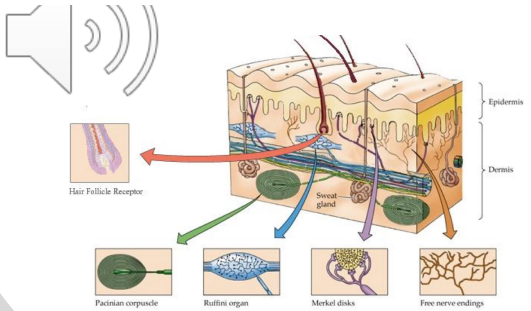
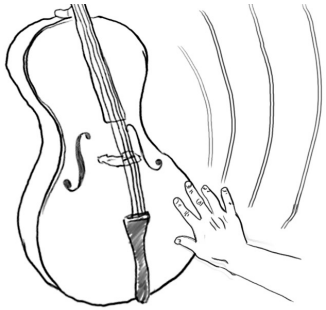




Vibrotactile perception of music

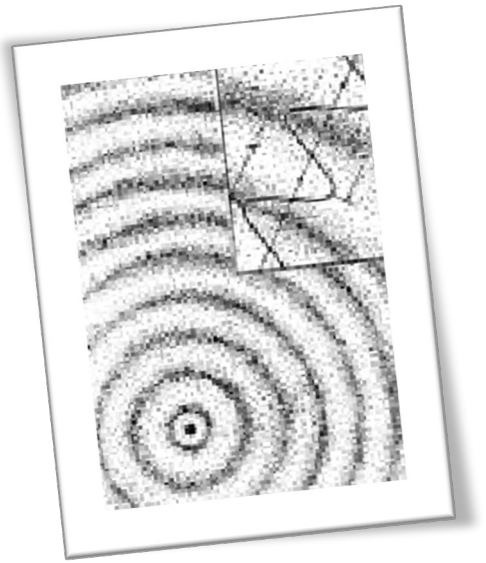
Frank A. Russo, PhD
Toronto Metropolitan University
KITE Research Institute, UHN

Overview

1. Vibrotactile Primer
2. Technology
3. Sensation
4. Perception
5. Conclusions

Smart Lab

I. What is vibrotactile stimulation



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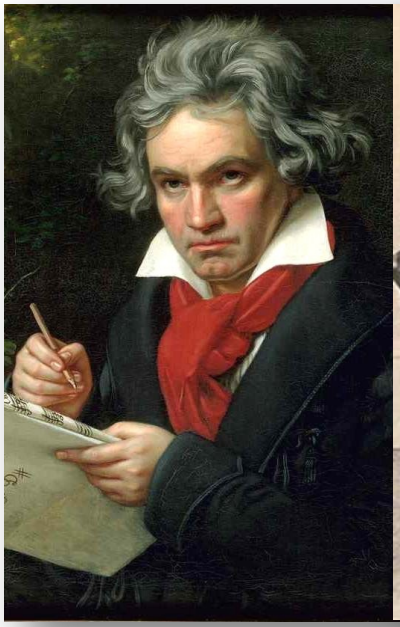
Touch: The mother sense

- The first of our senses to develop (Montagu, 2014);
  - pressure, texture, temperature, and **vibration**
- can convey many properties of music effectively
  - Carrier Frequency (pitch)
  - Frequency Modulation (timbre)
  - Amplitude Modulation (rhythm)

