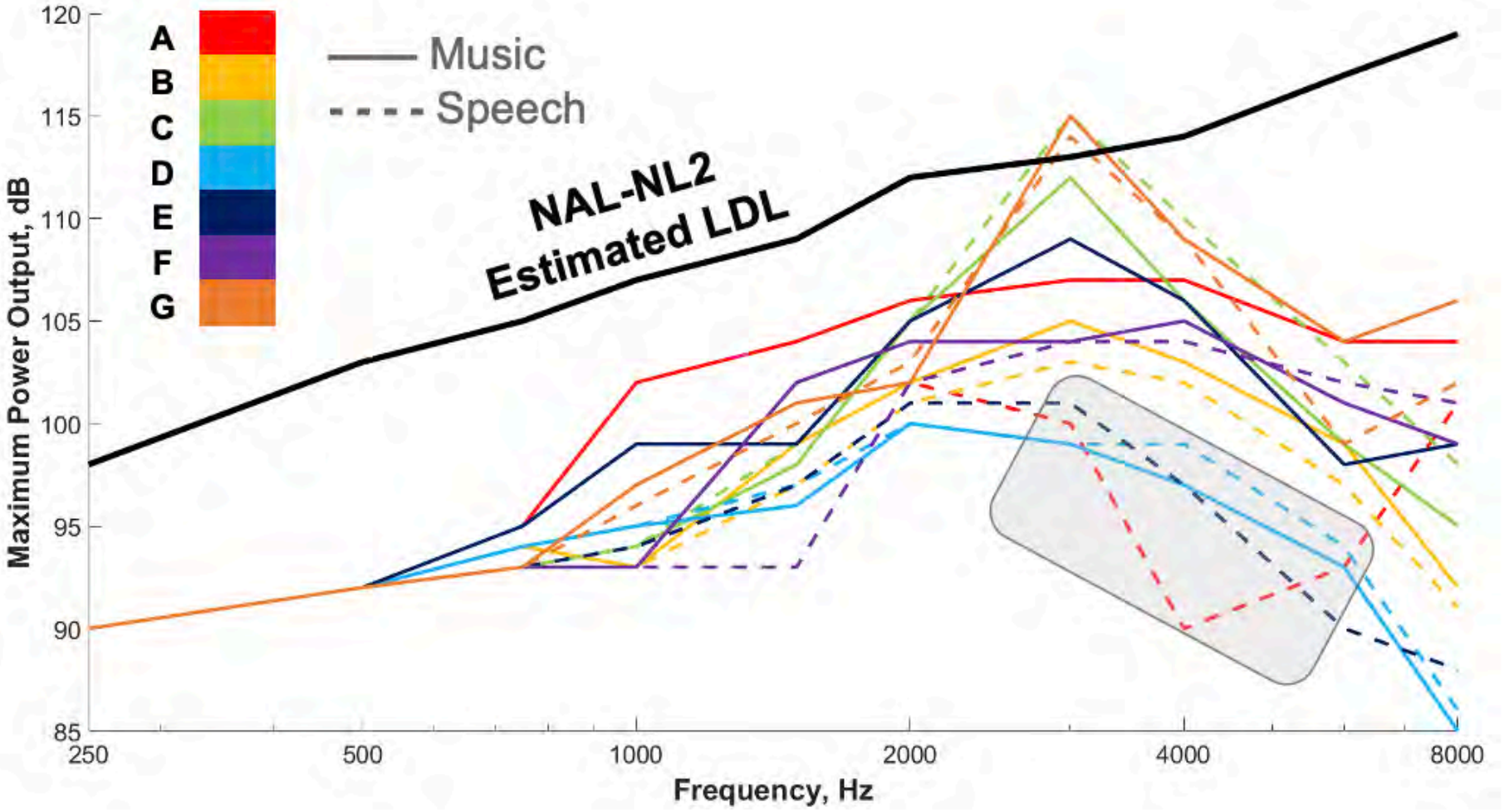
Speech Programs vs. Grand Mean

