THE SOUND MIND

Nina Kraus

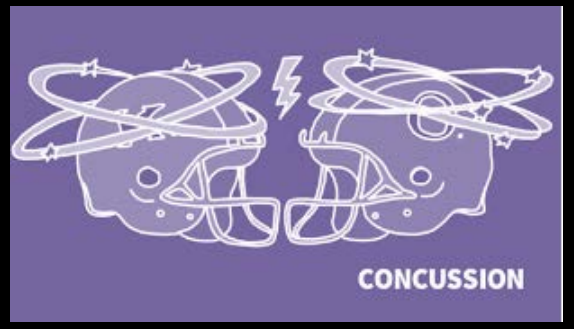
Northwestern University

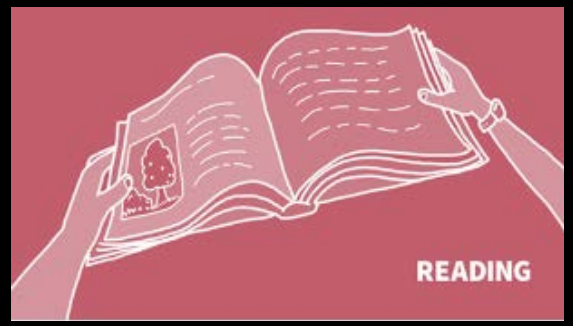
www.brainvolts.northwestern.edu

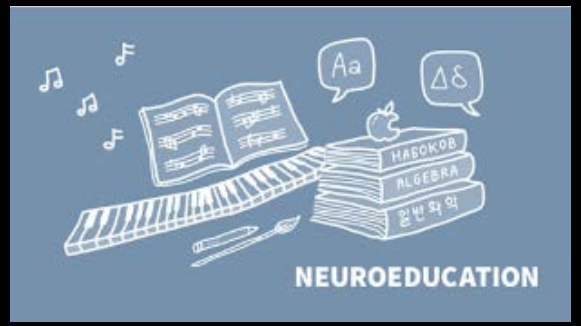
SOUND and the BRAIN

brainvolts

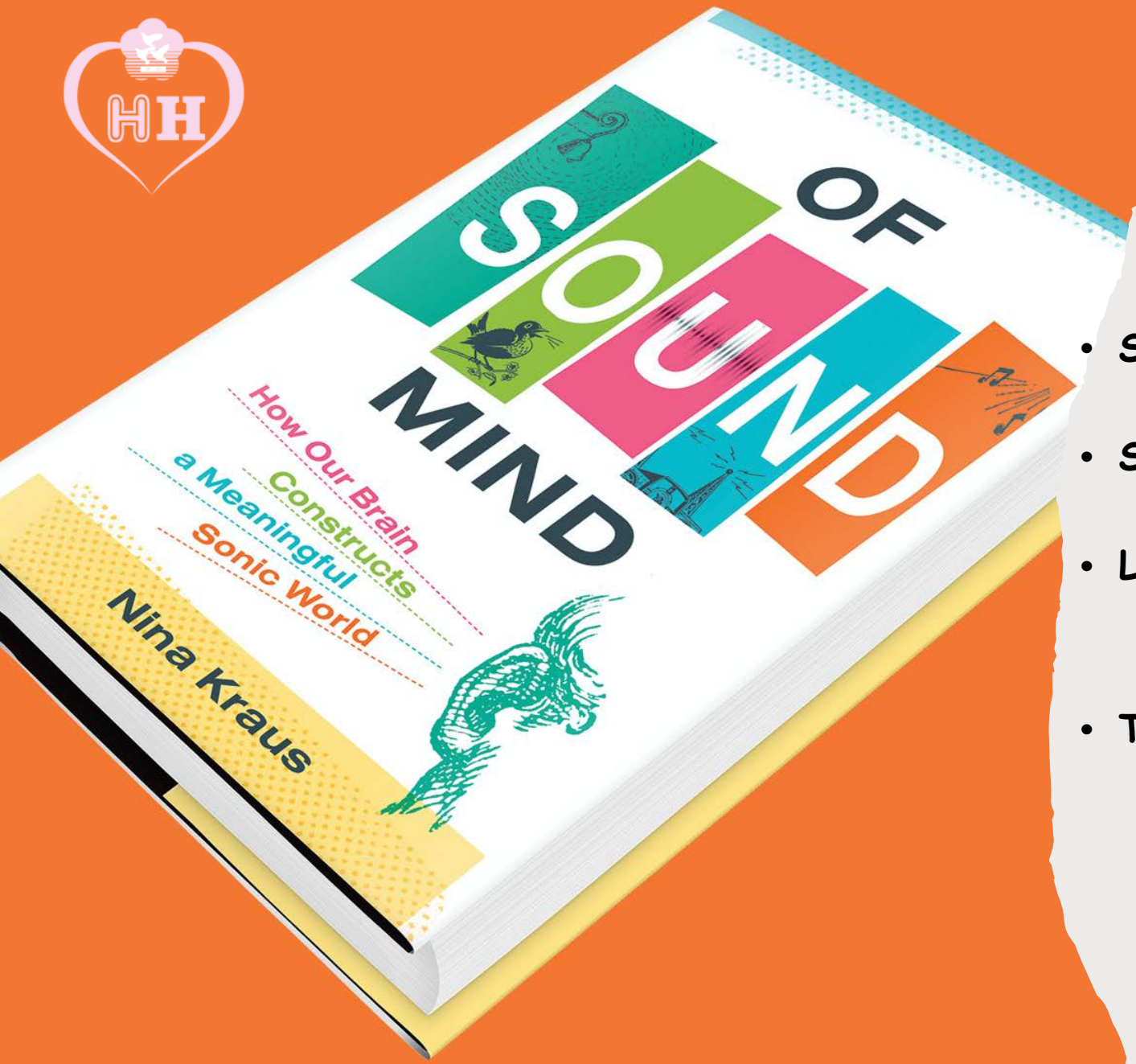