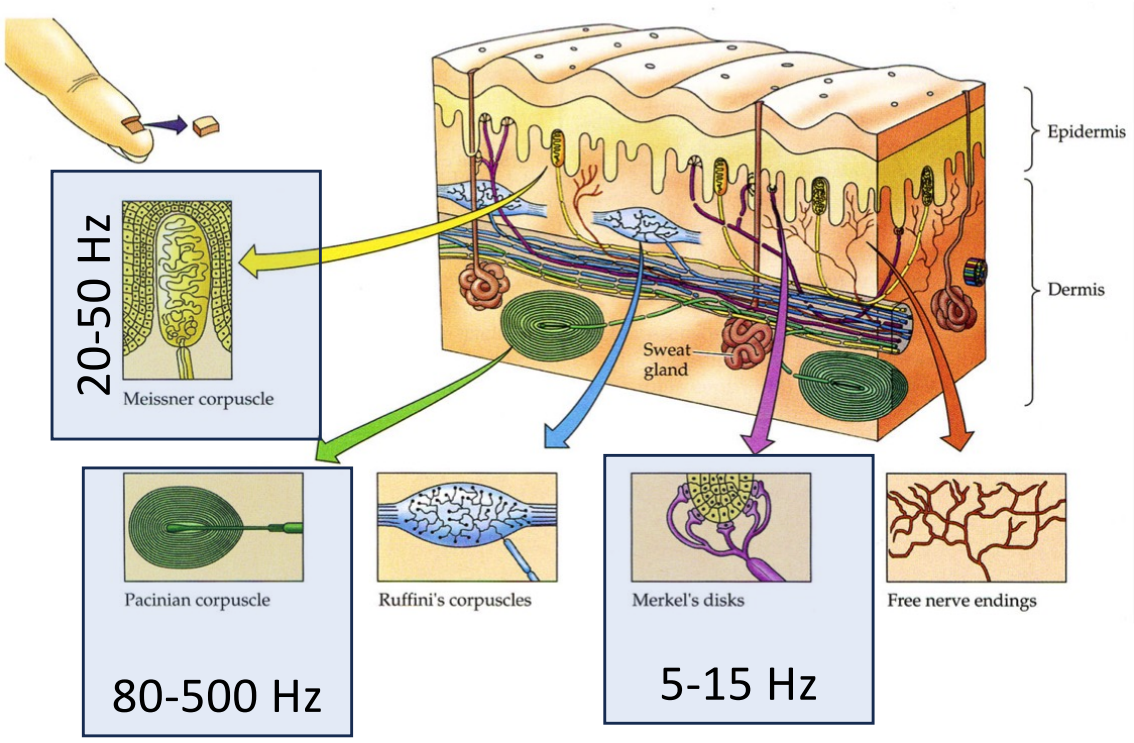
Smart Lab

A very selective history

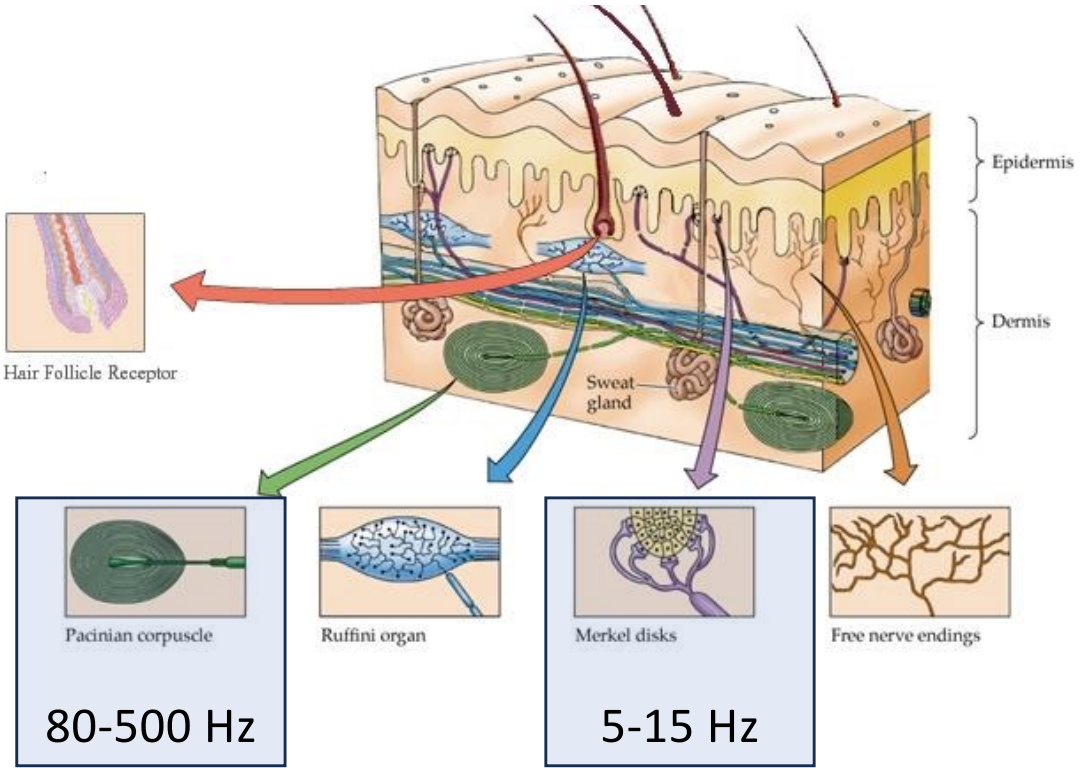


18th cent. 19th cent. 21th cent…

Glabrous (Smooth) Skin

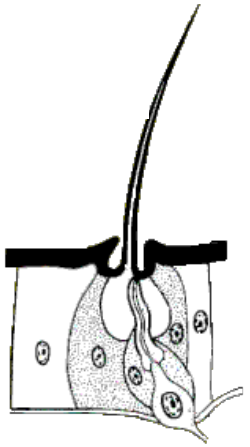


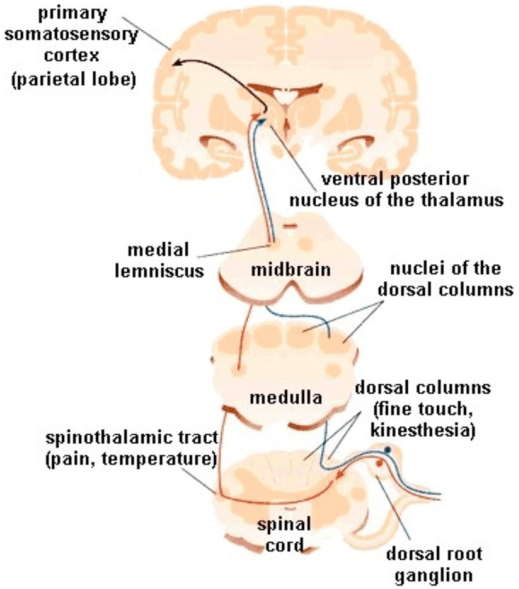
Non-Glabrous (“Hairy”) Skin



Physiological Similarities with Audition

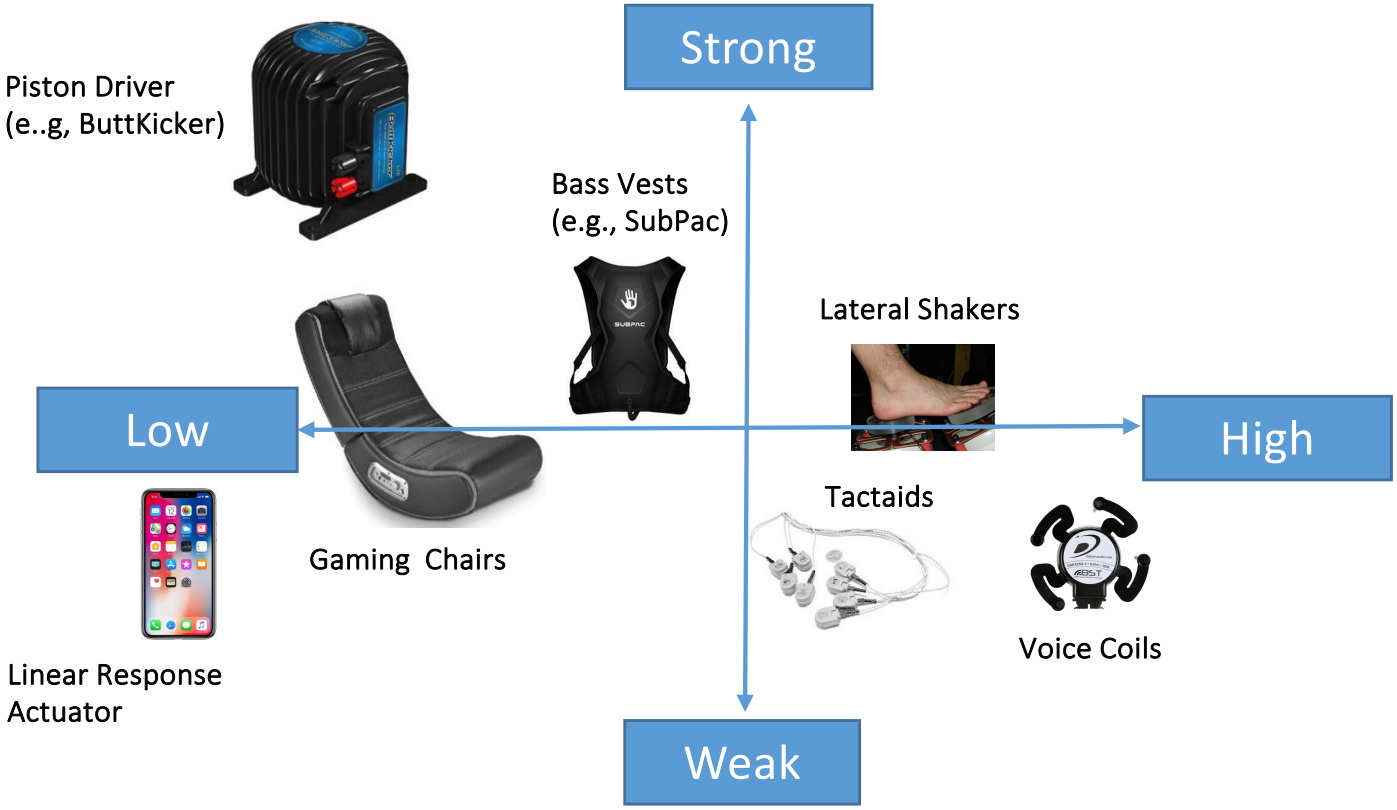
- Tactile and auditory receptors (cilia) are structurally similar; both are **mechanoreceptors** that bend in response to pressure changes
- The bending triggers neural impulses sent to the inferior colliculus in midbrain, which contains auditory, vibrotactile and auditory-tactile neurons.
- Vibrotactile evoked potentials can be recorded in somatosensory cortex but also in auditory cortex (Caetano & Jousmaki, 2006)
- Auditory recruitment is further enhanced in deaf and hearing impaired (Sharma & Glick, 2016)



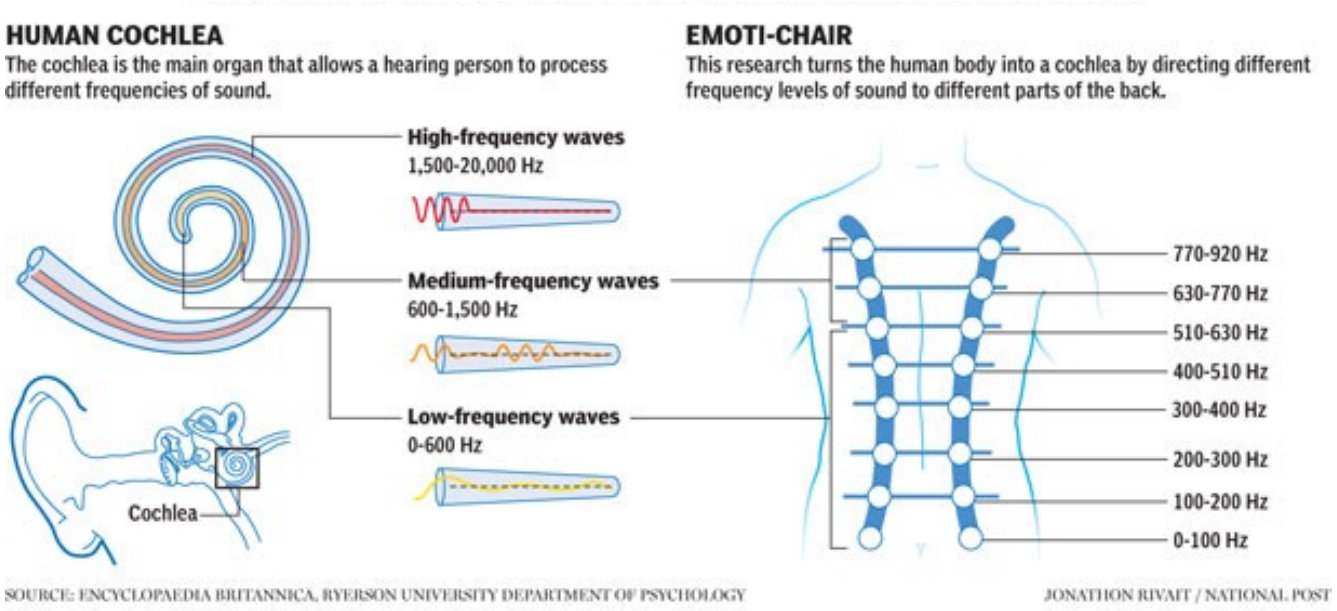


II. Vibrotactile technologies

Vibrotactile gear



Upward spread of masking and the Model Human Cochlea



Karam, Russo, Fels (2009), *Transactions on Haptics*
Karam, Russo, Fels (2009) *System and method for displaying sound as vibrations*. United States: US20110129093A1. Canada: CA2705418A1

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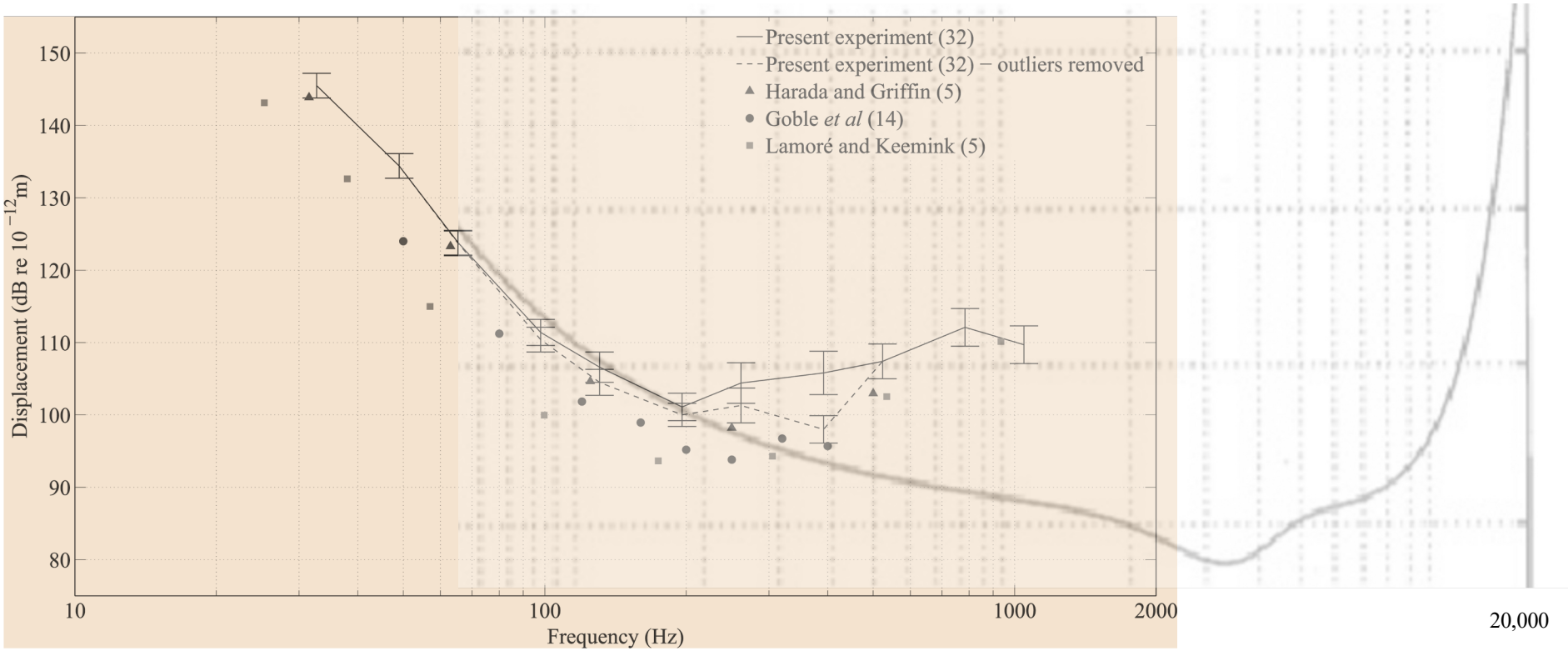
III. Sensation