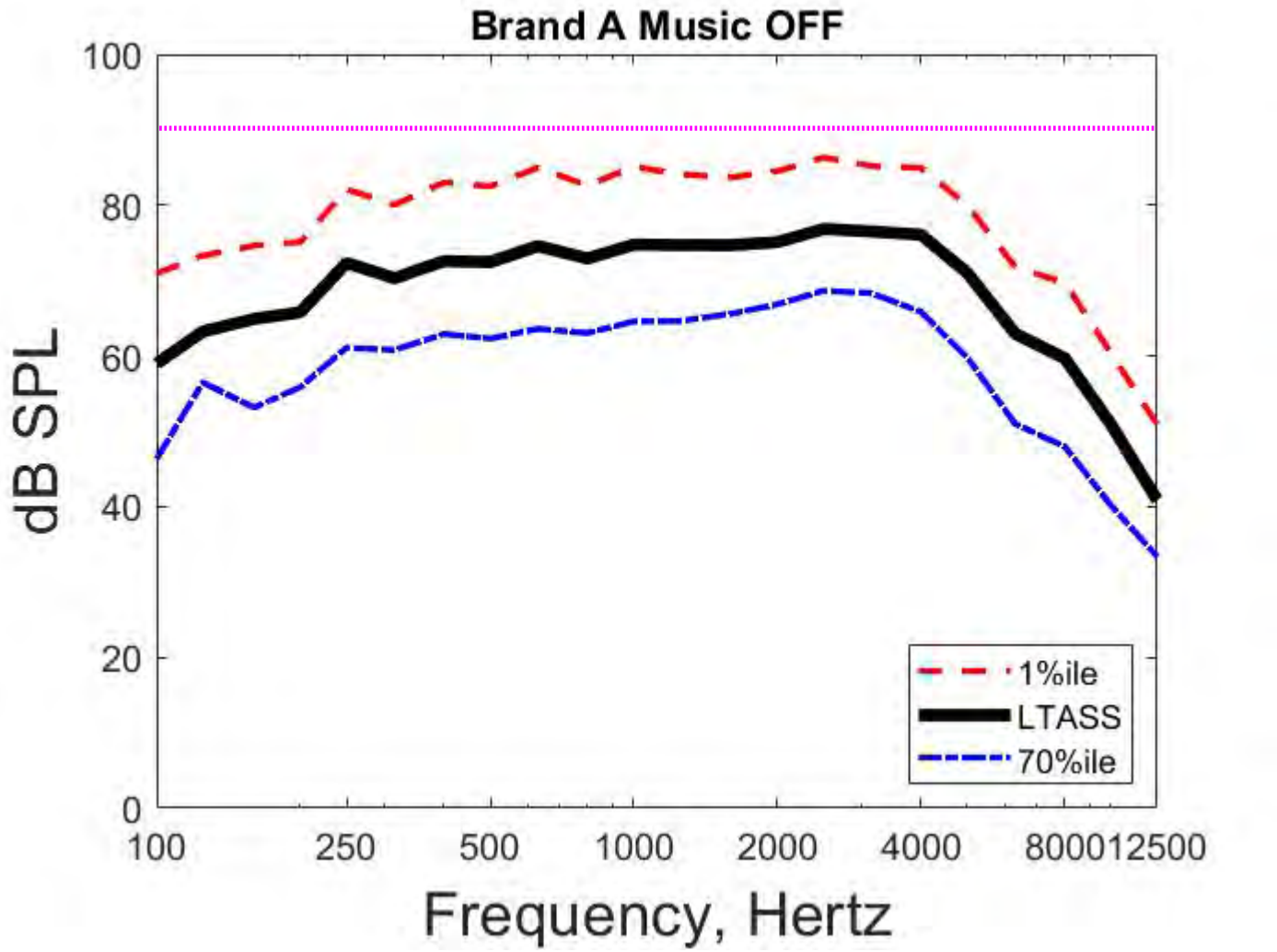


Music Programs vs. Speech Programs



