

Can musical training influence speech processing?

Theoretical issues, current debates, and clinical implications



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ARO Seminar Series on Music Perception

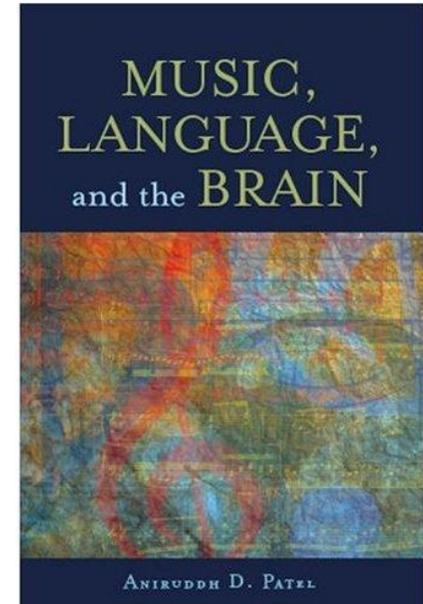
September 25, 2024

Outline: can musical training influence speech processing?

- Motivation for asking this question
 - Similarities between music and speech as communicative systems
 - Musical ability/training: associations with enhanced speech processing
 - Neural plasticity driven by musical training
- Even If the answer is yes, why use musical training to enhance speech in the real world?
(Not suggesting replacing speech-based training, but complementing it)
 - Music and reward
 - What is meant by “musical training”?
 - Examples of some populations that might benefit from such training
- Need theoretical frameworks to explain why musical training would enhance speech processing
 - OPERA hypothesis (Patel 2011 Frontiers; 2012 Annals NYAS; 2014 Hearing Research)
 - Now one of several frameworks

Similarities between speech and music as communicative systems

- Both use sound sequences with fine-grained modulations of timing, amplitude, and frequency
 - Both have “rhythm and melody”
- Both involve tight links btwn auditory and motor processing in learning and production
- Both involve hierarchically-structured sequences
 - Made from perceptually discrete elements combined in principled ways



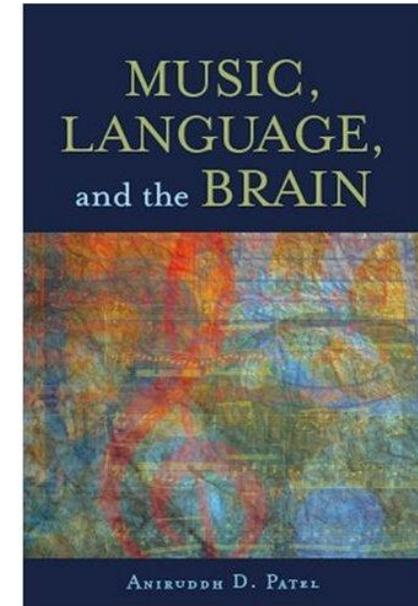
2008

Detailed analysis of similarities and differences in terms of:

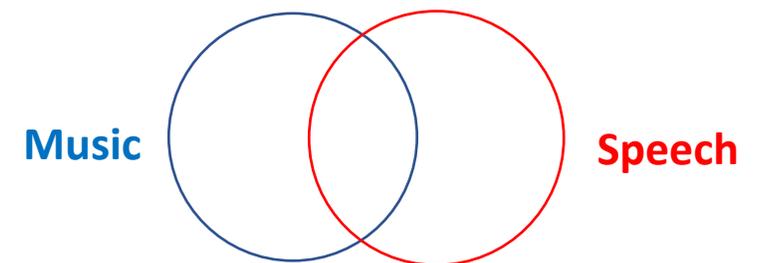
Pitch and timbre patterns,
Rhythm, Melody
Syntax, Affect

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2008

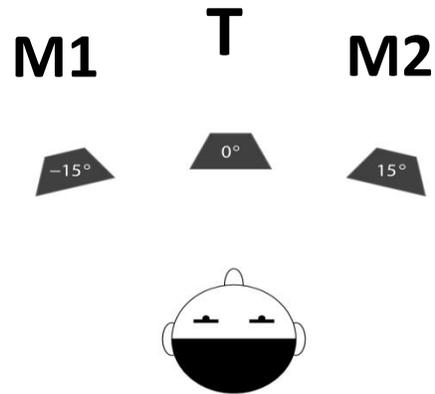


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Musical ability/training associated with enhanced speech processing: 2 examples

- Enhanced speech-in-noise perception



Understand target (T) flanked by Maskers (M1,M2): all are intelligible sentences

At what SNR can Target be understood? Musicians significantly better

Recent multi-site replication (Whiteford et al. Oxenham, 2024 SMPC)

Swaminathan et al. 2015 Sci. Rep.
“Cocktail party problem”

SIN benefits w/musical training – a topic of current debate
(see Coffey et al. 2017 Hear. Res. for a review & discussion)

- Enhanced second language learning

(e.g., phonology, prosody)

- Meta-analysis of 60 studies (>3K participants): Thompson, Salig, & Slevc 2024 PsyArXiv

- <https://osf.io/83p7m>

But to what extent are musician benefits in speech processing due to musical training vs. to pre-existing differences in auditory abilities?

- Twin studies: several music-relevant auditory abilities are moderately heritable



From Wesseldijk et al. 2023. Neurosci. Biobehav. Rev. (Review paper on music and genetics)

- Can musical training cause neuroplastic changes in auditory (or auditory-motor) processing circuits?