Detection Thresholds



Hopkins, et al. (2016), *PLoS One*

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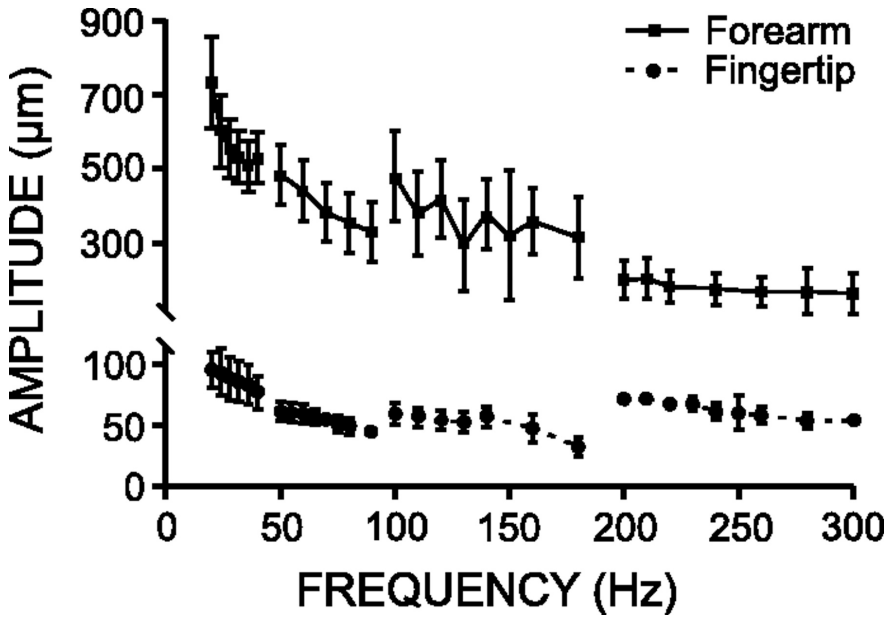
Magnitude Scaling:
Hairy (forearm) vs. Smooth (fingertip)

Mahns et al.(2006), *Journal of Neurophysiology*

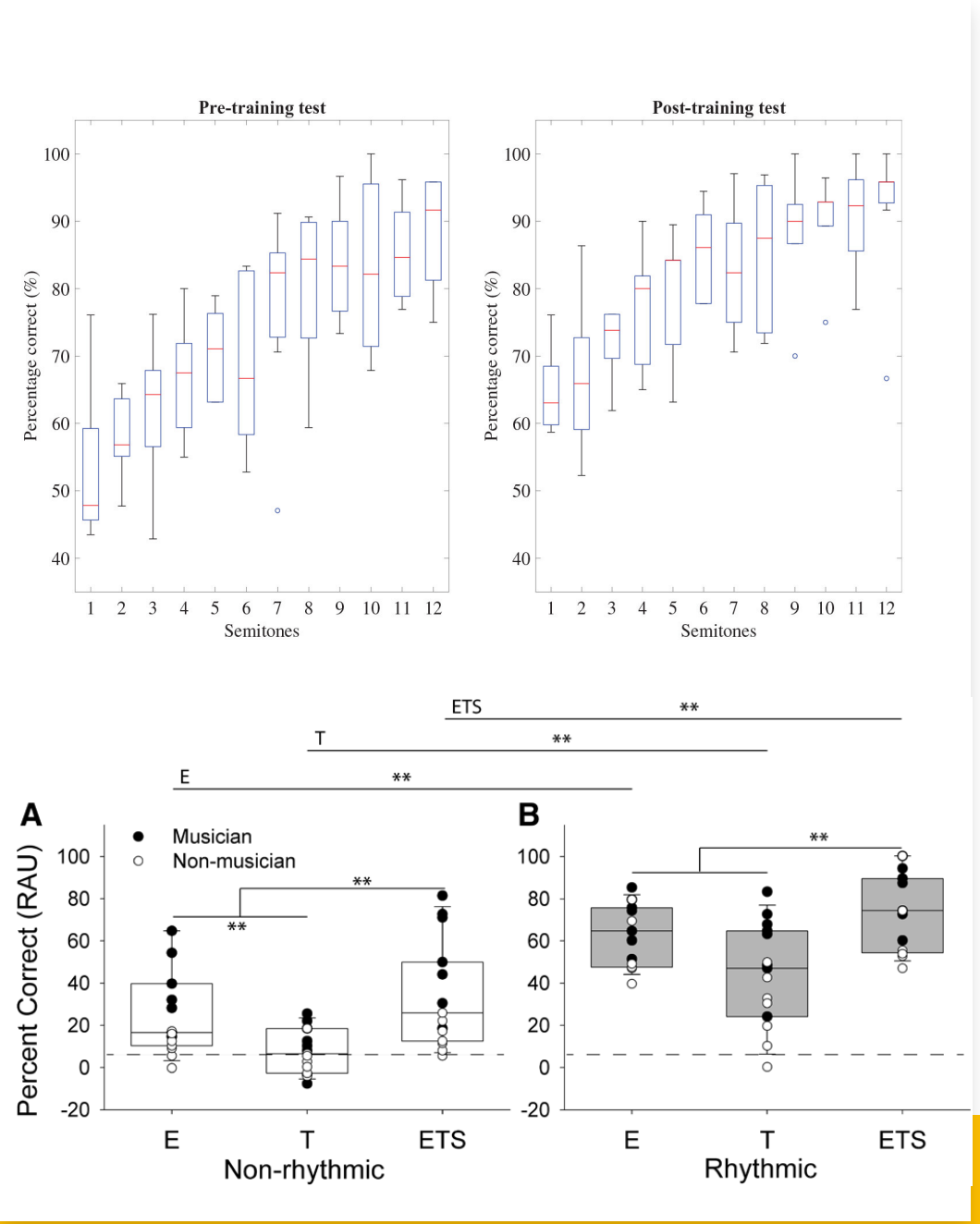
Lundström & Burström, L. (1989). Mechanical impedance of the human hand-arm system. International Journal of Industrial *Ergonomics*, 3(3), 235-242.



III. Perception

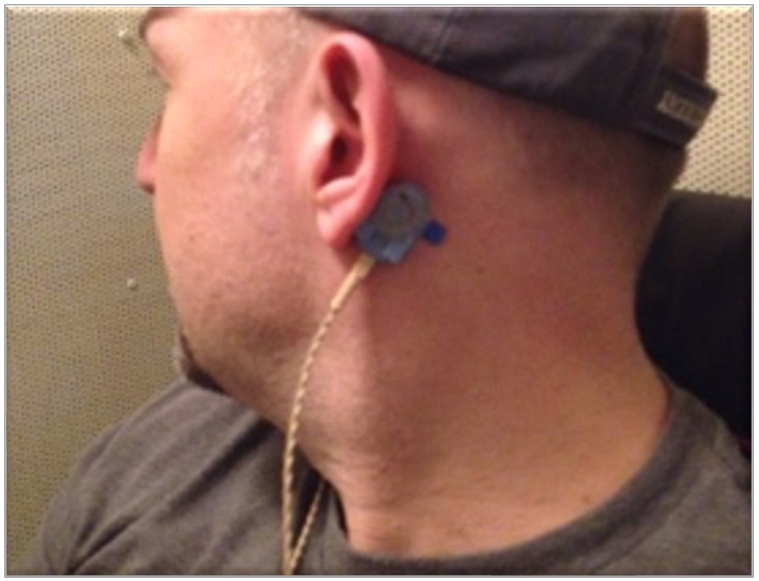
Pitch Perception

- Hopkins, Mate-Cid, Fulford, Seiffert, Ginsborg (2023), *Musicae Scientiae*
  - Population: Hearing Impaired
  - Task: same-different for tone pairs
  - *Result: Improvement following training*
- Huang, Lu, Sheffield, & Zeng, (2020), *Ear and Hearing*
  - Population: Cochlear Implant Users
  - Task: Melodic Identification
  - *Result: Multimodal Gain*