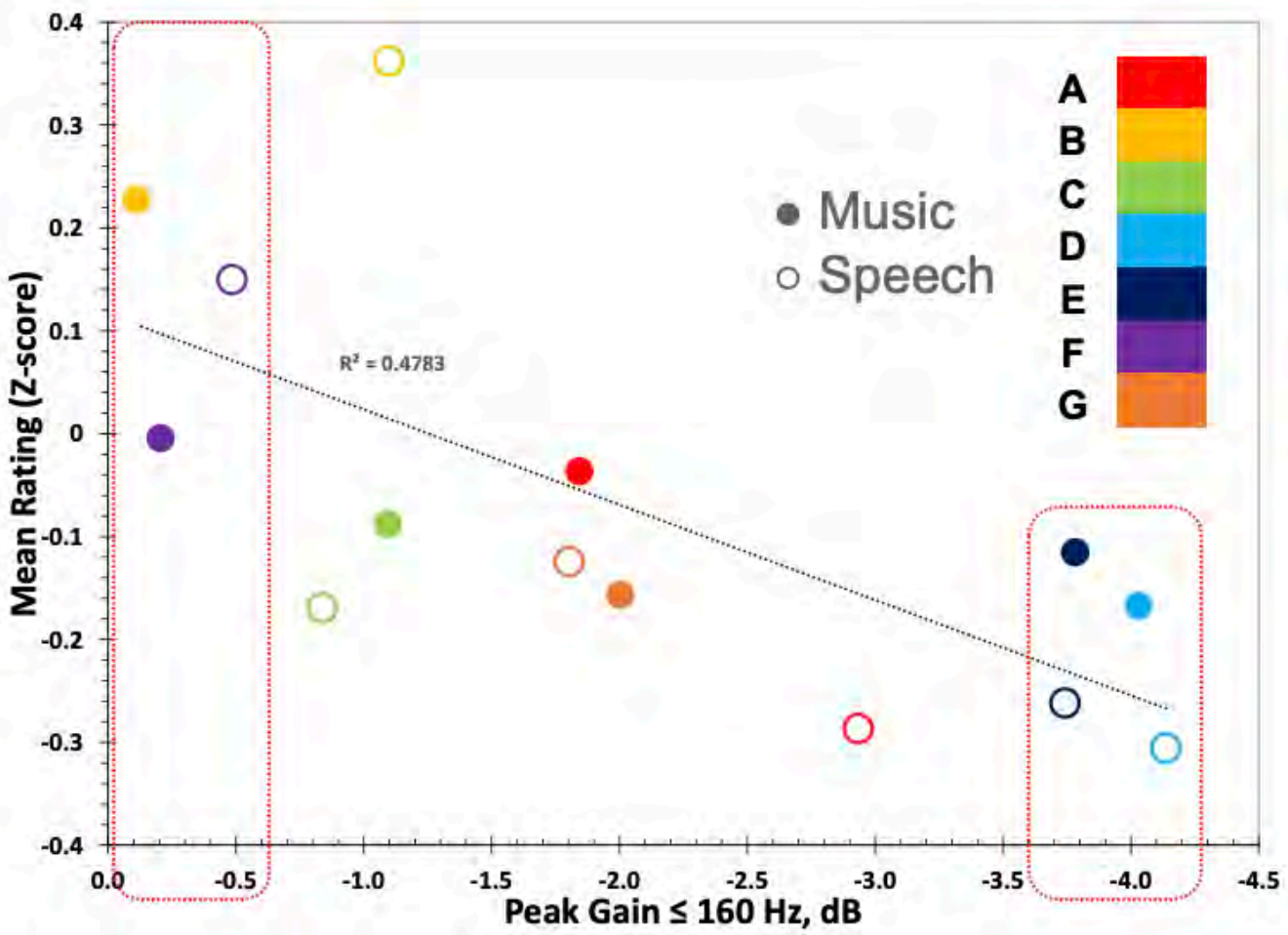
MPO (manufacturers' defaults)