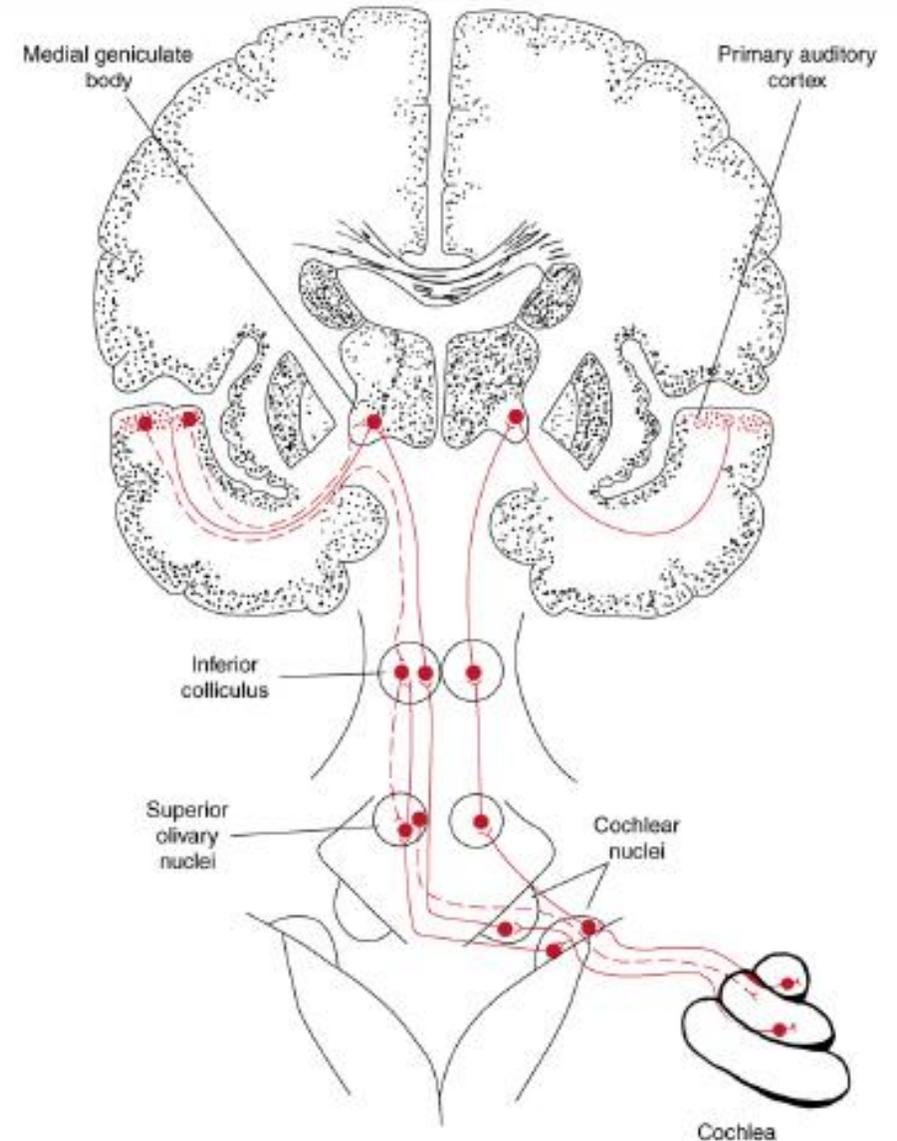
Music training can influence brain structure and function

- Schneider, P. et al. (2023). Neuroanatomical disposition, natural development, and training-induced plasticity of the human auditory system from **childhood to adulthood**: a 12-year study in musicians and nonmusicians. *Journal of Neuroscience*.
- Olszewska, A. M. et al. (2021). How musical training shapes the **adult brain**: Predispositions and neuroplasticity. *Frontiers in Neuroscience*.
- Herholz, S. C., & Zatorre, R. J. (2012). Musical training as a **framework for brain plasticity**: behavior, function, and structure. *Neuron*.
- Modern work considers the **interplay** of predisposing factors (e.g., genetically-governed differences in auditory cortex morphology and function) and experience-dependent plasticity driven by musical training
- Need for more longitudinal RCTs with active controls, controlling for motivation and other factors

Many active Qs about neural plasticity driven by musical training

Does plasticity start at the cortex and then propagate to subcortical regions?