Timbre Perception

- Participants: **Deaf** and Hearing
- Task: Same/Different judgment
- Method: Tones presented as vibration on back (non-glaborous) to hearing and deaf participants



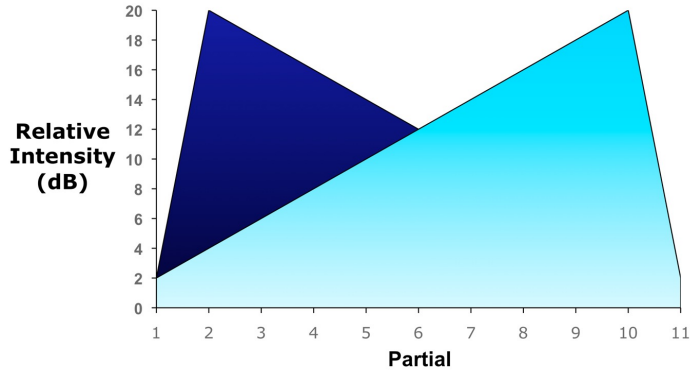
Russo, Ammirante & Fels (2012), *Journal of Experimental Psychology:HPP*



	Cello	Piano	Trombone
Cello	73		
Piano	81	73	
Trombone	90	90	87

- *all p's < .05 (non-parametric binomial test)*

Russo, Ammirante & Fels (2012), *Journal of Experimental Psychology:HPP*



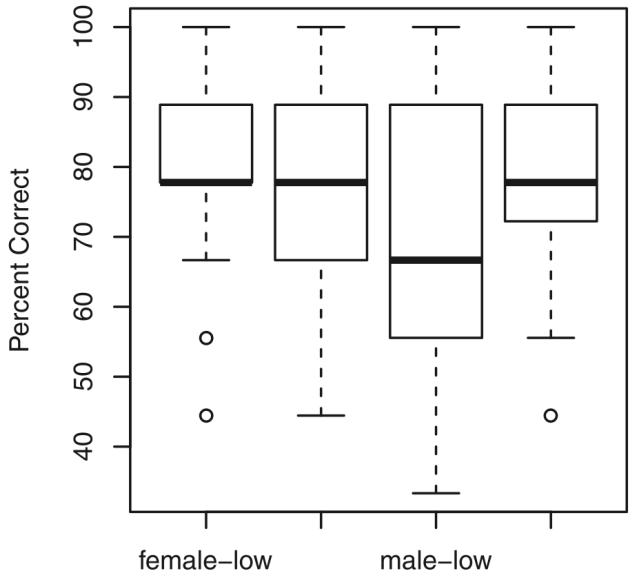
	Dull	Bright
Dull	90	
Bright	95	90

** all p's < .05 (non-parametric binomial test)*

Russo, Ammirante & Fels (2012), *Journal of Experimental Psychology:HPP*

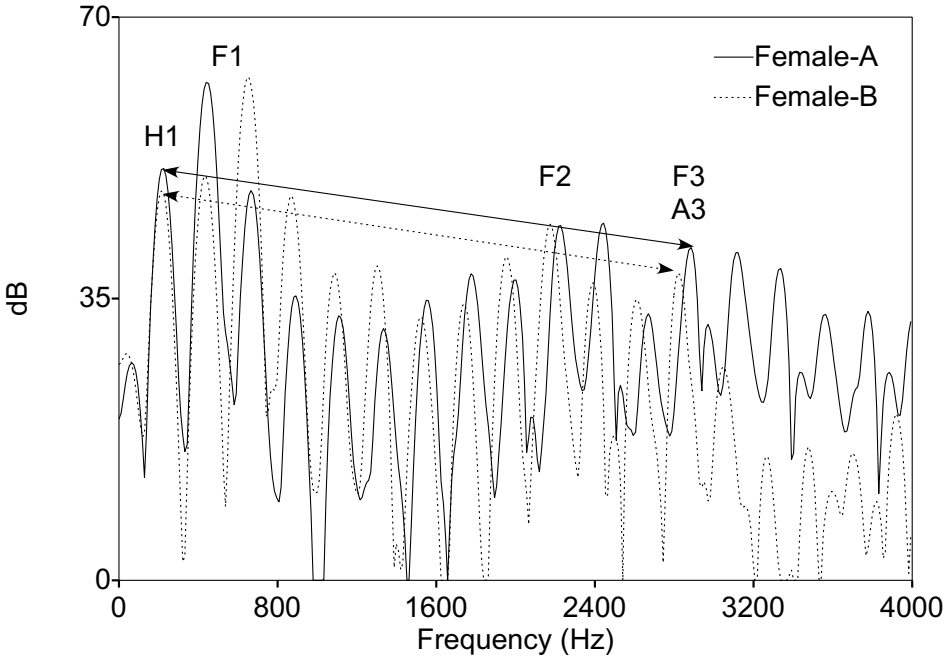
Voice Perception

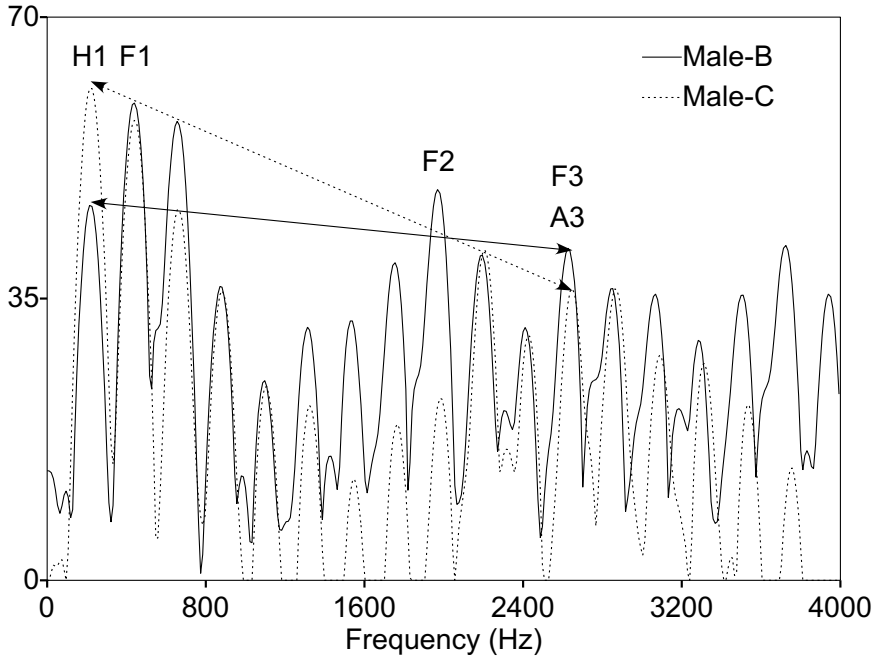
- Participants: Normal Hearing
- Method: Voices presented on back at same pitch/duration and matched for magnitude
- Task: Same/different judgment