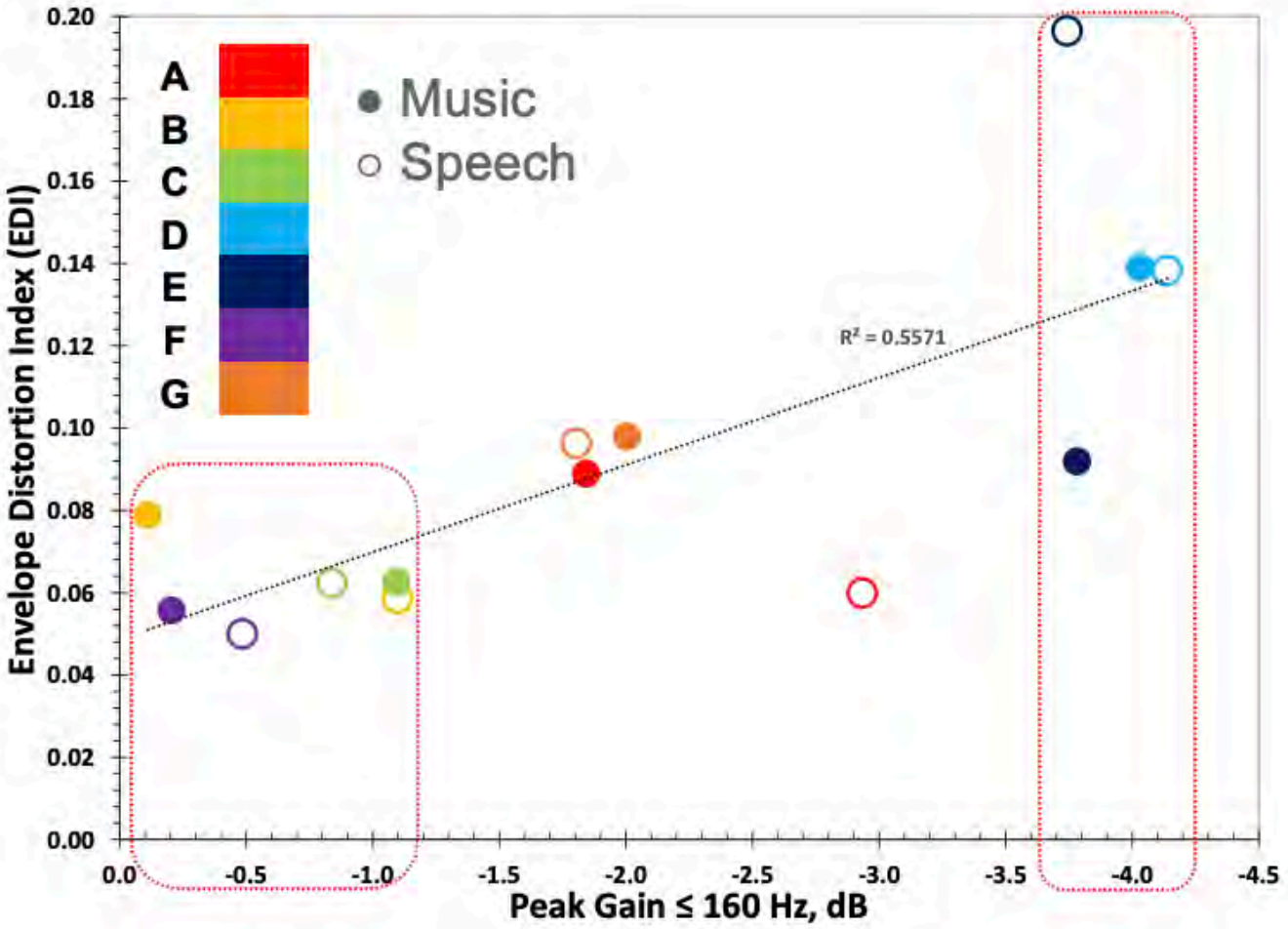

Brand A Music OFF
dB SPL
100
80
60
40
20
0
100
250
500
1000
2000
4000
8000
12500
Frequency, Hertz
1%ile
LTASS
70%ile