www.brainvolts.northwestern.edu







HH

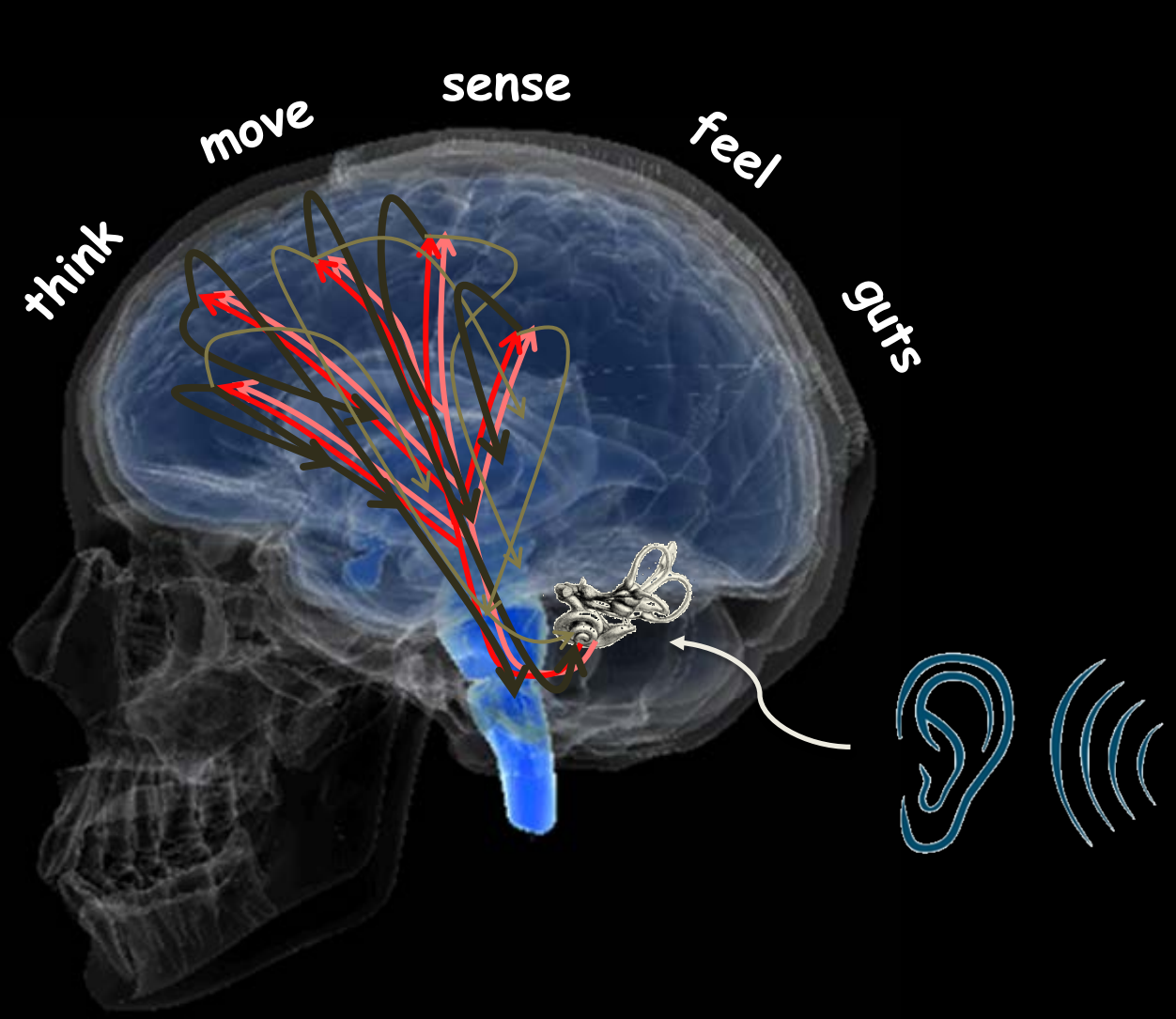


PART 1

HOW SOUND WORKS

- SIGNALS OUTSIDE THE HEAD
- SIGNALS INSIDE THE HEAD
- LEARNING:
  Merging signals outside the head with the sig
- THE LISTENING BRAIN: A Quest