Russo, Ammirante & Fels (2012), *Journal of Experimental Psychology:HPP*

Spectral Tilt





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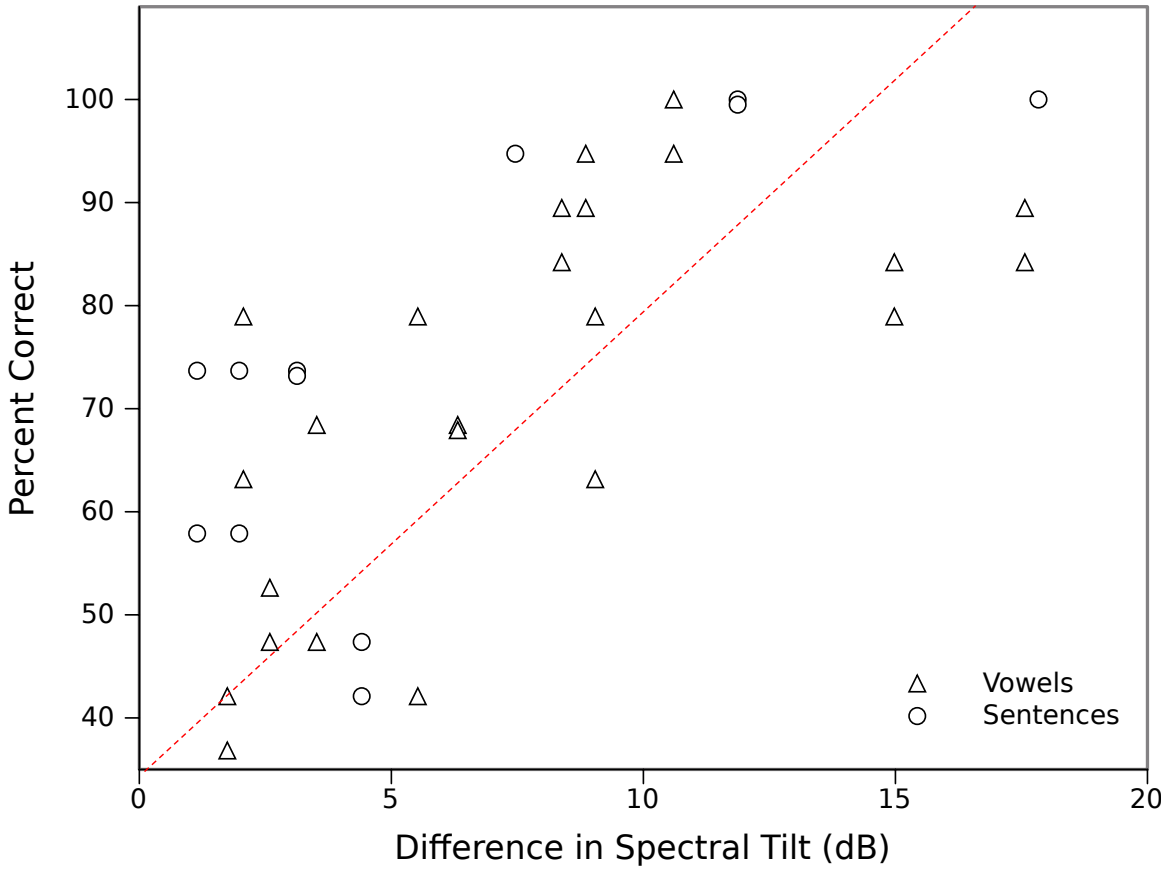
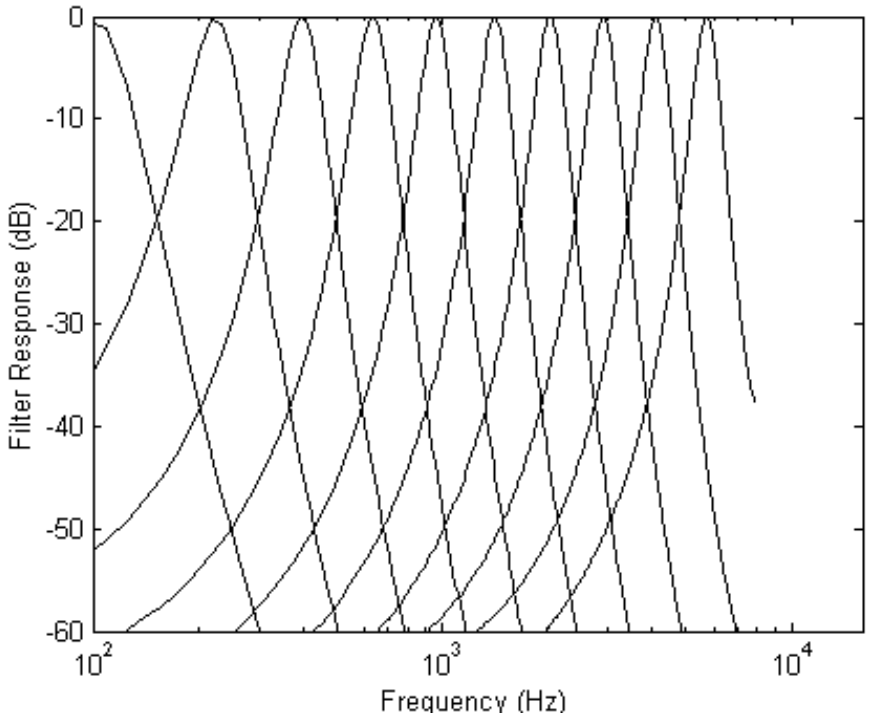
Ammirante, Russo, Good & Fels (2013), *PLoS ONE*

Spectral Tilt



Ammirante, Russo, Good & Fels (2013), *PLoS ONE*

"Cortical Integration of output from a Tactile Filter Bank?"



Russo, Ammirante & Fels (2012), *Journal of Experimental Psychology: HPP*

Rhythm Perception

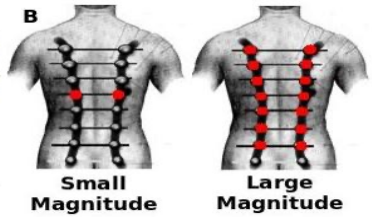
Participants: Normal Hearing

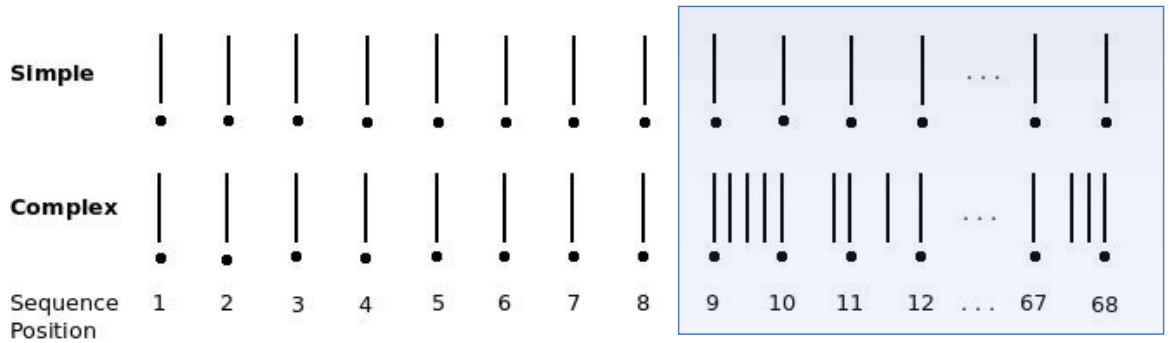
Method: Present rhythms on back under different conditions

Size (Small, Large)

Modality (Auditory, Tactile with Sound Mask, Auditory-Tactile)

Rhythmic Complexity:

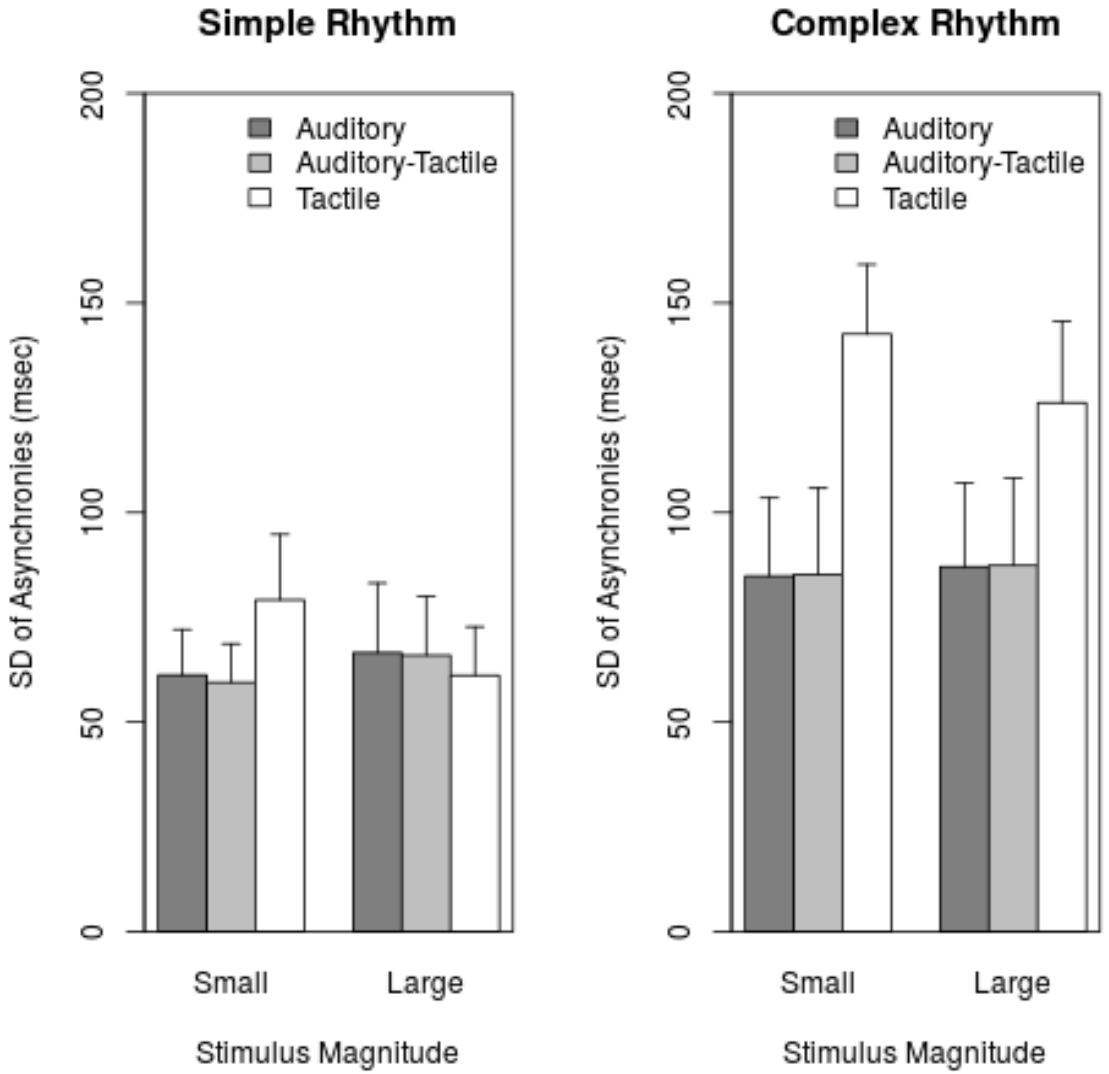




Task: Sensorimotor Synchronization (tap to the beat)