Subject Descriptions

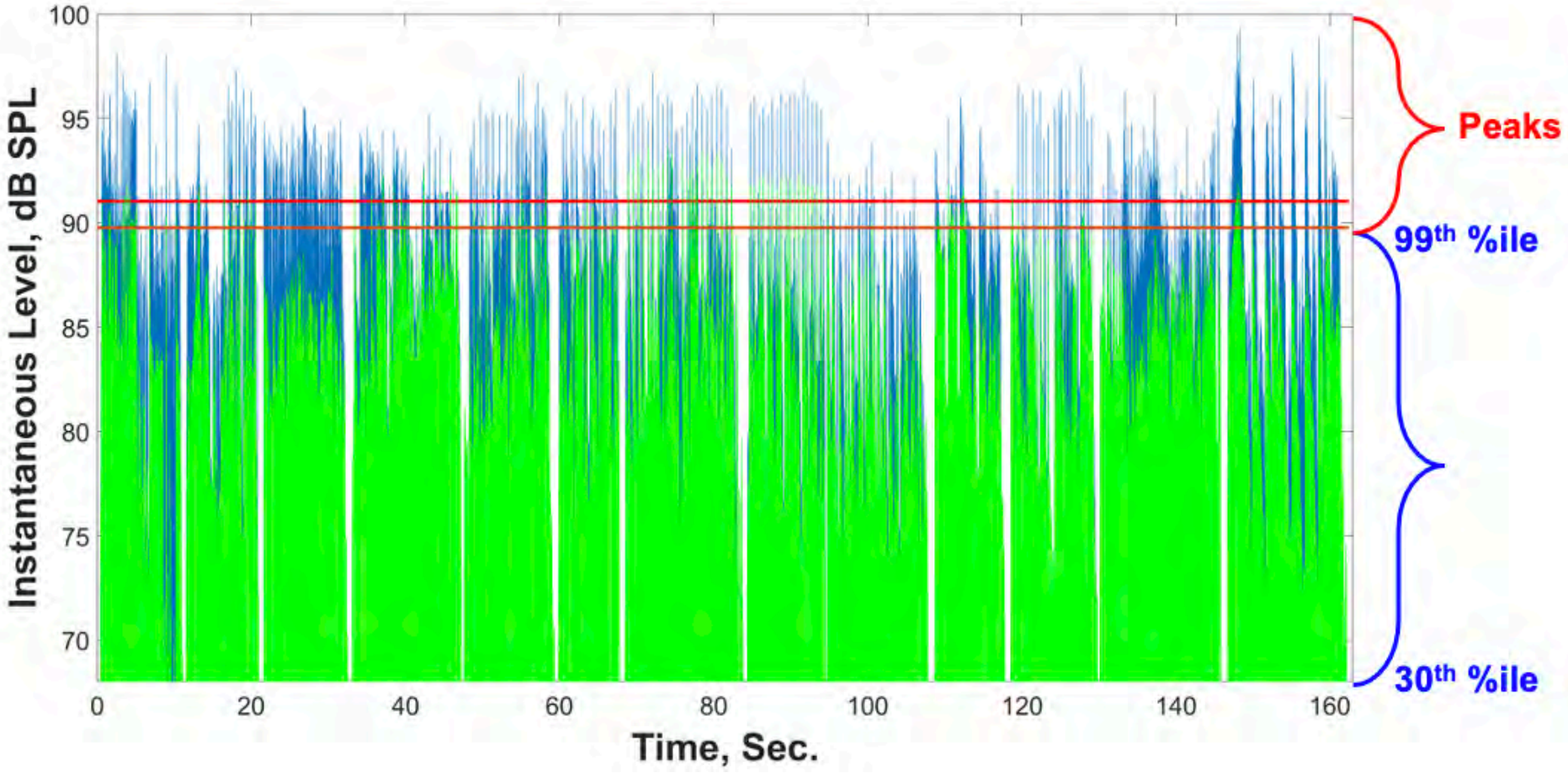
Ultra Low-Freq. Peak Gain vs. Ratings

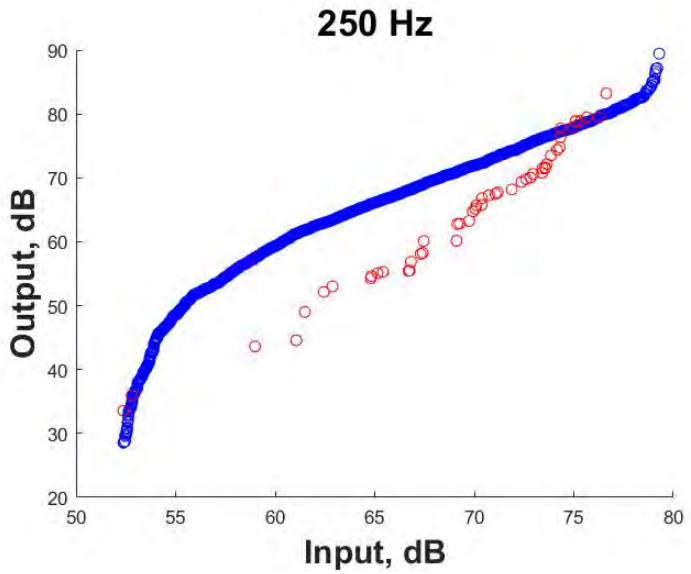