SOUND ENGAGES BRAIN, BODY AND MIND



OK

degraded

The Hearing brain is vast

Lemniscal
Extralemniscal

Afferent
EFFERENT

emotion

How we feel

Auditory Cortex

Auditory Thalamus

Auditory Midbrain

Auditory Brainstem

Auditory Nerve

Ear

Auditory

Motor

How we move

Cognitive

How we think

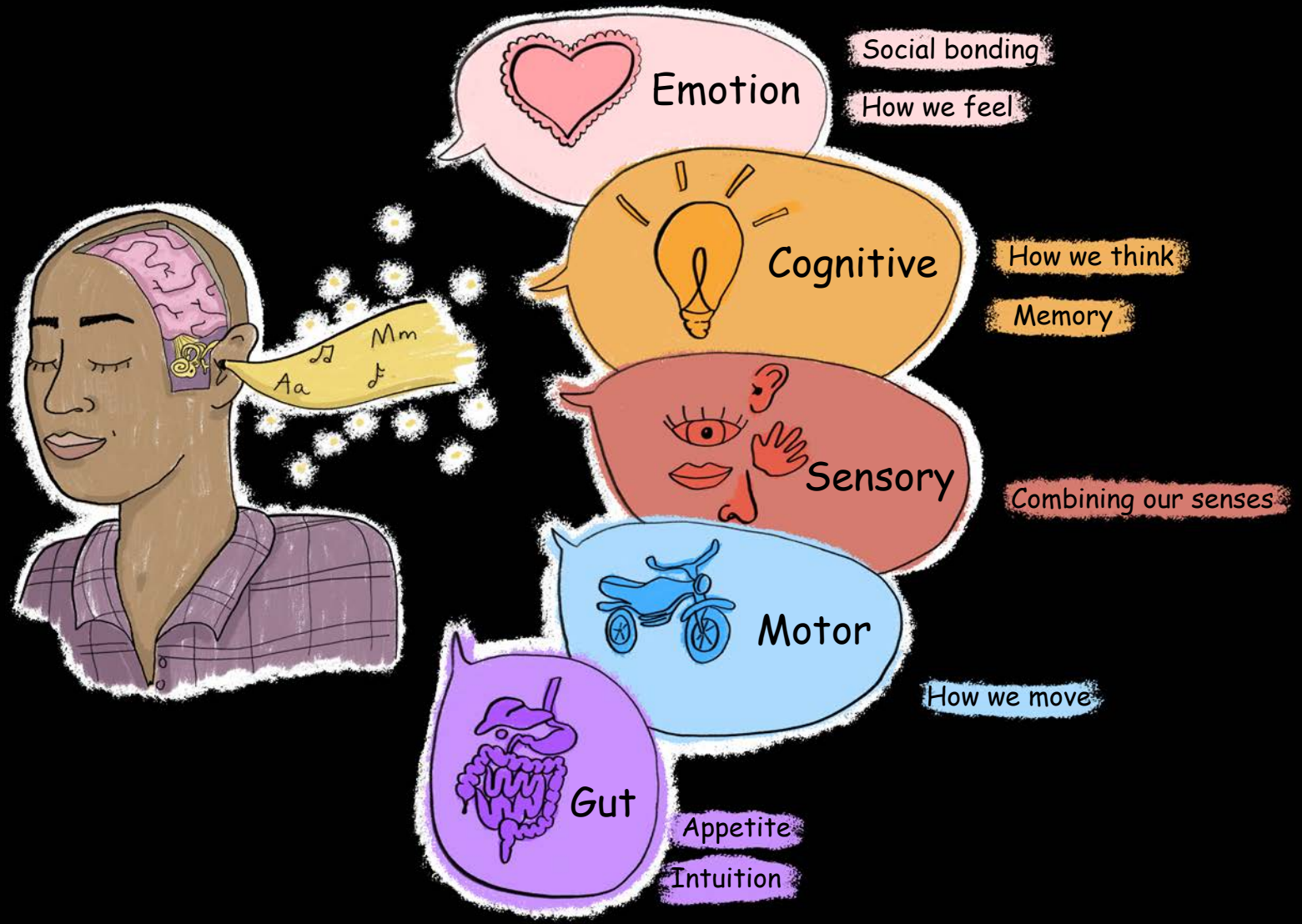
Sensory

How we sense the world

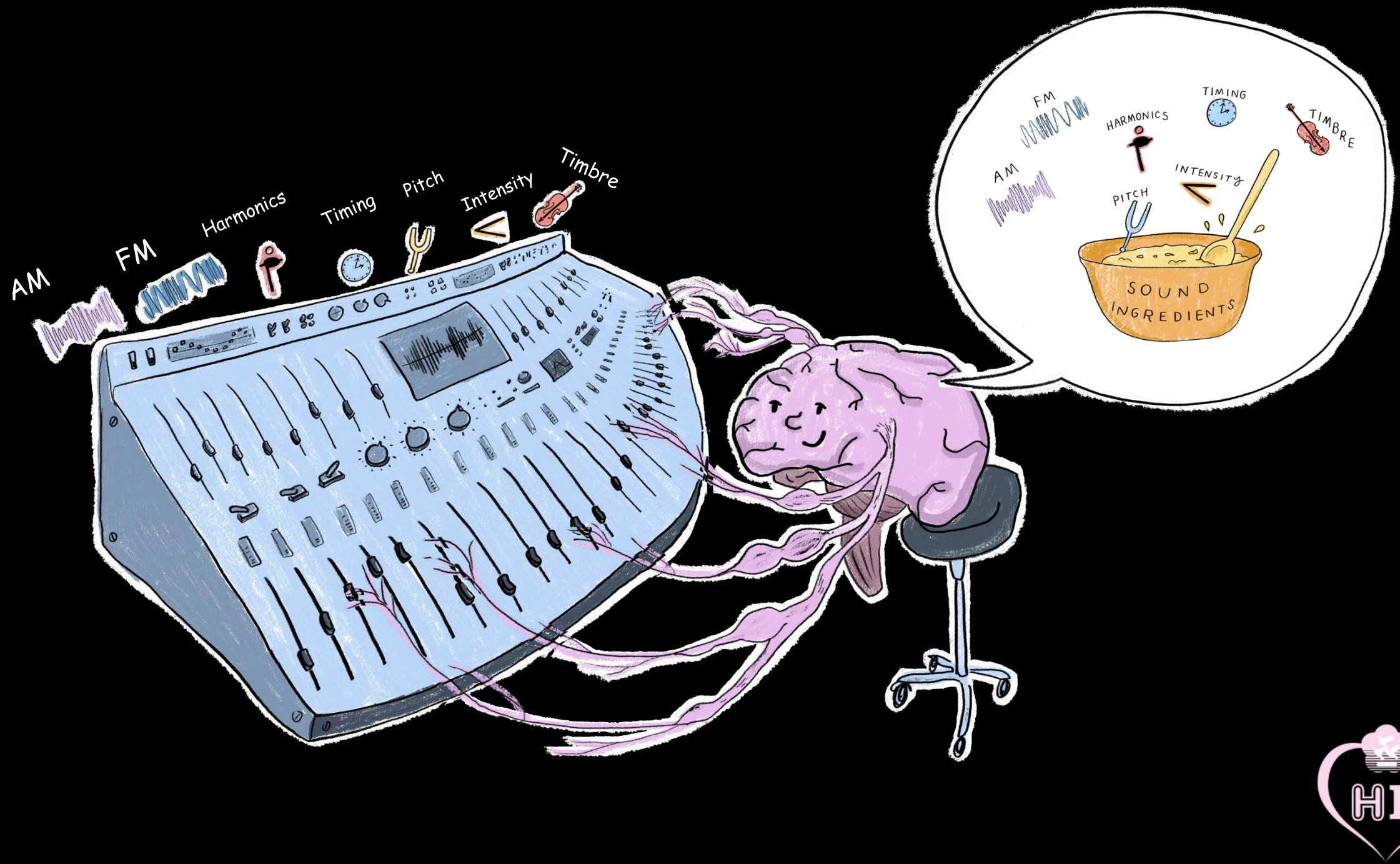
Kraus & White-Schwoch, *Trends Cog Sci*, 2015