MacLean et al. 2024 *Cerebral Cortex*

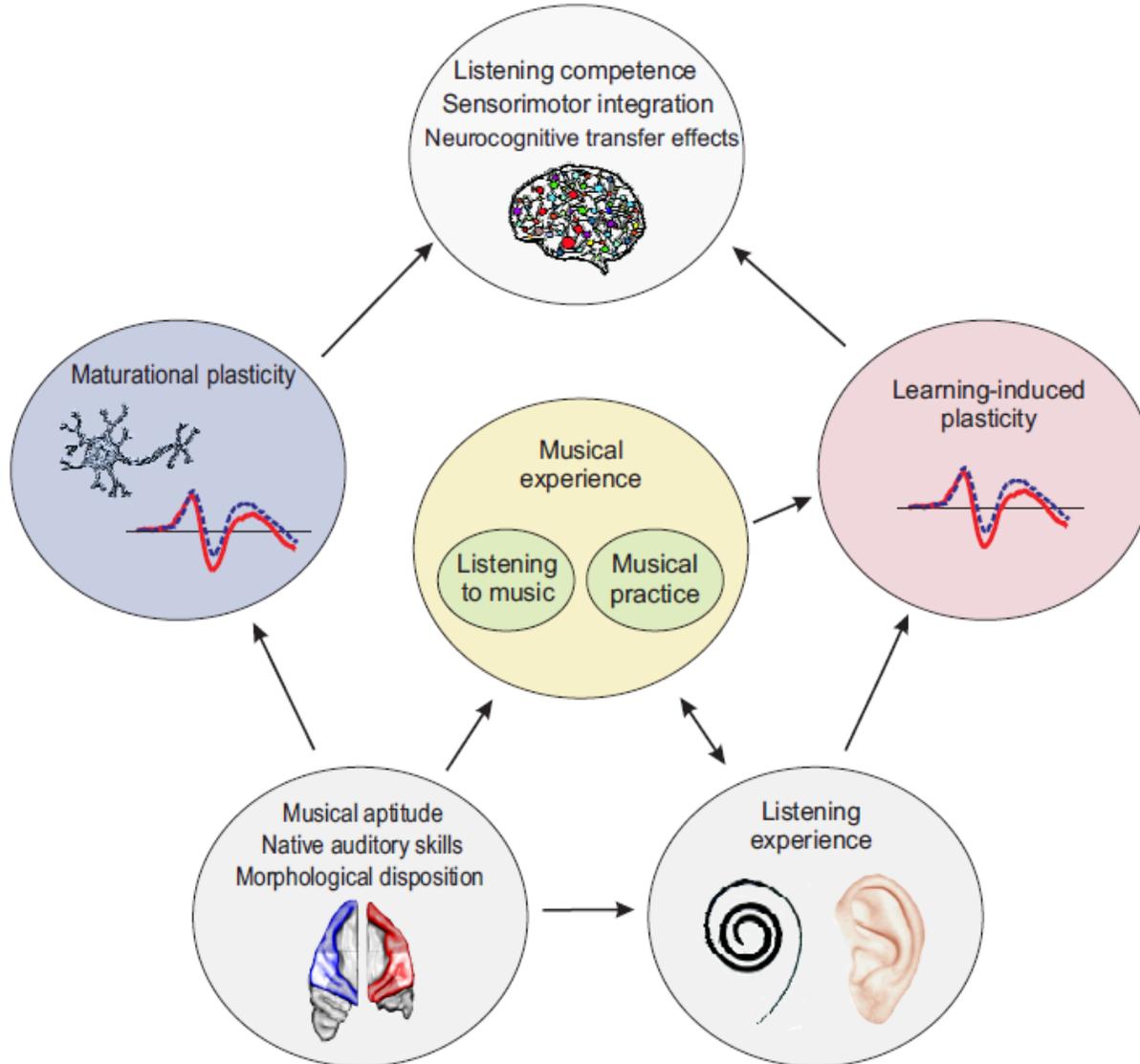


Patel & Iversen (2007) TiCS

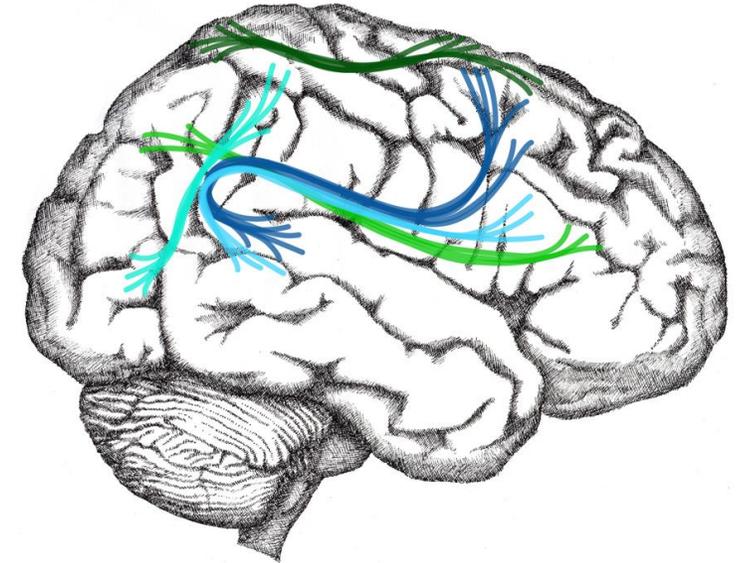
Musical experience and the brain: beyond “nature vs. nurture”

6444 • J. Neurosci., September 13, 2023 • 43(37):6430–6446

Schneider et al. • Neuroplasticity of the Human AC: A 12-Year Study



Plasticity driven by musical training is not confined to auditory cortex

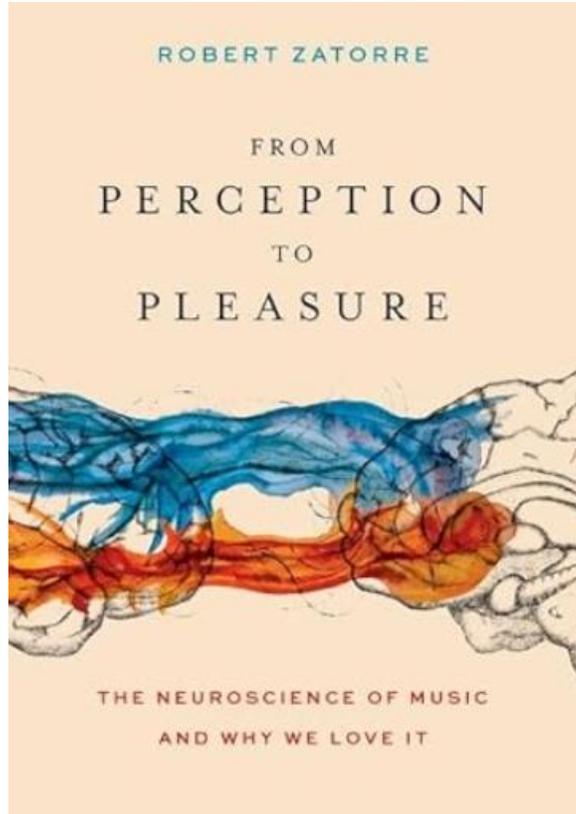


Auditory dorsal stream,
from Zatorre (2024)
From Perception to Pleasure

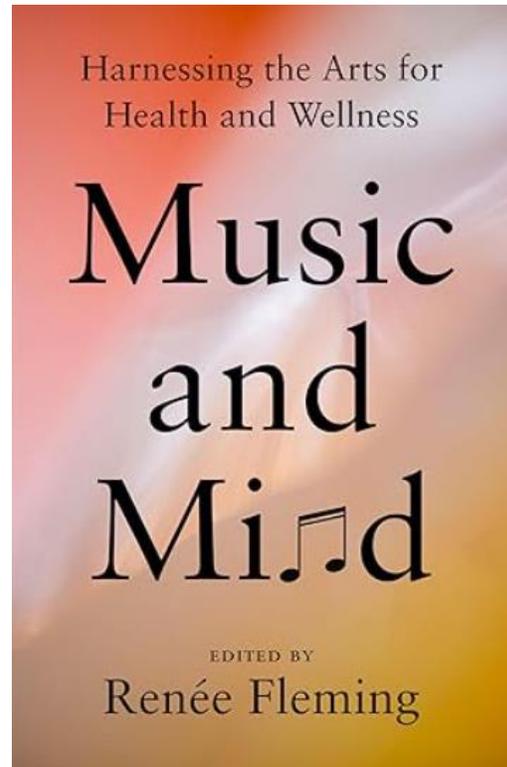
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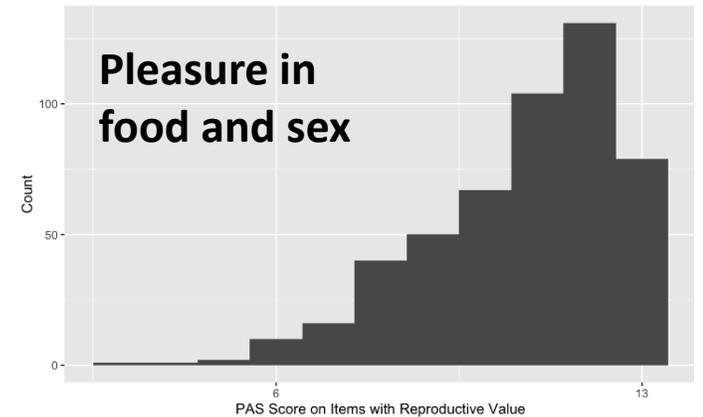
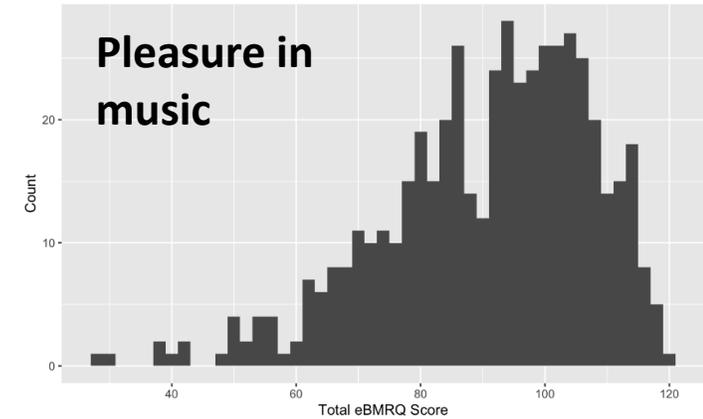
Engaging with music is rewarding for many people