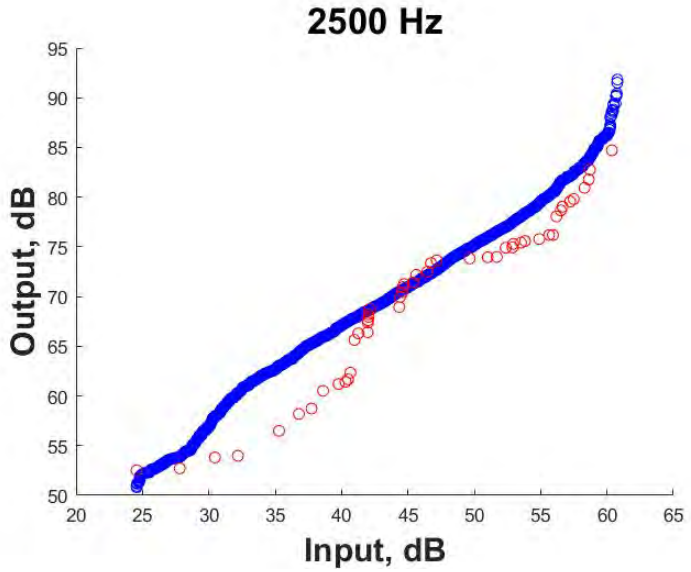
Ultra Low-Freq. Peak Gain vs. Temporal Envelope Distortion



Instantaneous Input Levels @ 160 Hz
(Broadband Instantaneous Input Levels)