Ammirante, Patel, Russo (2016), *Psychonomic Bulletin & Review*

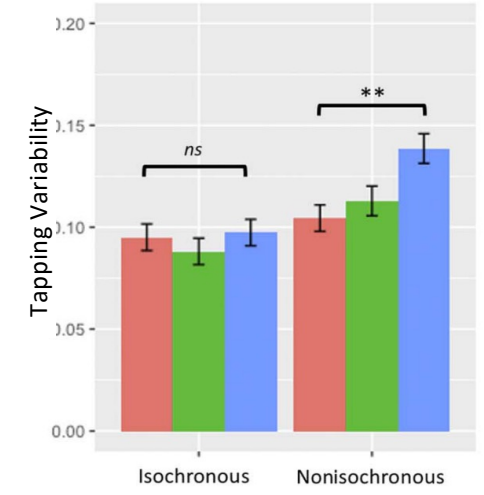
Results

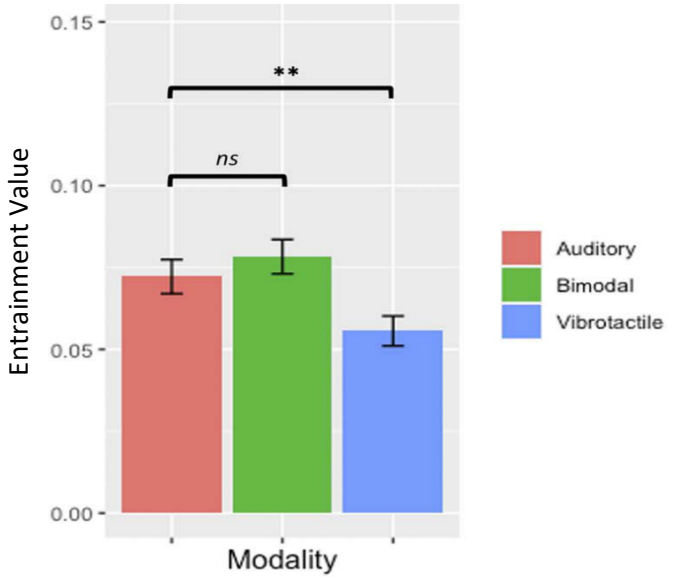


Ammirante, Patel, Russo (2016), *Psychonomic Bulletin & Review*

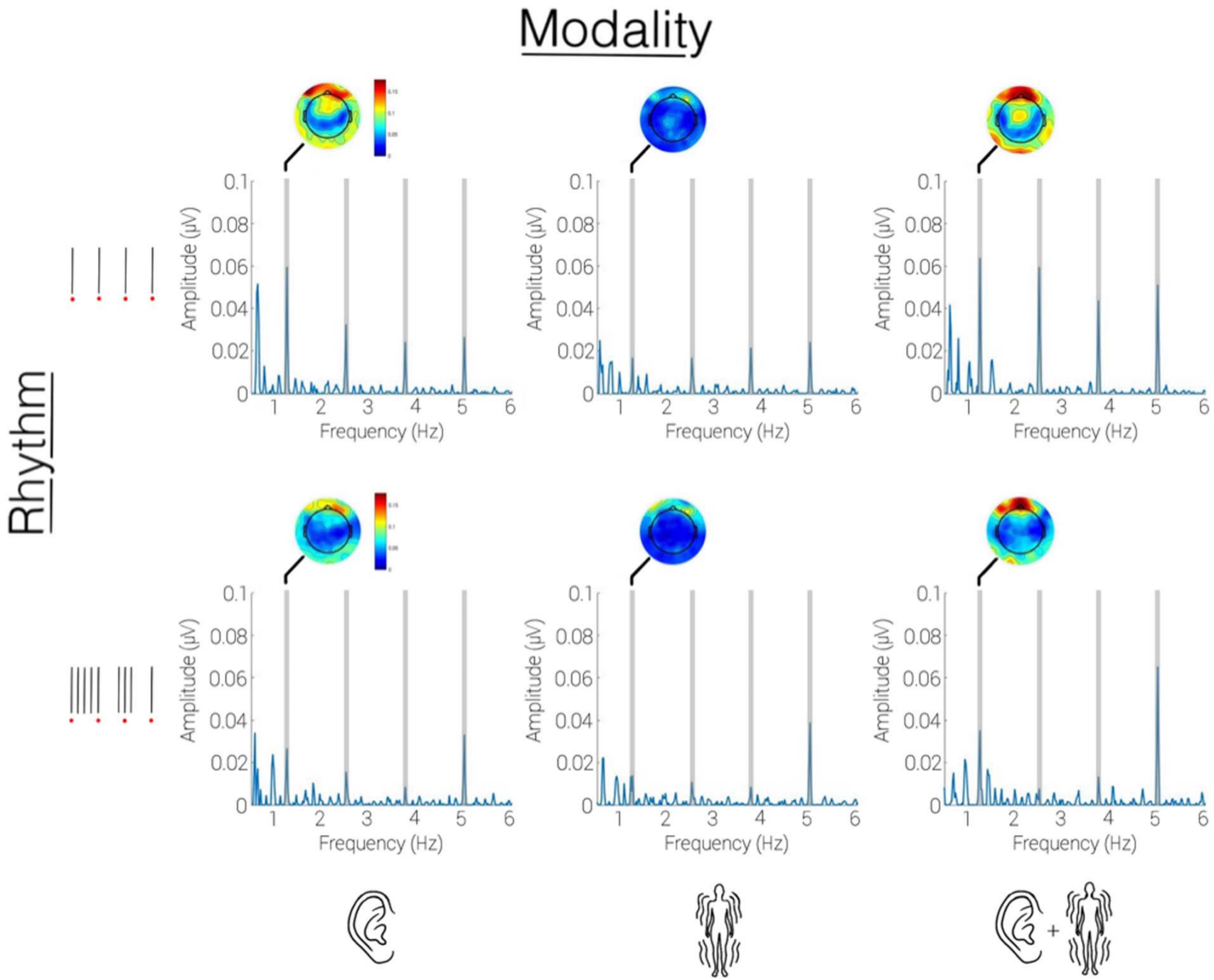
Sensorimotor Synchronization and Neural Entrainment

- Participants: Normal Hearing with sound masking
- Method: Simple or complex rhythm presented with auditory, vibrotactile or bimodal stimulation
- Task:
  - Sensorimotor synchronization (SMS)
  - Perception only (EEG)





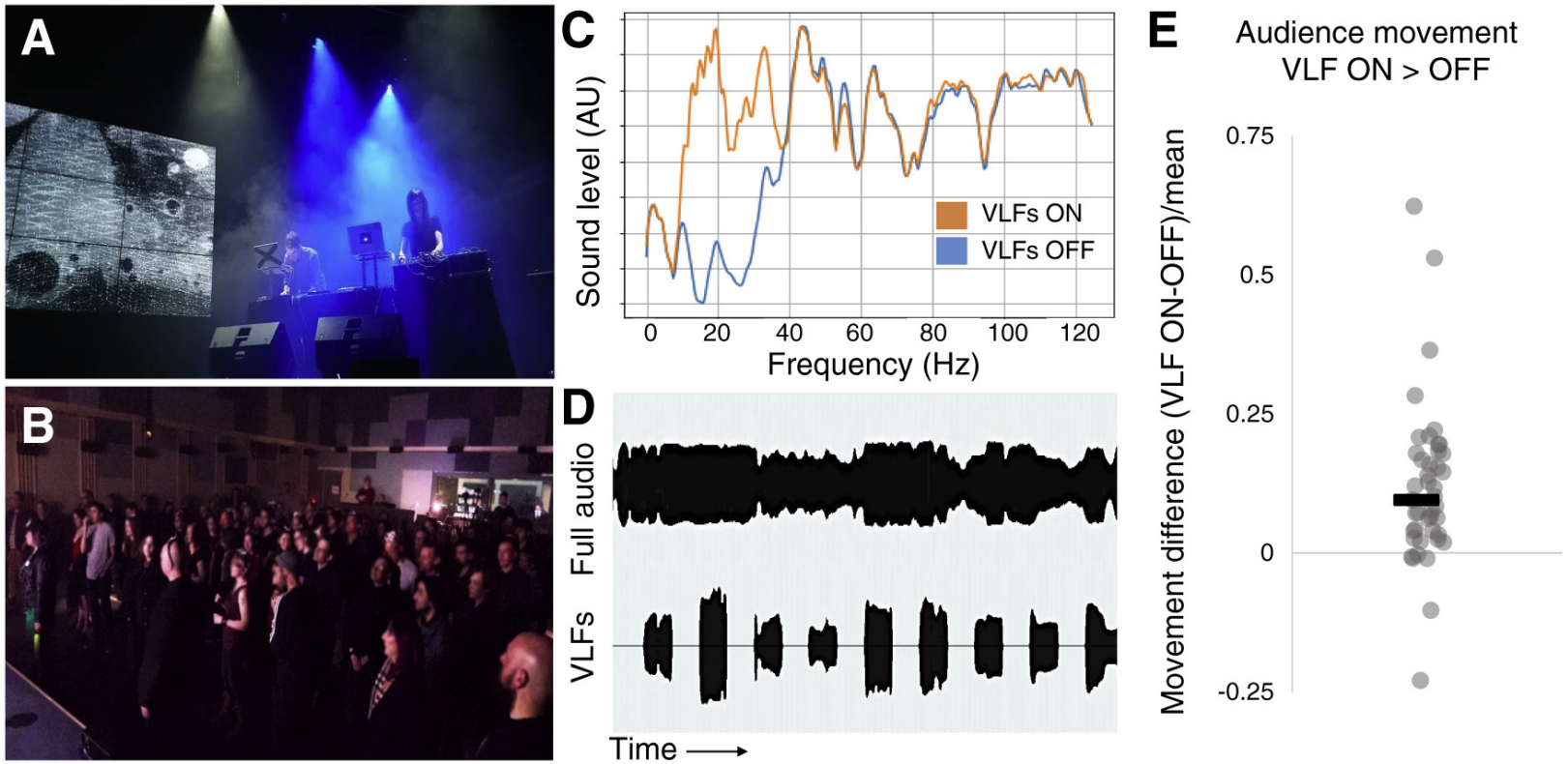
Gilmore & Russo (2021), *Cognitive Neuroscience*