(2024, OUP)



Zatorre (2024) “Musical enjoyment and the reward Circuits of the brain”

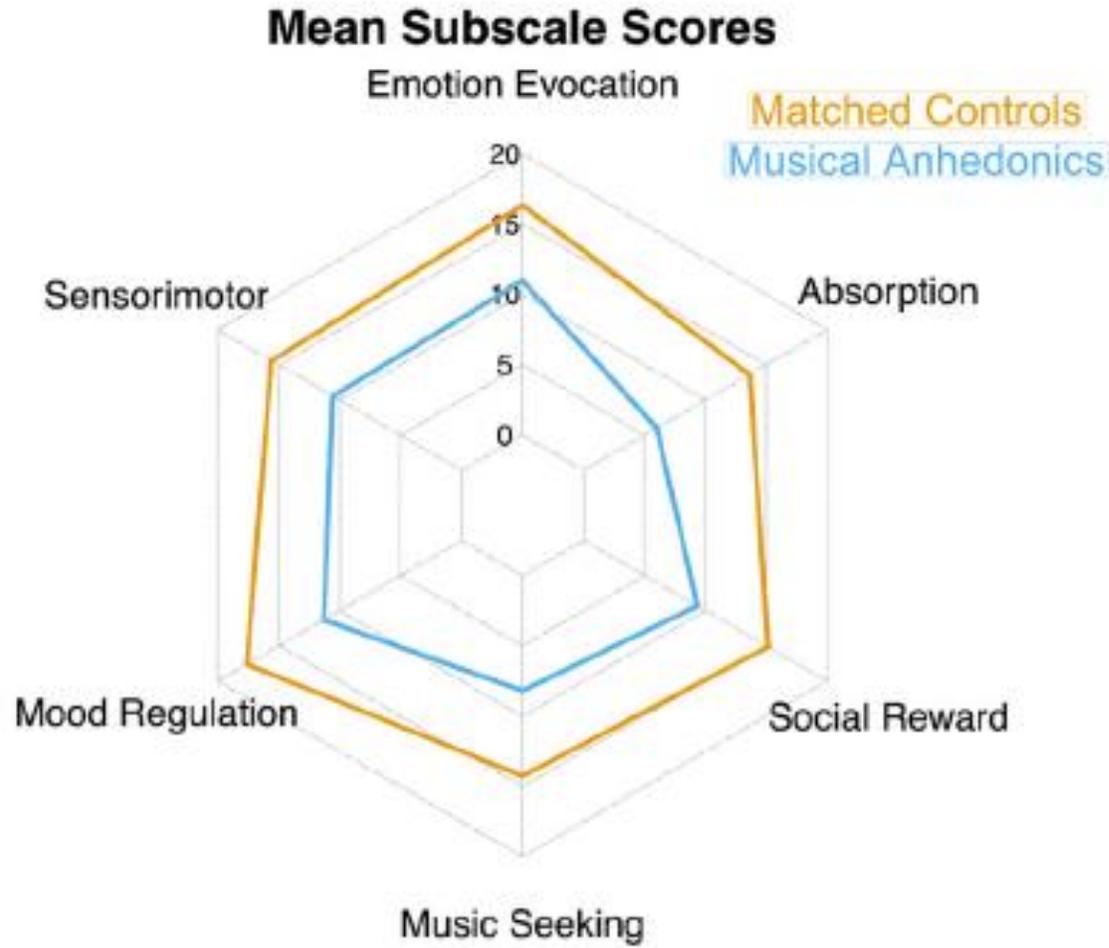


Kathios, Patel, Loui 2024 Cognition (N = 501)

Can leverage this to get people to engage in music-based activities

Musical pleasure has several facets (relatively independent)

And some people get little pleasure from music



**Extended Barcelona Music Reward Questionnaire
(eBMRQ)**

Cardonna et al. 2022 Annals NYAS

Building on BMRQ:
Mas-Herrero et al. 2013. Music. Percept.

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What degree/type of musical training is needed to influence speech processing?

- Degree: an empirical question
 - Existing longitudinal studies showing an effect of music training on speech processing often take place over several months
 - E.g., Moreno 2009 Cereb. Ctx. – 6 months of training of 8 year olds, w/active control
 - Why making the music training enjoyable is a key issue
- Type: scaled to current abilities and interests (cf. music therapy)
- Degree/type analogy: exercise for health