The Hearing brain is vast

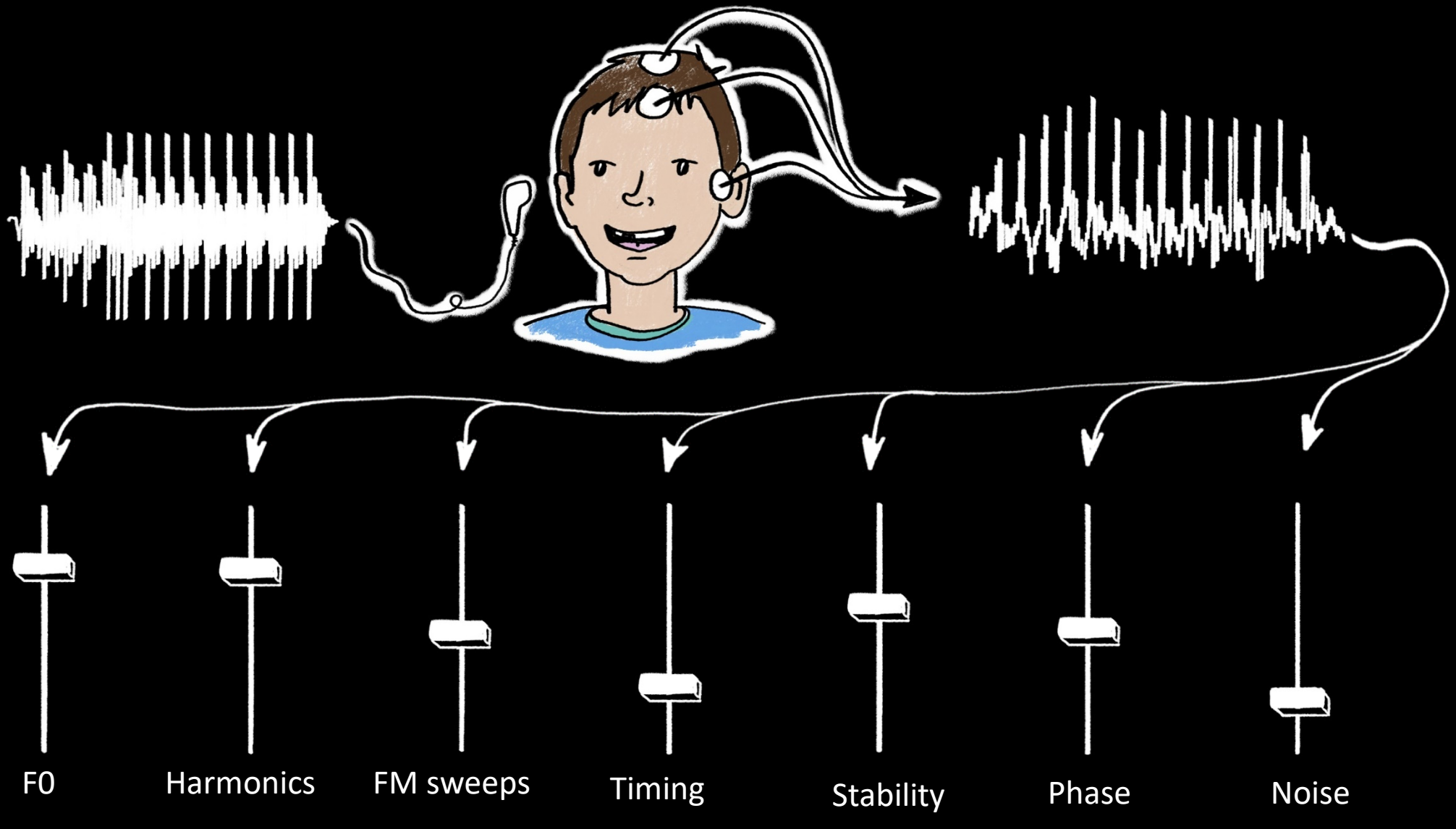
Lemniscal
Extralemniscal



Afferent
EFFERENT

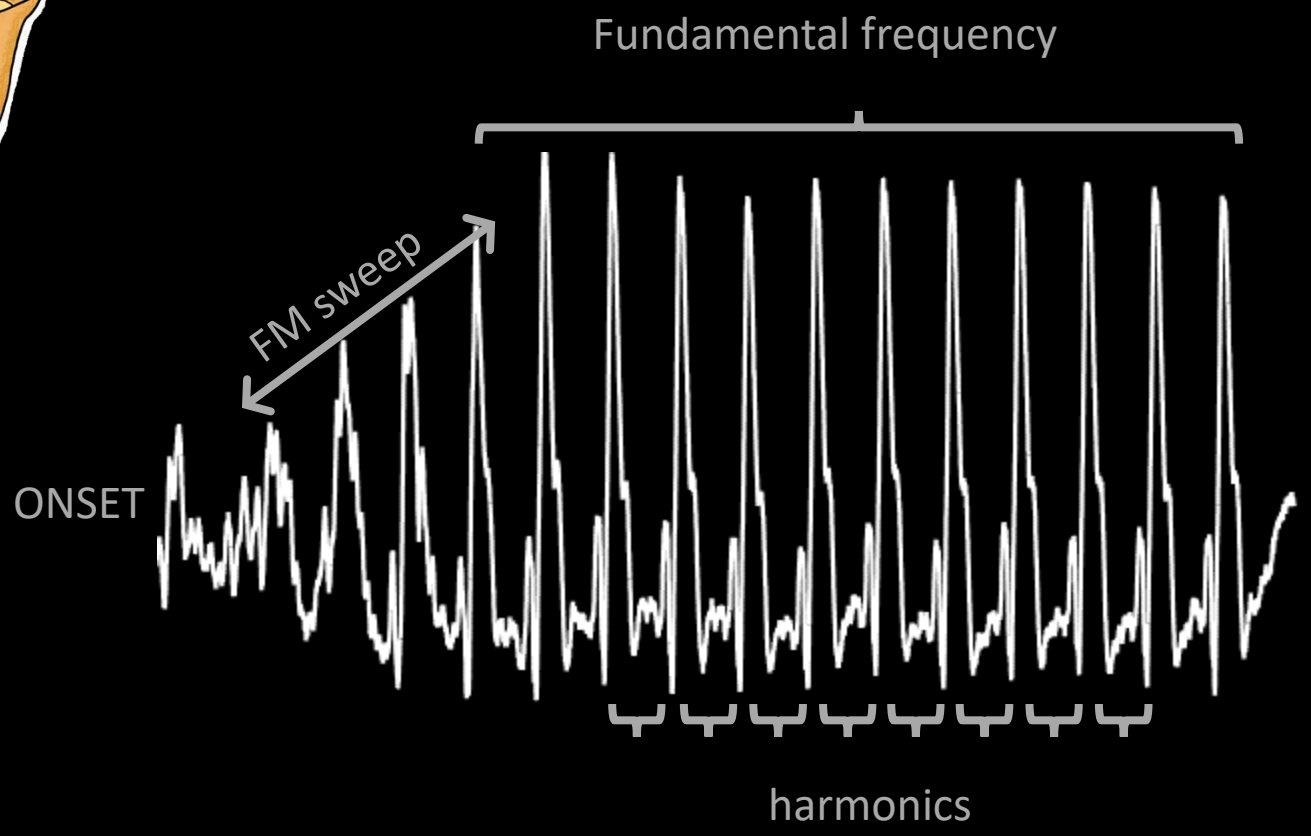

AM
FM
Harmonics
Timing
Pitch
Intensity
Timbre
FM
HARMONICS
TIMING
TIMBRE
AM
INTENSITY
PITCH
SOUND
INGREDIENTS

FFR
Frequency Following Response



mighty “da”