Gilmore & Russo (2021), *Cognitive Neuroscience*

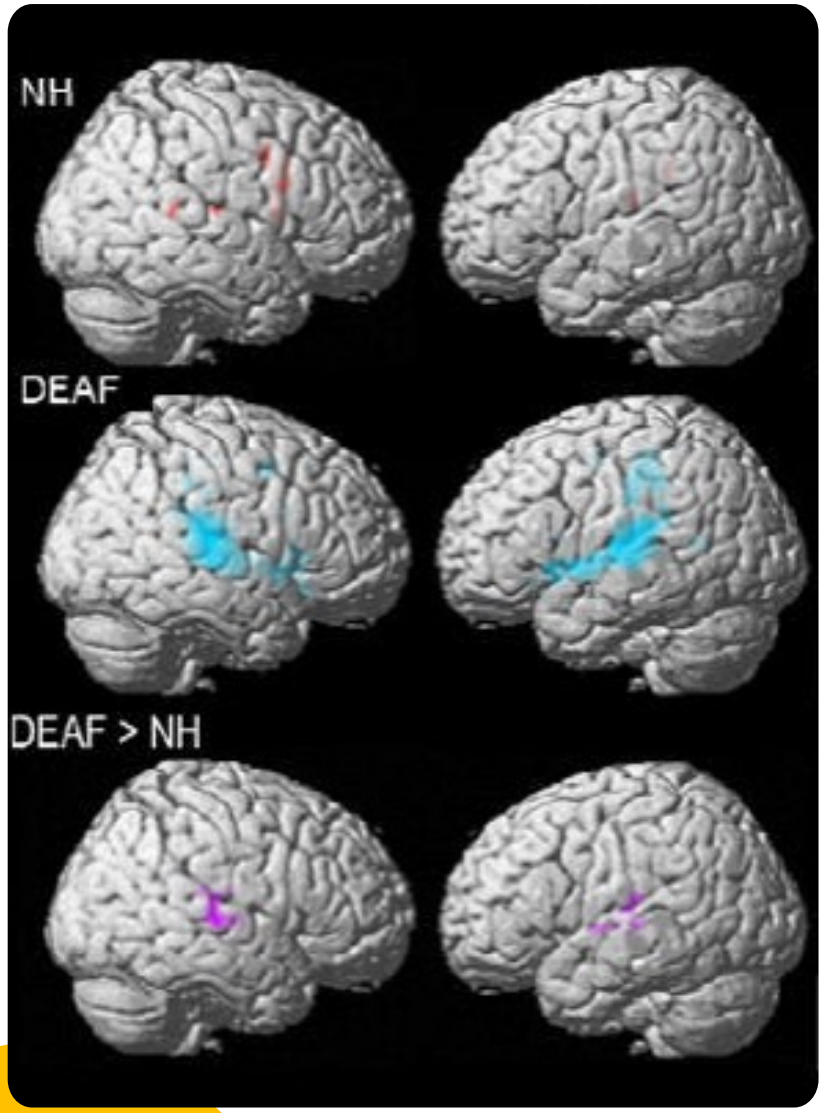
Desire to move

- Undetectable very low frequency sound increases desire to move



Cameron, Dotov, Flaten, Bosnyak, Hove & Trainor (2022), Current Biology

Auditory recruitment in vibrotactile stimulation: Cross-modal reorganization



robust recruitment of AC in deaf

- Kral & Sharma (2023), *Trends*
- Enhanced vibrotactile sensitivity, Levänen & Hamdorf (2001), *Neuroscience Letters*

Auer, Bernstein, Sungkarat, & Singh (2007) *NeuroReport*

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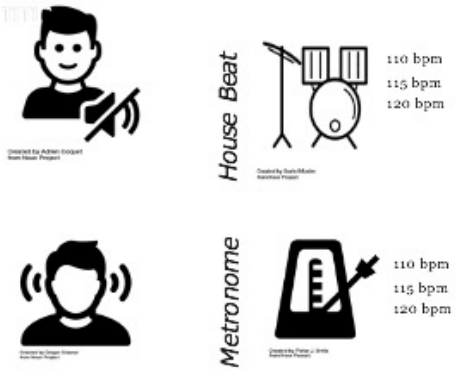
Deaf Gain?

- "…a reframing of 'deaf' as a form of sensory and cognitive diversity that has the potential to contribute to the greater good of humanity" *(Bauman & Murray 2009)*
- A Shift away from a focus on Deficit

Gilmore & Russo, *under review*

Deaf Gain Study

- Participants: Deaf and Normal Hearing with sound masking
- Rhythm Complexity
  - metronome vs. house
- Tasks
  - Sensorimotor Synchronization
- Listen
  - Neural Entrainment



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Gilmore & Russo, *under review*

Hypotheses

H1: Enhanced beat perception in Deaf individuals compared to hearing individuals across all rhythms

Lower SMS variability

Increased levels of neural entrainment

H2: Deaf individuals will show a marked enhancement of beat perception for house rhythms (i.e., more complex rhythms)

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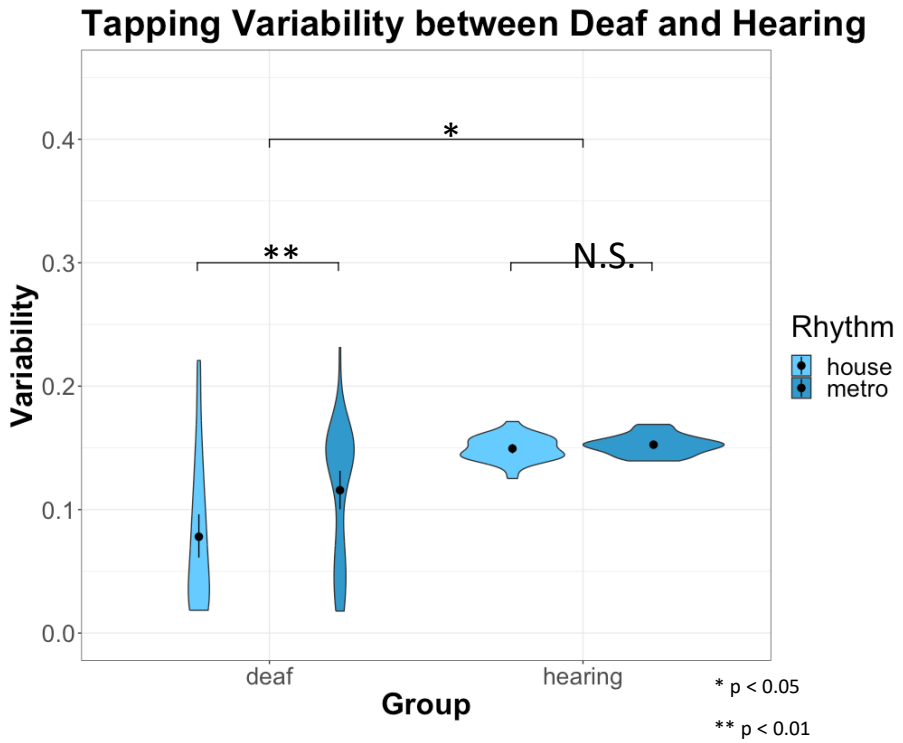
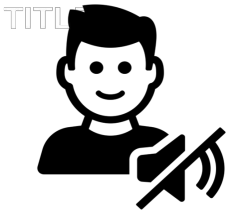
Results: Sensorimotor Synchronization

- Deaf individuals show better SMS (lower variability) compared to hearing individuals
- Marked enhancement for more complex rhythms in the Deaf group