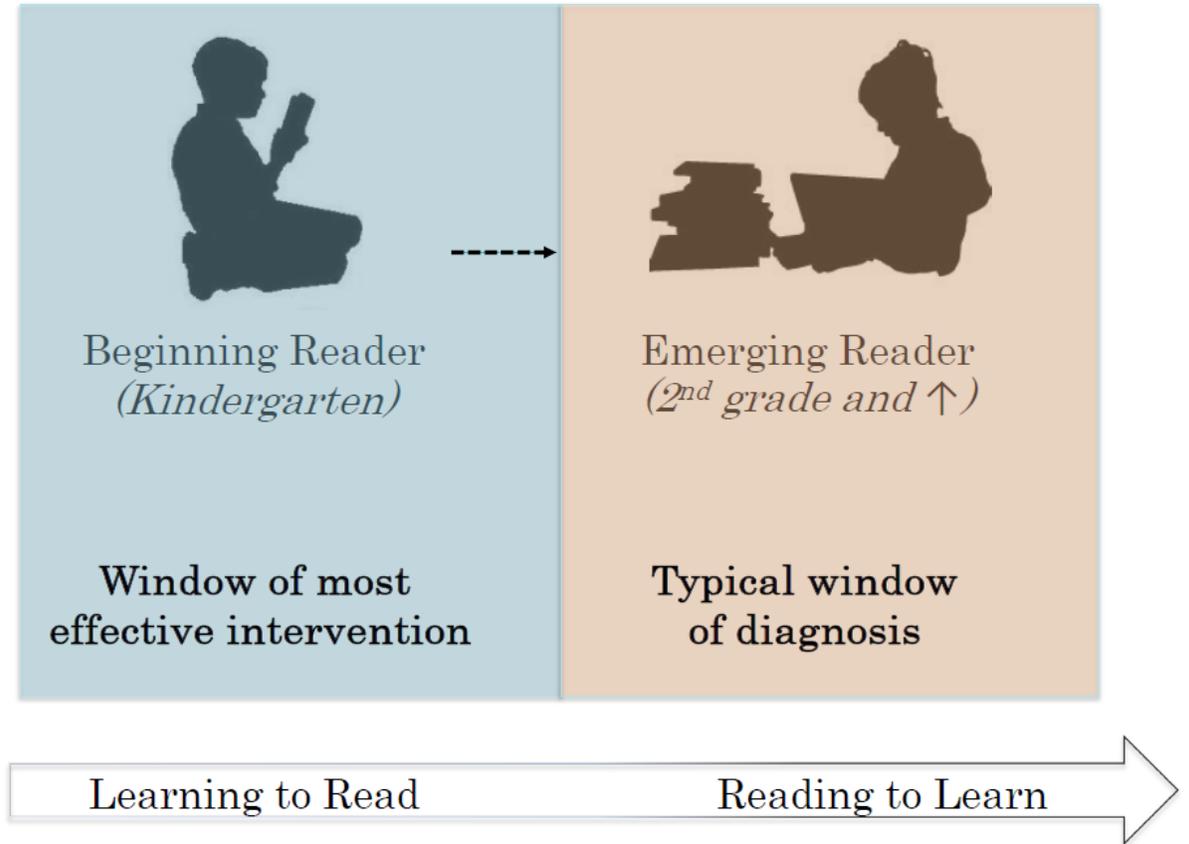
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Some populations that might benefit

- Young children at risk for dyslexia
 - A key predictor: probs with phonological processing
- Phonological processing utilizes temporal/rhythmic patterns in speech
- Numerous studies find associations btwn musical rhythmic processing and phonological processing
 - Reviewed in Nayak 2022 *Neurobiol. of Lang.*
- Musical training in early childhood can take advantage of sensitive period effects
 - Penhune 2020 *Curr. Opin. Behav. Sci.*

The Dyslexia 'Paradox'



(Courtesy of Jenny Zuk, Boston Univ.)

Some populations that might benefit

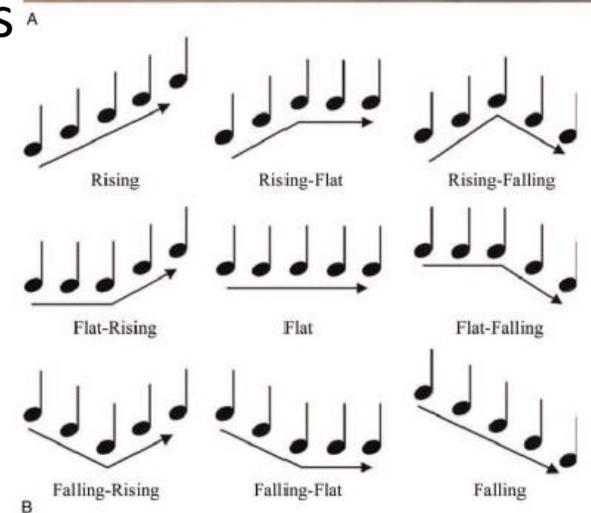
- Healthy older adults with declining speech-in-noise perception abilities
 - Perron et al. (2021). The frontotemporal organization of the arcuate fasciculus and its relationship with speech perception in young and older amateur singers and non-singers. *Human Brain Mapping*
- Choir singing can also help combat social isolation in older adults



Pascale Tremblay
U. Laval

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- Choir singing can also help combat social isolation in older adults
- Cochlear implant users who struggle with prosody perception
 - Chari et al. Limb 2020 Otol. & Neurotol.

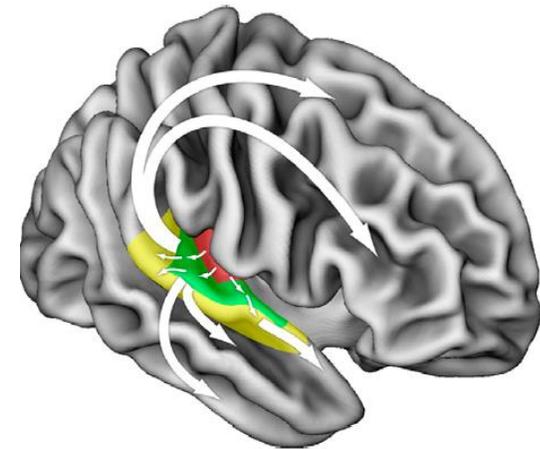
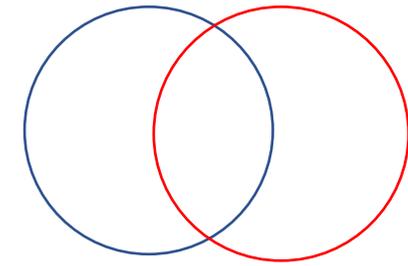


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 - One inspiration: Kraus & Chandrasekaran 2010 “Music training for the dev. of auditory skills.” Nat. Rev. Neuro.
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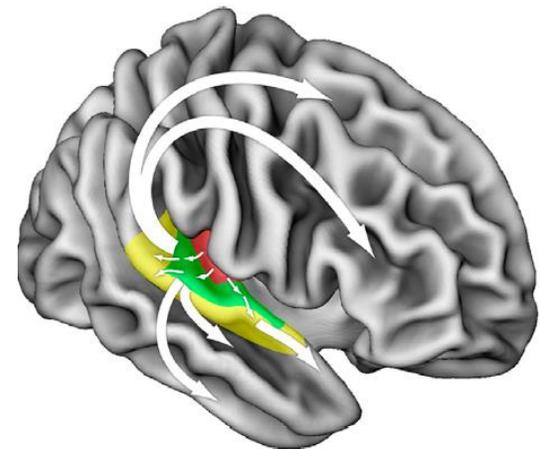
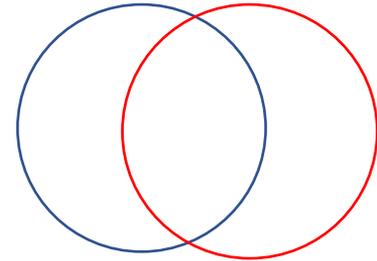
Idea 1: Neural overlap