ffr to speech

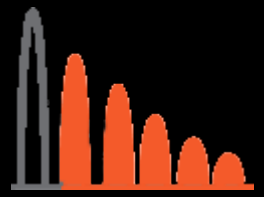


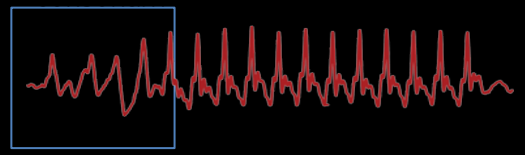
Consonant vowel

FFR Frequency Following Response

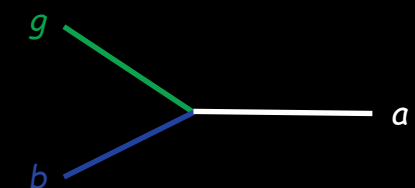
Fundamental frequency

Harmonics

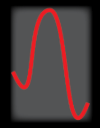


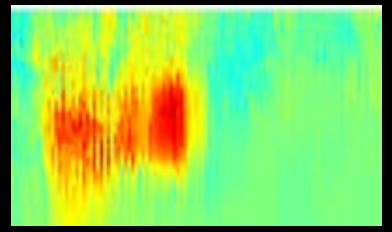


Timing
in-quiet



Timing
in-noise

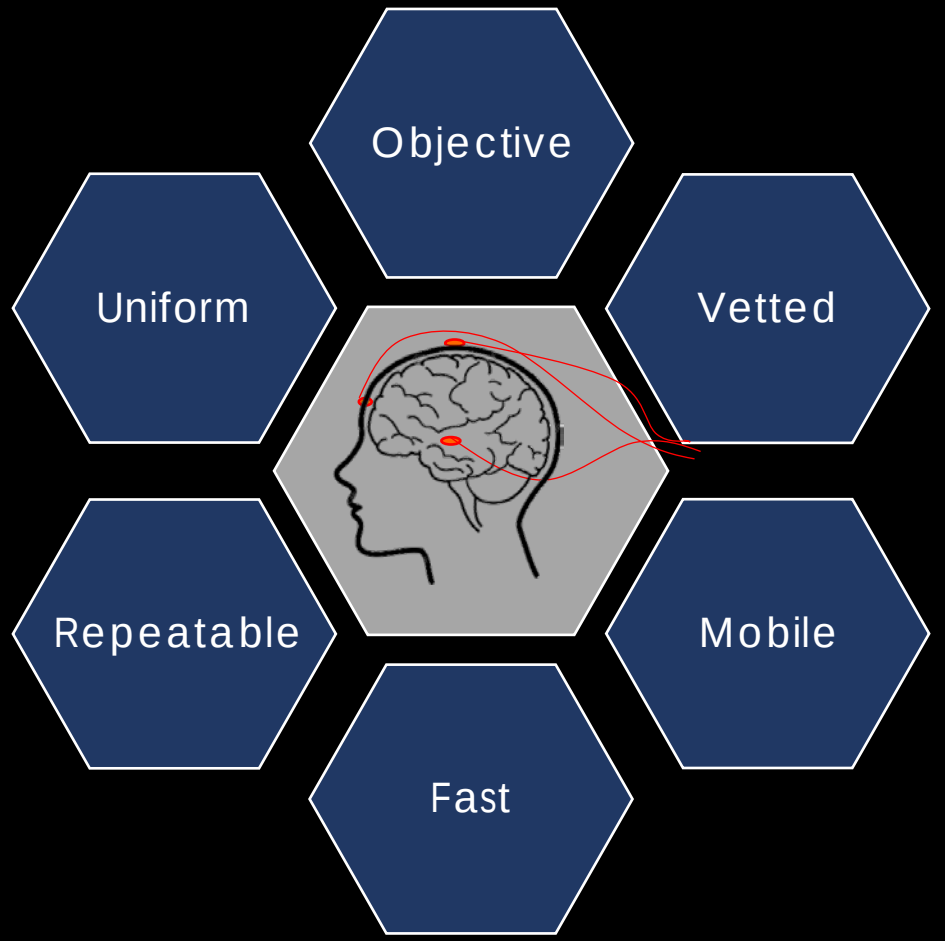




Accuracy
stimulus-to-response correlation

Stability

FFR Frequency Following Response



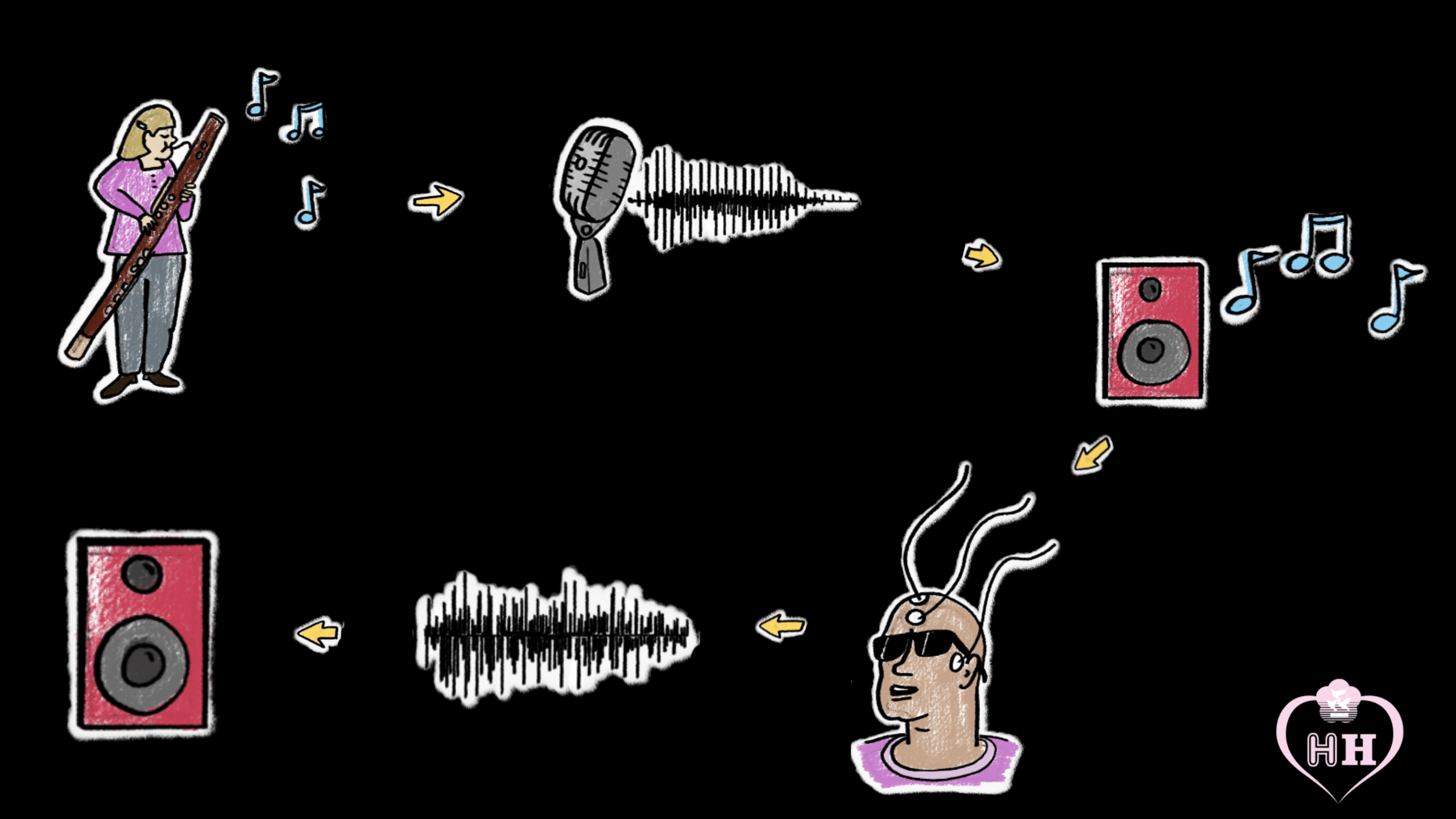
ANALYZING the FFR

A tutorial for decoding the richness of auditory function

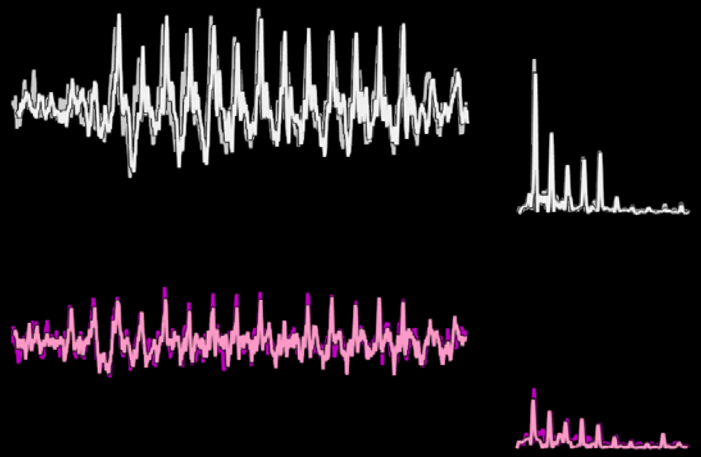
- FFR Components
  - Timing
  - Fundamental Frequency (F0)
  - Harmonics
  - Non-stimulus Activity
- Timing
  - Peak Picking
  - Frequency Specific
  - Autocorrelation
  - Phase Consistency
  - Cross-Phaseogram
- Magnitude
  - Broadband
    - RMS and SNR
  - Frequency Specific
    - Fast Fourier transform
- Fidelity
  - Stimulus-to-response correlation
  - Response-to-stimulus correlation
  - Response consistency