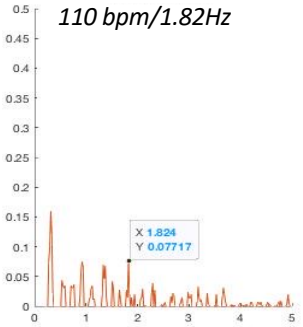


Results: EEG *(fft)*

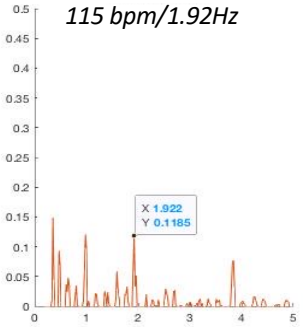


Metronome

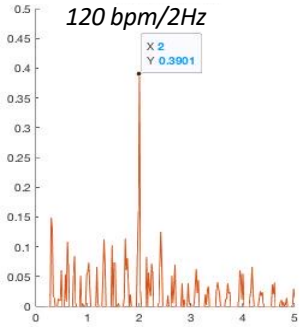
110 bpm/1.82Hz

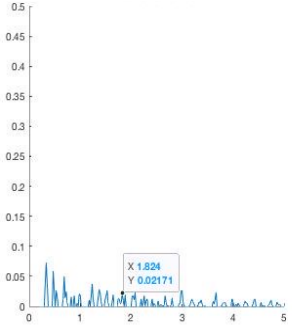


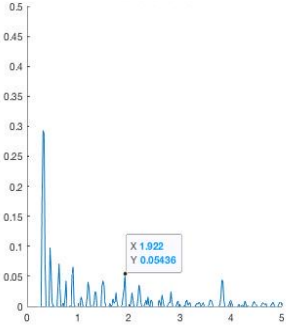
115 bpm/1.92Hz

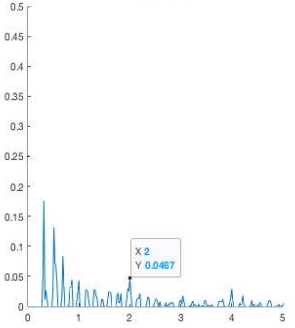


120 bpm/2Hz

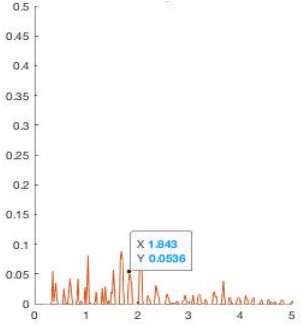


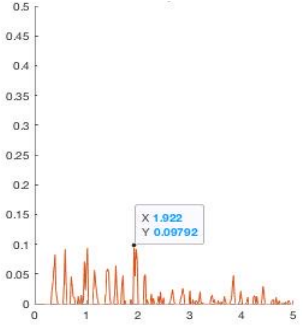


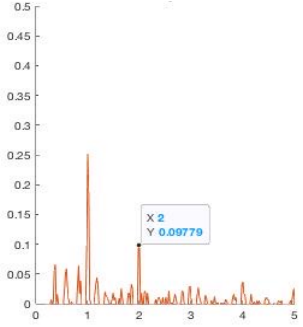


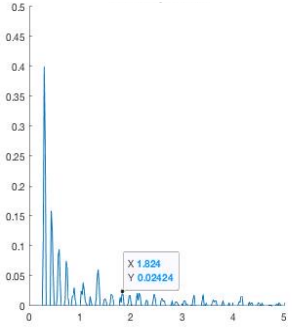


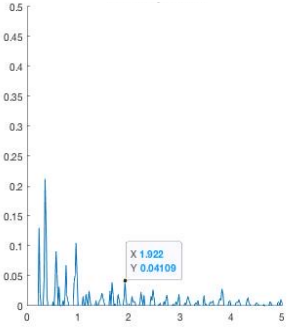
House

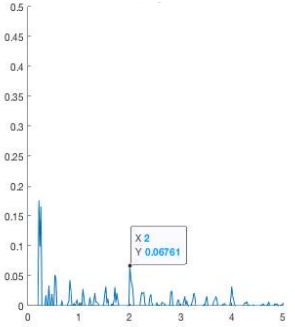






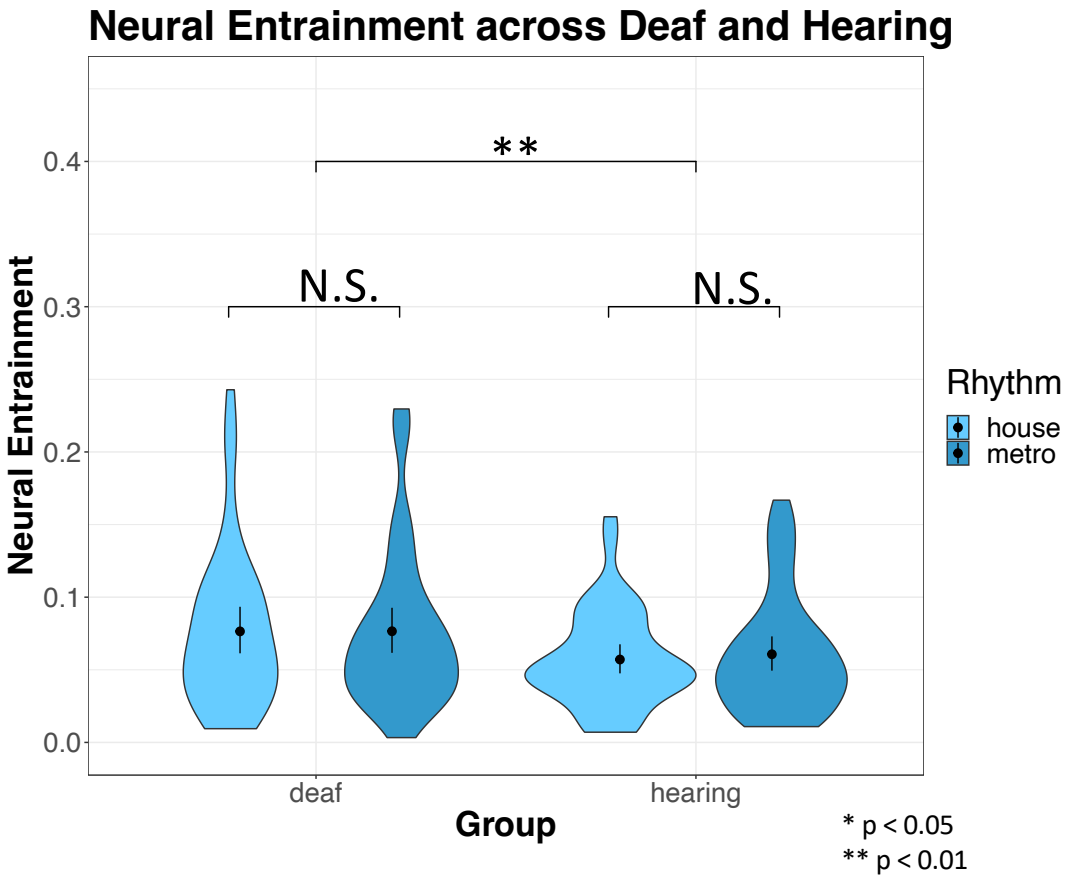






Results: EEG

- Deaf individuals show higher levels of neural entrainment to the beat frequency
- No interaction of rhythm complexity



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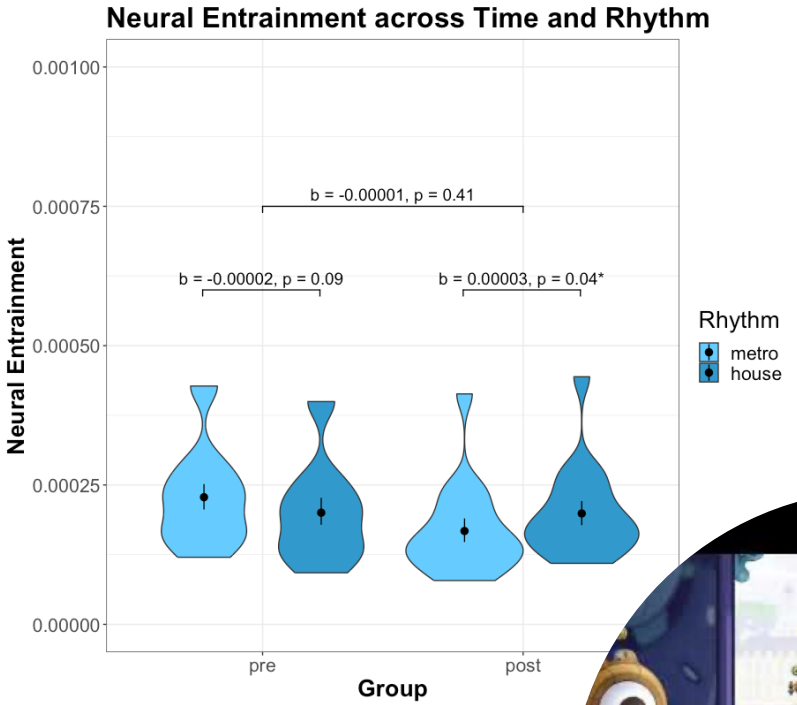
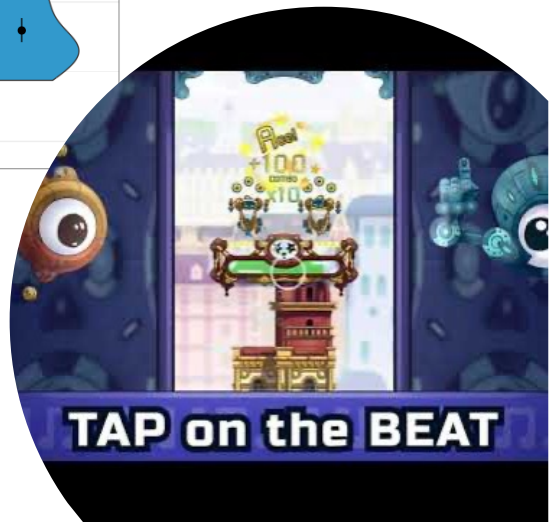
Can training with vibrotactile stimulation simulate the Deaf gain: *Not yet.*

- Participants: Normal Hearing with sound masking
- Rhythm Complexity
  - Simple vs Complex
- Tasks
  - 12-weeks vibrotactile training
    - Gamified sensorimotor synchronization (Dalla Bella, 2022, *Rhythm Workers)*
- Pre-Post EEG (Perception)
  - Neural Entrainment





Gilmore & Russo, *in progress*

IV. Conclusions, Future Directions

- *Vibrotactile perception of music ~ auditory perception of music*
  - Detection thresholds are nonlinearly related to frequency, though limited to a lower range
  - Melody perception is possible; some benefit of electro-tactile for CI users
  - Timbre and voice perception are possible even without amplitude envelope cues
  - Rhythm perception is possible and likely enhanced under audio-tactile conditions
  - Evidence for *Deaf gain* revealed in frequency discrimination and rhythm perception

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Special thanks:
Sean Gilmore (TMU)
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Gabe Nespoli (TMU)
Aniruddh Patel (Tufts University)
Simone Dalla Bella (U de Montreal)