- There is overlap in some of the brain mechanisms that process the sounds of instrumental music and speech
- Low-level (e.g., midbrain)
 - e.g., sensory encoding of frequency, timing patterns
- Mid-level (e.g., secondary auditory cortex)
 - e.g., processing of pitch contour patterns
- High-level (e.g., aud-frontal networks)
 - e.g., auditory working memory



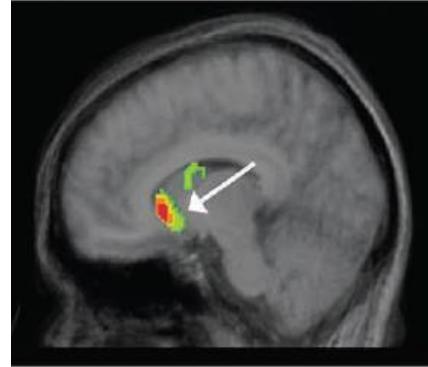
Idea 2: Asymmetric demands

- For some overlapping mechanisms, music places **higher demands** on processing than speech does
- Low-level (e.g., midbrain)
 - e.g., sensory encoding of pitch, timing patterns
- Mid-level (e.g., non-primary auditory cortex)
 - e.g., processing of pitch contour patterns
- High-level (e.g., aud-frontal networks)
 - e.g., auditory working memory



Idea 3: Activating plasticity

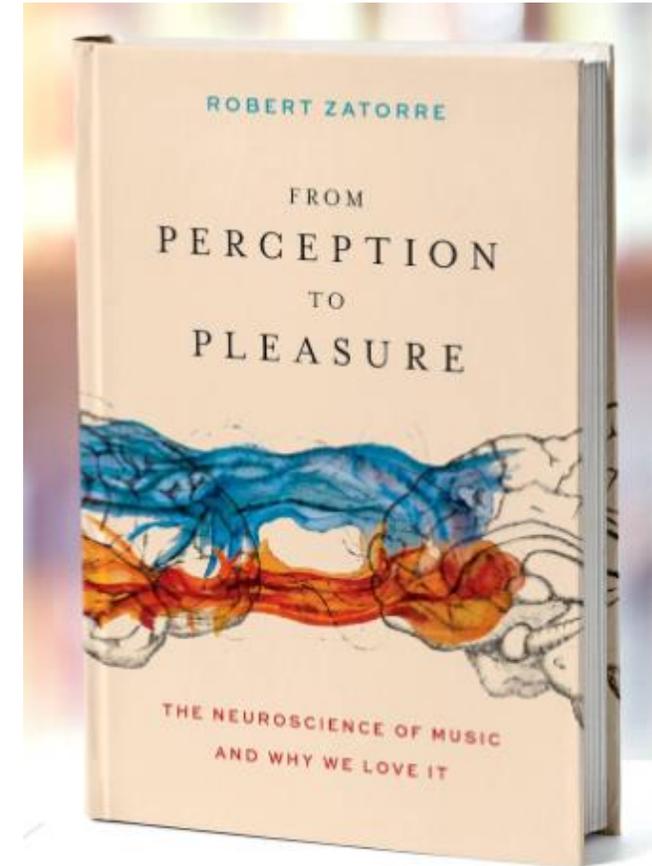
- Musical training combines high processing demands with 3 factors that promote neural plasticity
- Emotion
 - e.g., dopaminergic system
- Repetition
 - e.g., “massed training”
- Selective Attention
 - e.g., to specific sound features



Salimpoor et al. (2011)
Nature Neuroscience



Polley et al. (2006) *J. Neurosci*



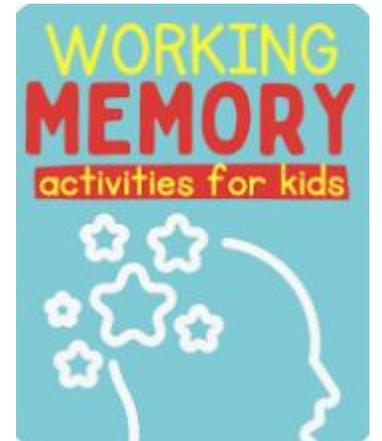
How & Why? Overview of framework

- 1. Overlapping networks for music & speech processing
- 2. Asymmetric processing demands (music > speech)
- 3. Plasticity driven by emotion, repetition, and attention
- 2&3 drive the networks to higher levels of performance than needed for ordinary speech processing
- Yet since speech shares these networks with music, speech processing benefits

The “OPERA hypothesis”

Patel (2011) *Frontiers in Psychol.*

- Original version focused on the demands music places on sensory processing
 - **O**verlap
 - **P**recision - sensory encoding of acoustic features
 - **E**motion
 - **R**epetition
 - **A**ttention
- Expanded OPERA hypothesis : considers the demands on both sensory *and* cognitive processing
 - Patel (2014) *Hearing Research*

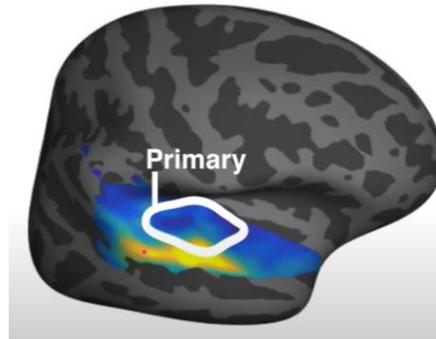


Cf. Yurgil et al. 2020
Frontiers
(music training &
working memory
Review)

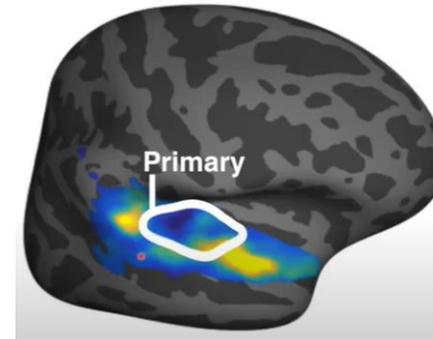
Overlap vs. non-overlap in speech and music processing

- Non-primary auditory cortex has neural populations selective for speech or music (found in fMRI studies playing listeners a wide range of sounds)

Speech selective population (yellow)



Music selective population (yellow)



- Norman-Haignere et al. 2015 *Neuron* (selective regions in both hemispheres)
- Boebinger et al. 2021 *J. Neurophys.* (included nonmusicians & non-Western music)

- People can have differential impairment of speech or music processing: congenitally or acquired after brain damage

- Sihvonen et al. 2024 *J. Neurosci.* (lesion patterns causing acquired amusia vs. aphasia)