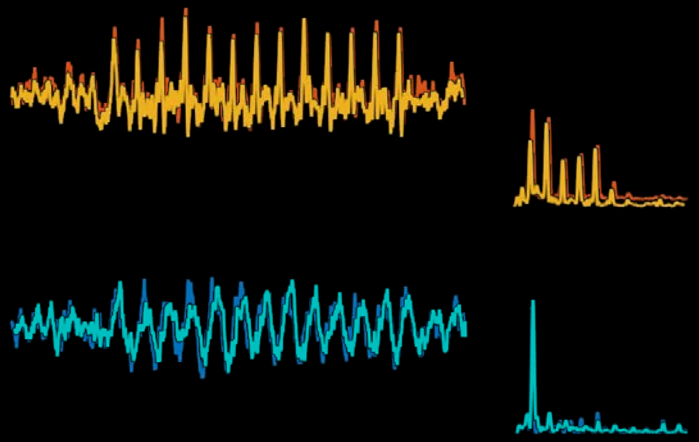
Krizman & Kraus *Hear Res* 2020

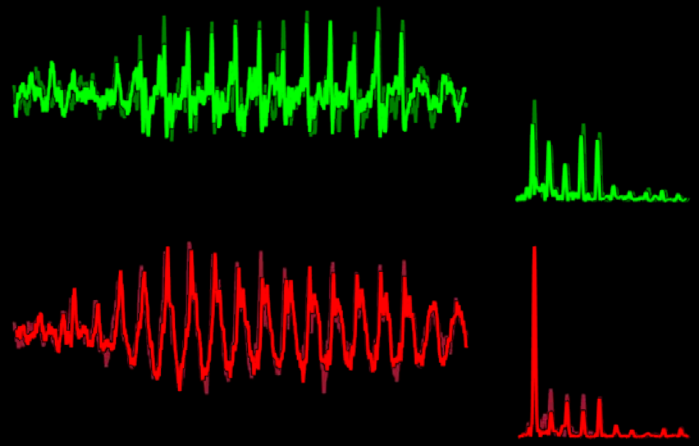
LISTENING TO THE BRAIN



sonic fingerprintS



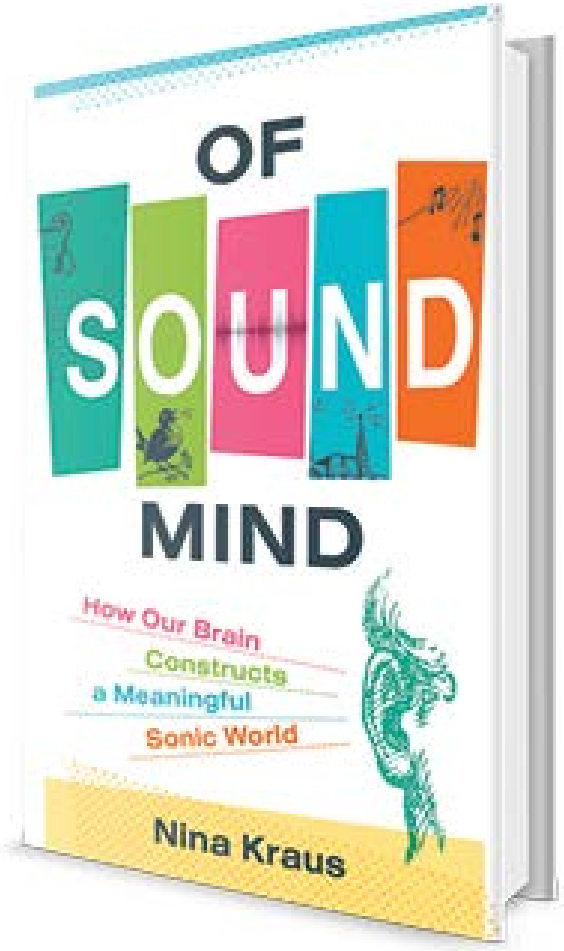




Interim Summary – The Hearing Brain

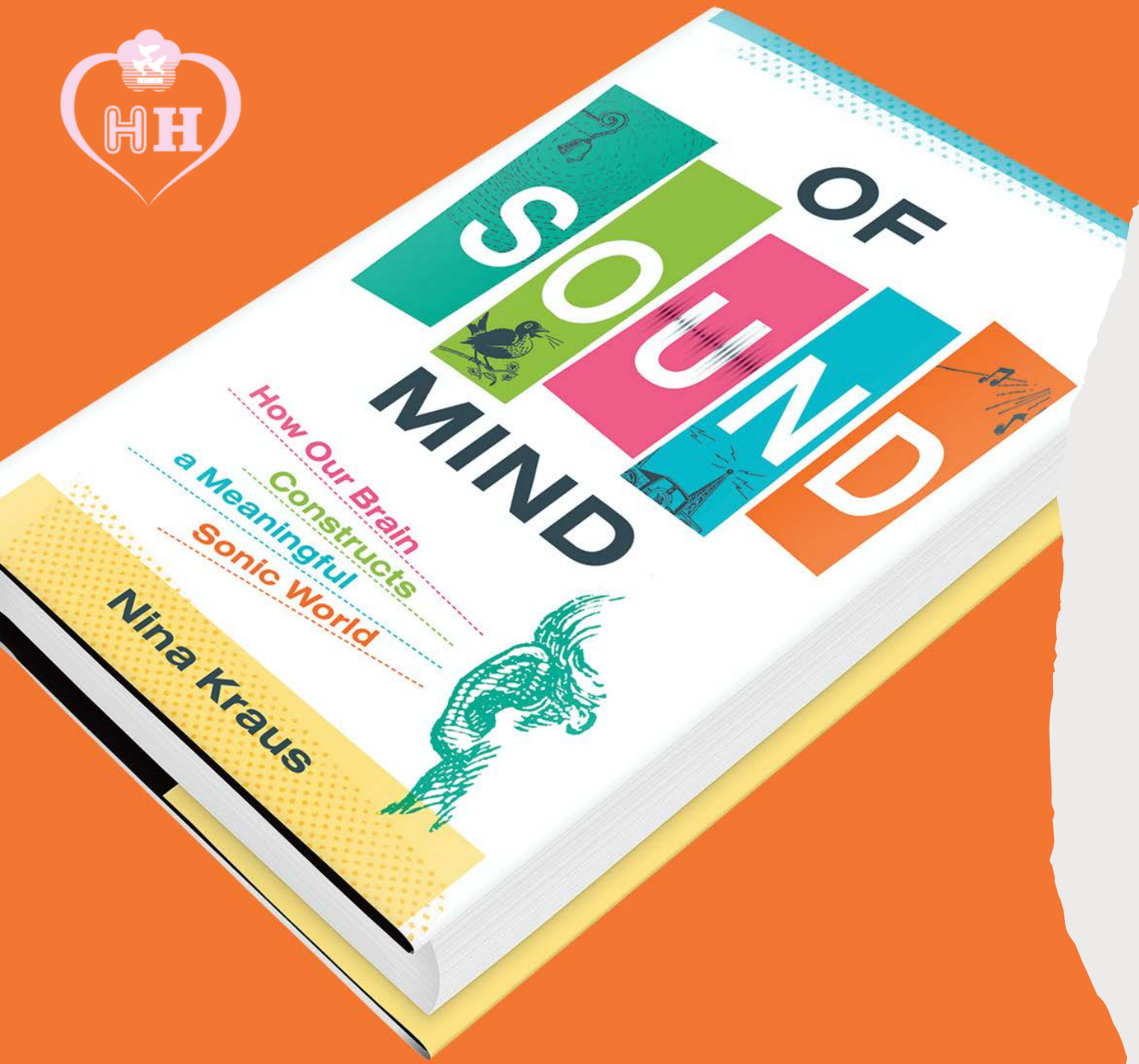
- HEARING engages much more than the classic auditory pathway
- We can assess the integrity of this holistic processing with the FFR
- ....in groups.....in individuals
- Our life in sound makes us, *us*