Ultra-Low Freq. **Input** Affects *Higher freq.* **Output**

Appears to be an input problem <200 Hz, not an output problem

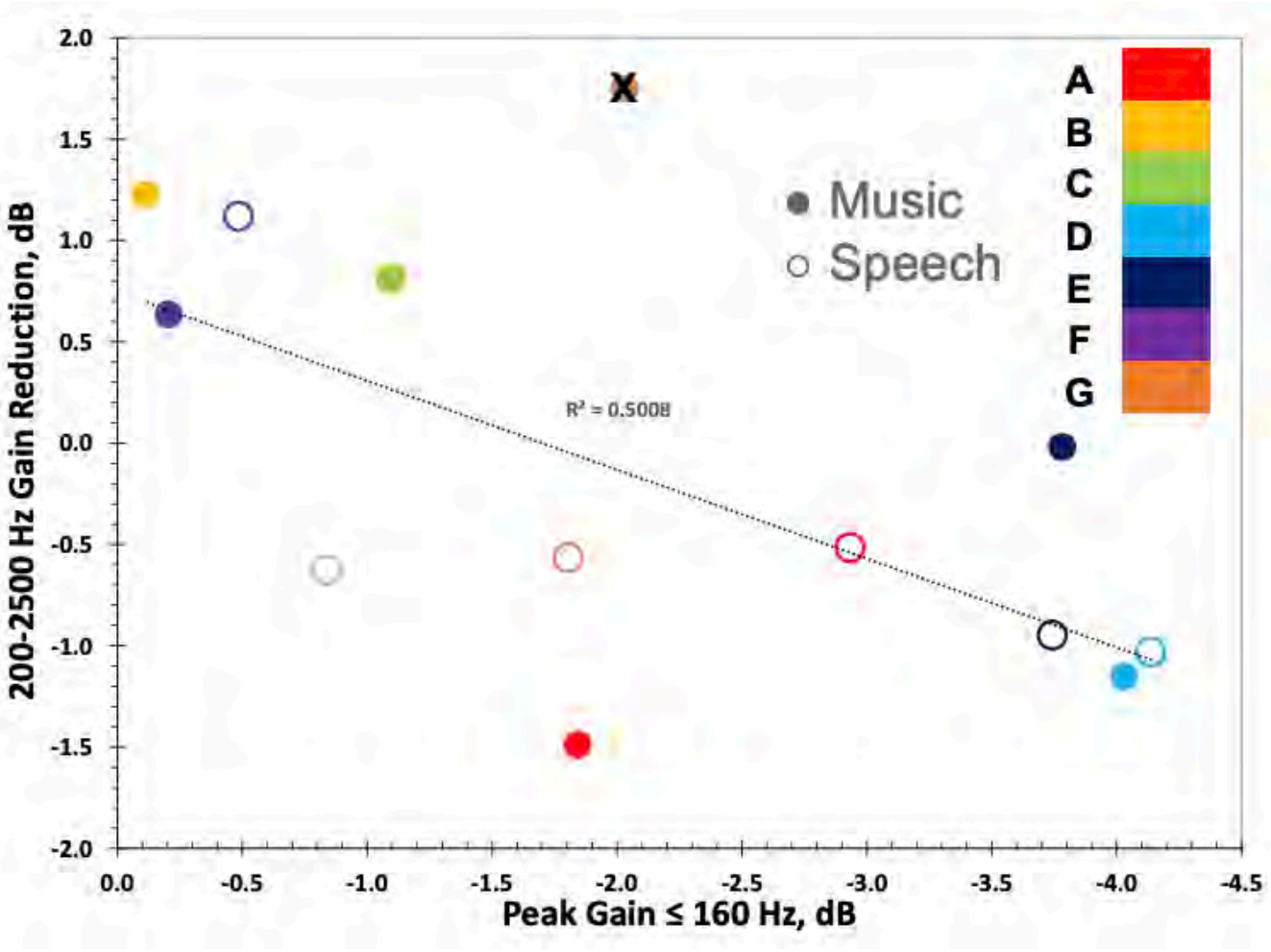
Red

Output levels for time segments (64 ms) when **160 Hz** **input levels** >99th %ile

Blue

Output levels for time segments when **160 Hz** **input levels** were between 30th and 99th %iles

Ultra Low-Freq. Peak Gain vs. 200-2500 Hz Gain Reduction



Explanatory Factors: Summary

- Ultra low-frequency input limiting 👍👍👍👍
  - (1) reduced LF output, (2) LF envelope distortion, (3) downstream effects on higher freq., (4) B & F: low-cut mics
- Bits 👎👍
  - E with 16 bits and G with 18 bits were among the poorer performers, but so was D with 24 bits
- High-frequency response 👎👍
  - D had the lowest ratings and lowest output ≥8kHz
- MPO 👍
- Features, comp. ratios, overall freq. shape 👎👎👎

Limitations (next steps)

- Normal-hearing vs. hearing-impaired listeners
- Effects of vents/open fittings
  - Streaming (recorded) vs. mic (recorded) vs. mic (live)
- Unidimensional rating vs. multi-dimensional
- **Analysis by music sample/genre**

Conclusions

- Quality of recorded music via hearing aid microphone input leaves **room for improvement**
- Bigger **differences between brands** than between speech and music programs
  - Brands with the worst ratings in the speech program significantly improved in the music program (vice versa)
  - No differences between musicians and non-musicians
- Evidence: **ultra low-freq. input limiting** is a major factor
- Evidence: **low MPO** may be a factor in certain cases
  - **Take home: max output dynamic range → MPOs ≈ LDLs**

Thank You!

- Contact Info
  - sandearbox@gmail.com (Emily)
  - alexan14@purdue.edu (Josh)

- For audio samples and more:
  - https://web.ics.purdue.edu/~alexan14/music
  - https://open.spotify.com/playlist/0WyDe1oWmODyjzZOf6Izpa?si=SJufWvyvSxiBSpyfVGa54Q

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