Peretz 2006
TiCS

Recent example of overlap in neural processing of speech and music

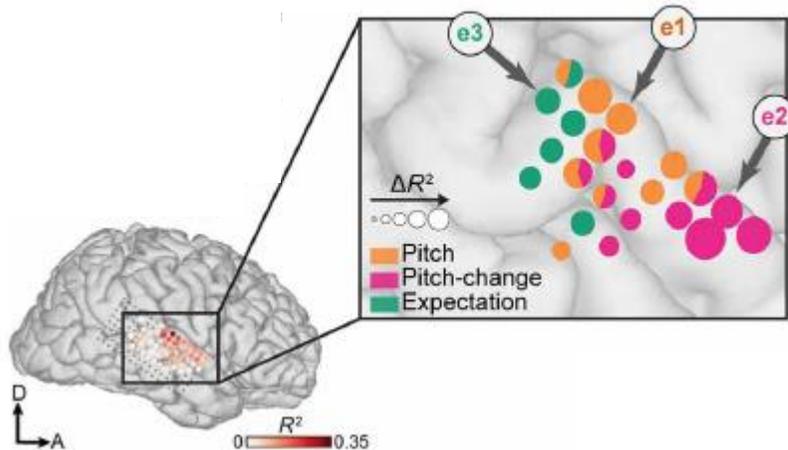
- Spoken sentences from TIMIT database



- Melodies from naturalistic musical recordings

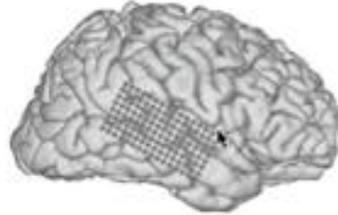
Found electrodes that responded to both speech and music:

Some responded similarly to pitch changes of comparable size and direction between speech syllables or musical tones

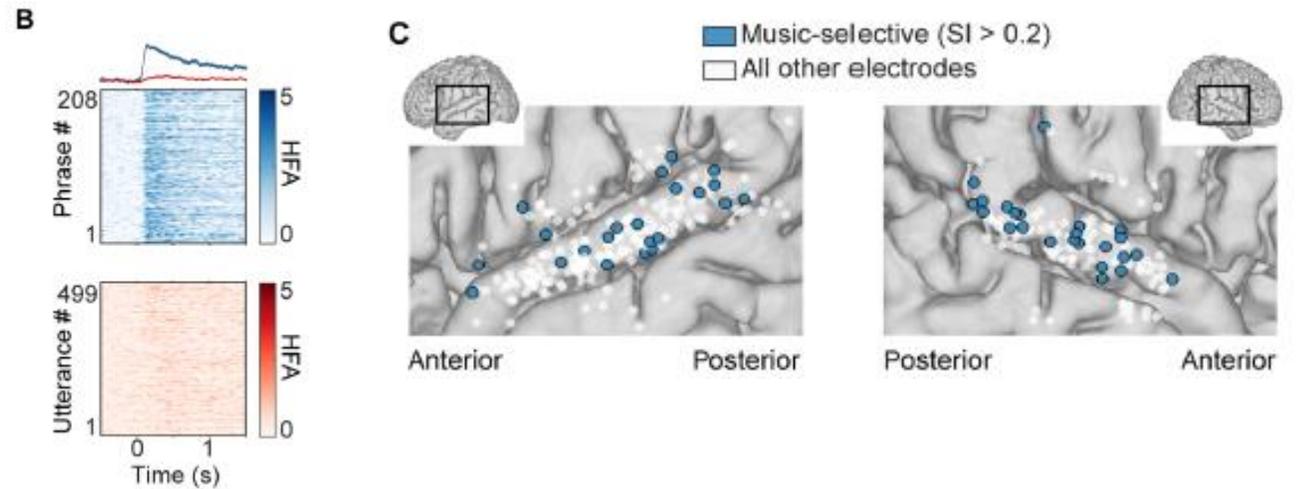


Electrocorticography (ECoG):

- Direct recordings from brain surface (clinical monitoring for seizures)
- Each electrode \sim local neural population
- High frequency activity (HFA): 70-150Hz



Found music-selective electrodes



HFA: high-freq activity

Music-selective electrodes responded to how unexpected a note is given the preceding notes, based on a statistical model trained on Western popular melodies

cf. previous findings on subtle speech intonation processing deficits in “congenital amusia” (e.g., Liu et al. 2010 Brain)

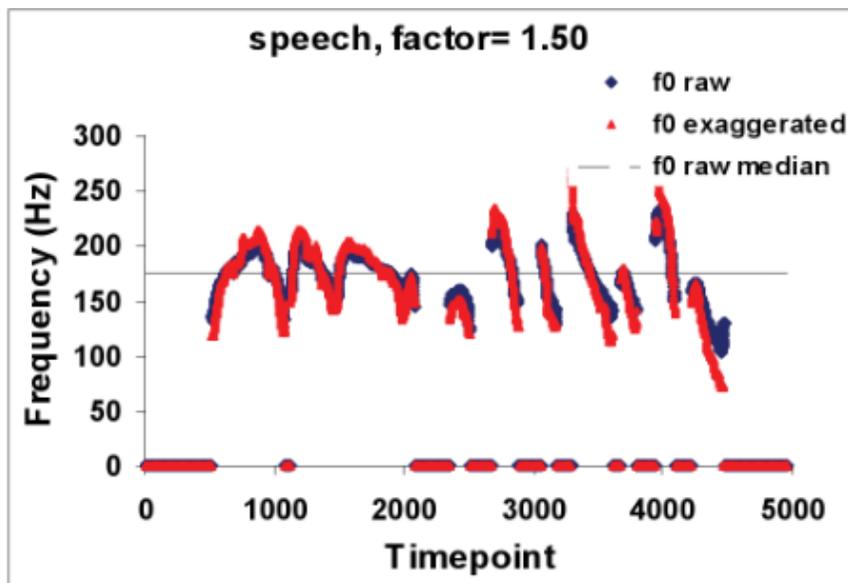
Precision of pitch contour processing: demands made by speech vs. music

- Pitch contours important in both domains
- But music relies more on the fine-grained details of such contours than does ordinary speech communication

Benefits of better
pitch contour
processing in speech?