OUR LIFE IN SOUND SHAPES OUR BRAIN

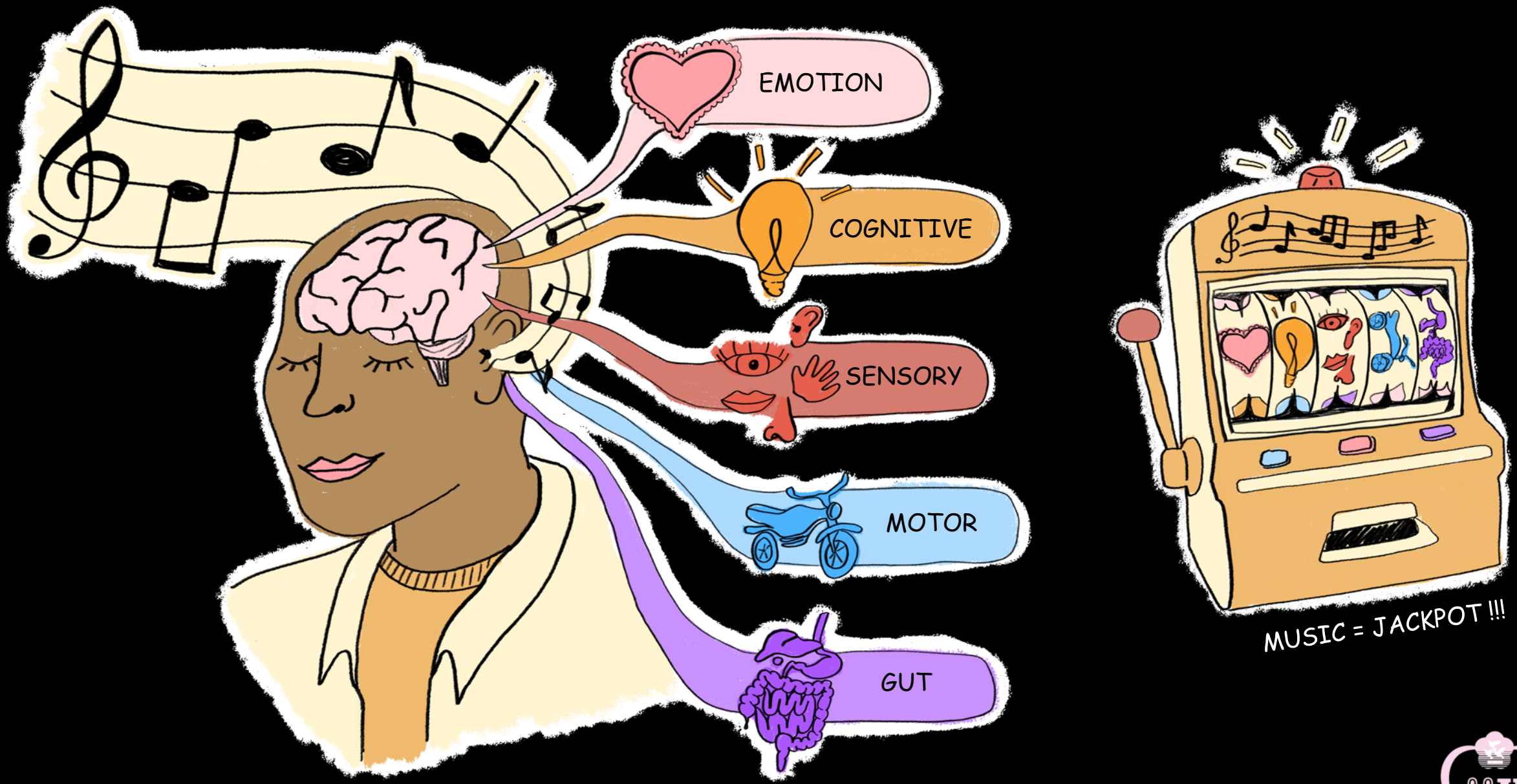


PART 2

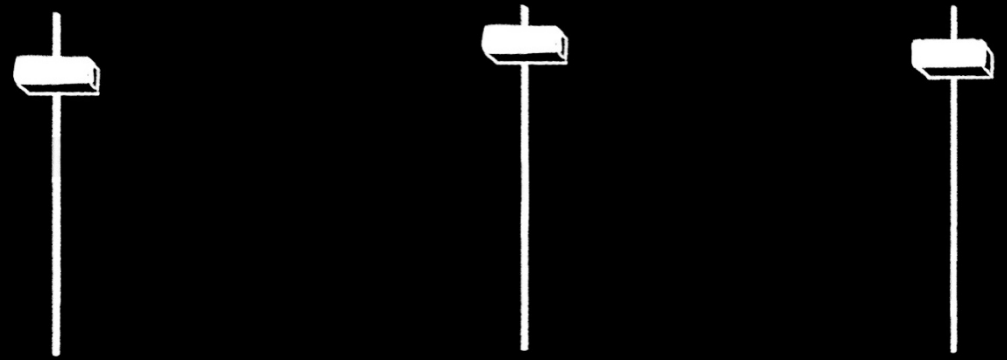
OUR SONIC SELVES



- MUSIC IS THE JACKPOT:
- RHYTHM: Inside and Outside the Head
- THE ROOT OF LANGUAGE IS SOUND
- MUSIC AND LANGUAGE: A Partnership
- THE BILINGUAL BRAIN
- BIRDSONG
- NOISE: Stop that Racket, It's Hurting My Brain
- AGING
- SOUND AND BRAIN HEALTH: Athletes and Conc
- OUR SONIC PAST, PRESENT, AND FUTURE


EMOTION