Processing of spoken
pitch contours aids
understanding speech
in multi-taker settings

Liu et al. (2015)
Neuropsychologia



Zatorre & Baum (2012) *PLoS Biol*

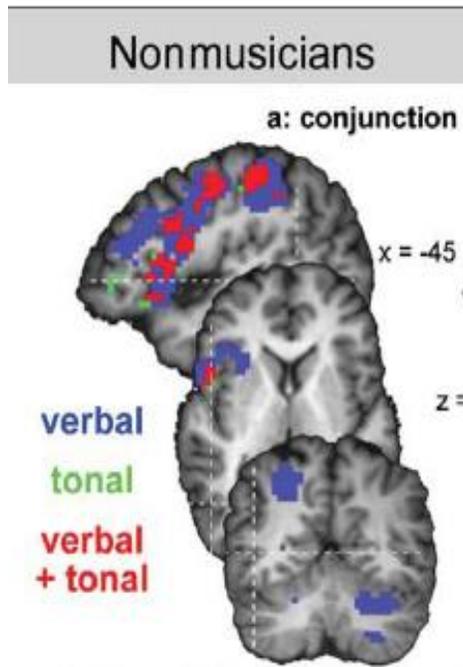


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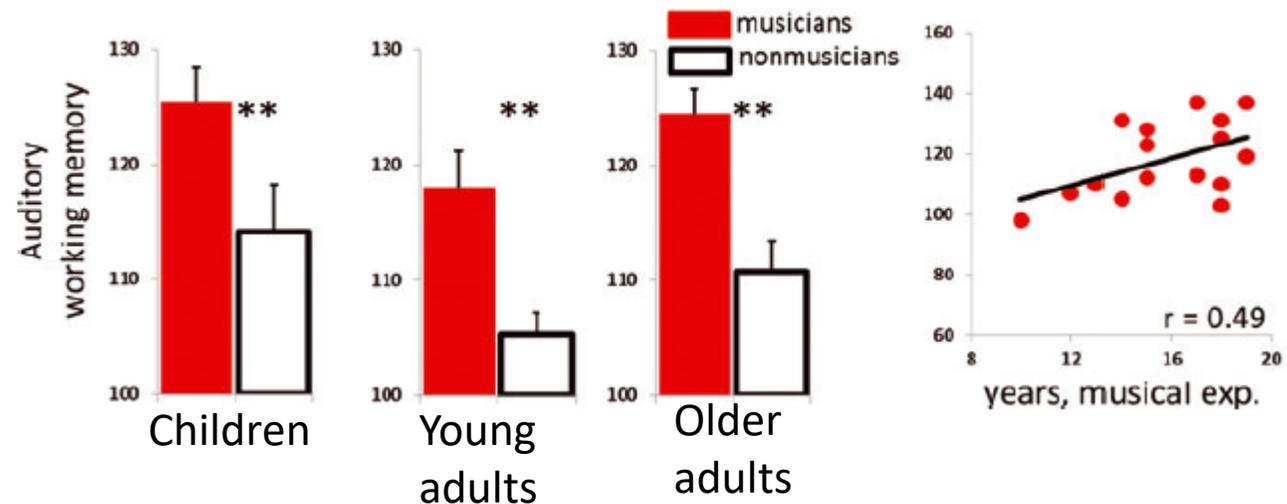
OPERA can be applied to processing of pitch, rhythm, WM, etc.

- Auditory working memory (no “semantic recoding” in music)
- WM for tonal material overlaps with verbal WM in the brain



Schulze et al. (2010) *Hum. Brain Mapping*

Strait & Kraus (2011) *Music Percep*



Meta-analysis of musician advantage in auditory WM:

Talamini et al. (2017) *PLoS One*

OPERA now one of several frameworks aiming to explain why music training could influence speech processing

- E.g. SEP (Fujii & Wan), PATH (Tierney & Kraus), PRISM (Fiveash et al.)
 - For an overview, see:
 - Fiveash et al 2021. Processing rhythm in speech and music: Shared mechanisms and implications for developmental speech and language disorders. *Neuropsychology*

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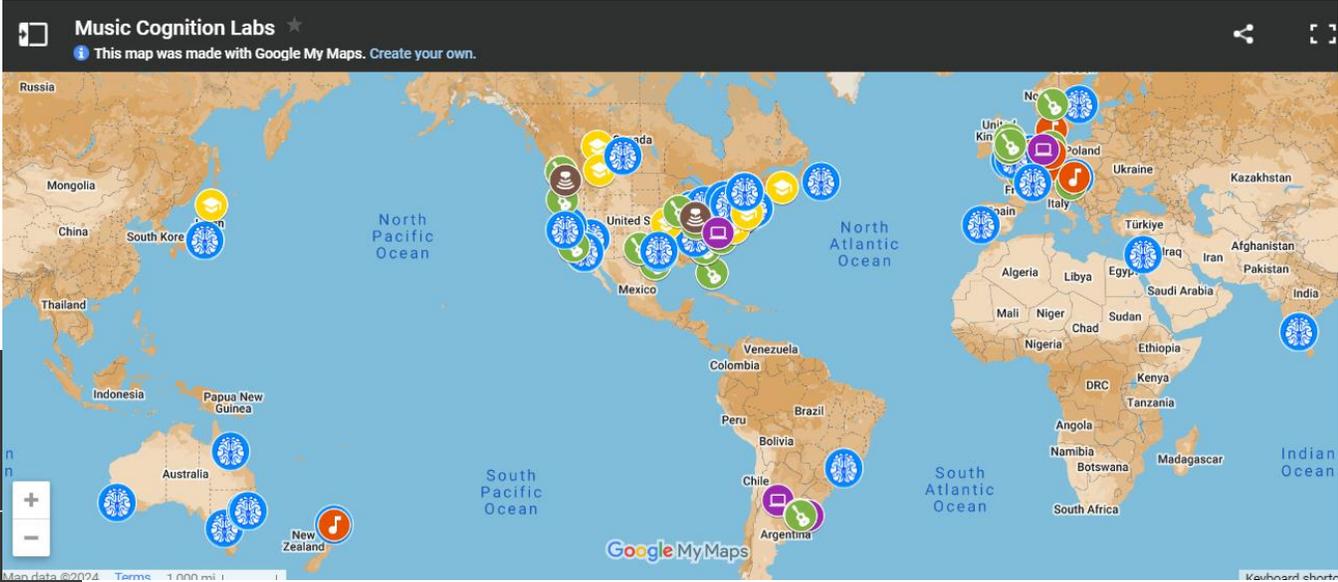
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Conclusion

- Can musical training improve speech processing?
- Addressing this question has both theoretical and practical implication for research on auditory processing
- Existing data and theoretical frameworks motivate pursuing this question
 - A need for more longitudinal RCTs, especially with children
 - With active controls
 - Employing both behavioral and neural measures
- 2 resources for those interested in music cognition or music & health...



Society for Music Perception & Cognition



Academic programs

- North America
- Bachelor's Degree Programs
- Master's Degree Programs
- Other Graduate Programs
- PhD Programs



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