COGNITIVE
SENSORY
MOTOR
GUT
MUSIC = JACKPOT !!!

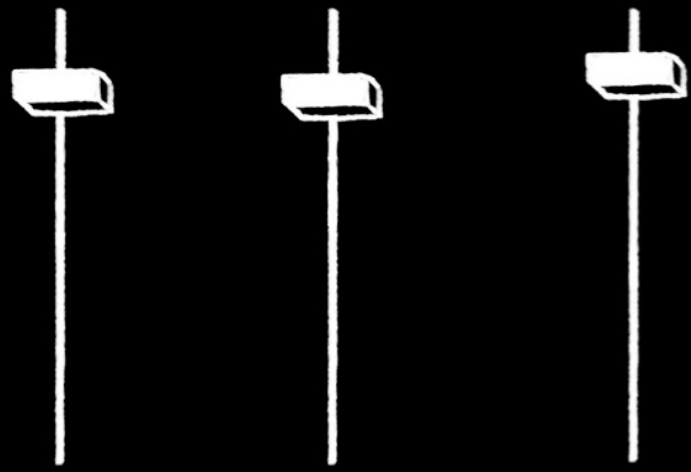
musician Signature



Harmonics FM Sweeps timing

review: Kraus & White-Schwoch, Neuroscientist, 2016

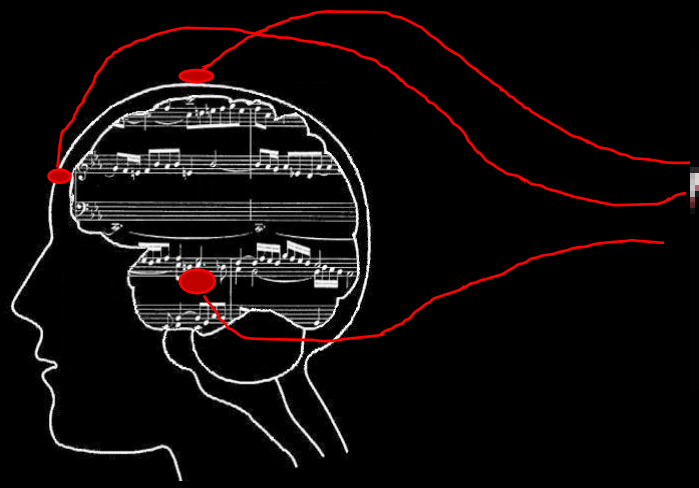
music & Language signatures overlap

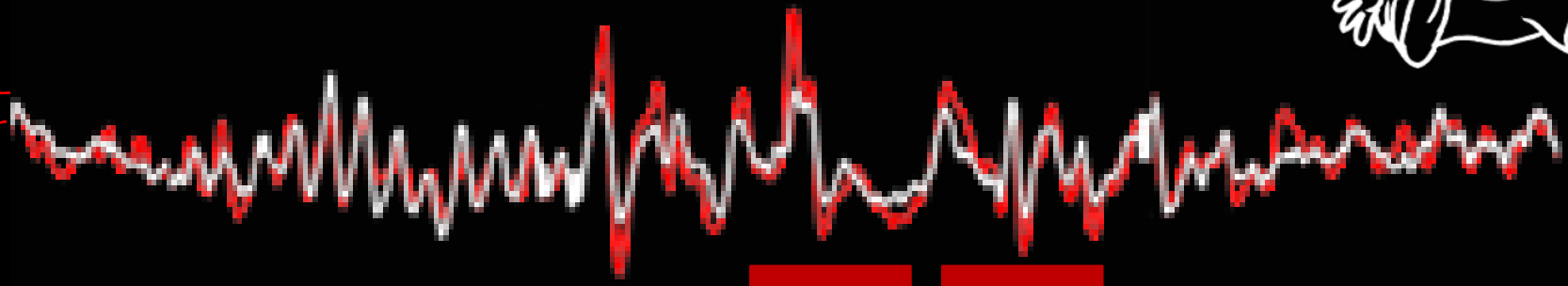


Harmonics Timing fm sweeps

review: Kraus & White-Schwoch, Neuroscientist, 2016

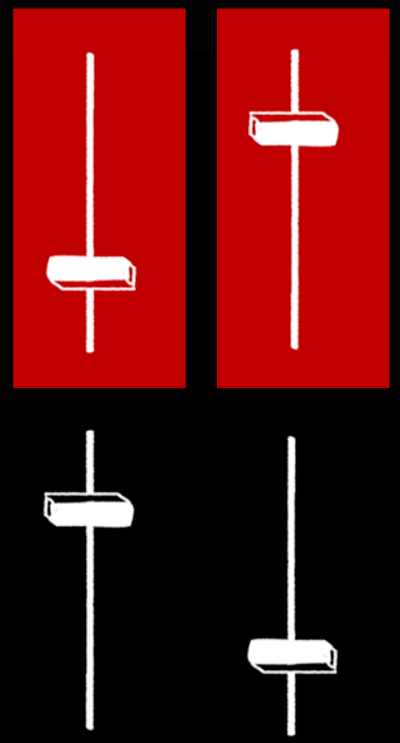
music and Emotion





Musicians

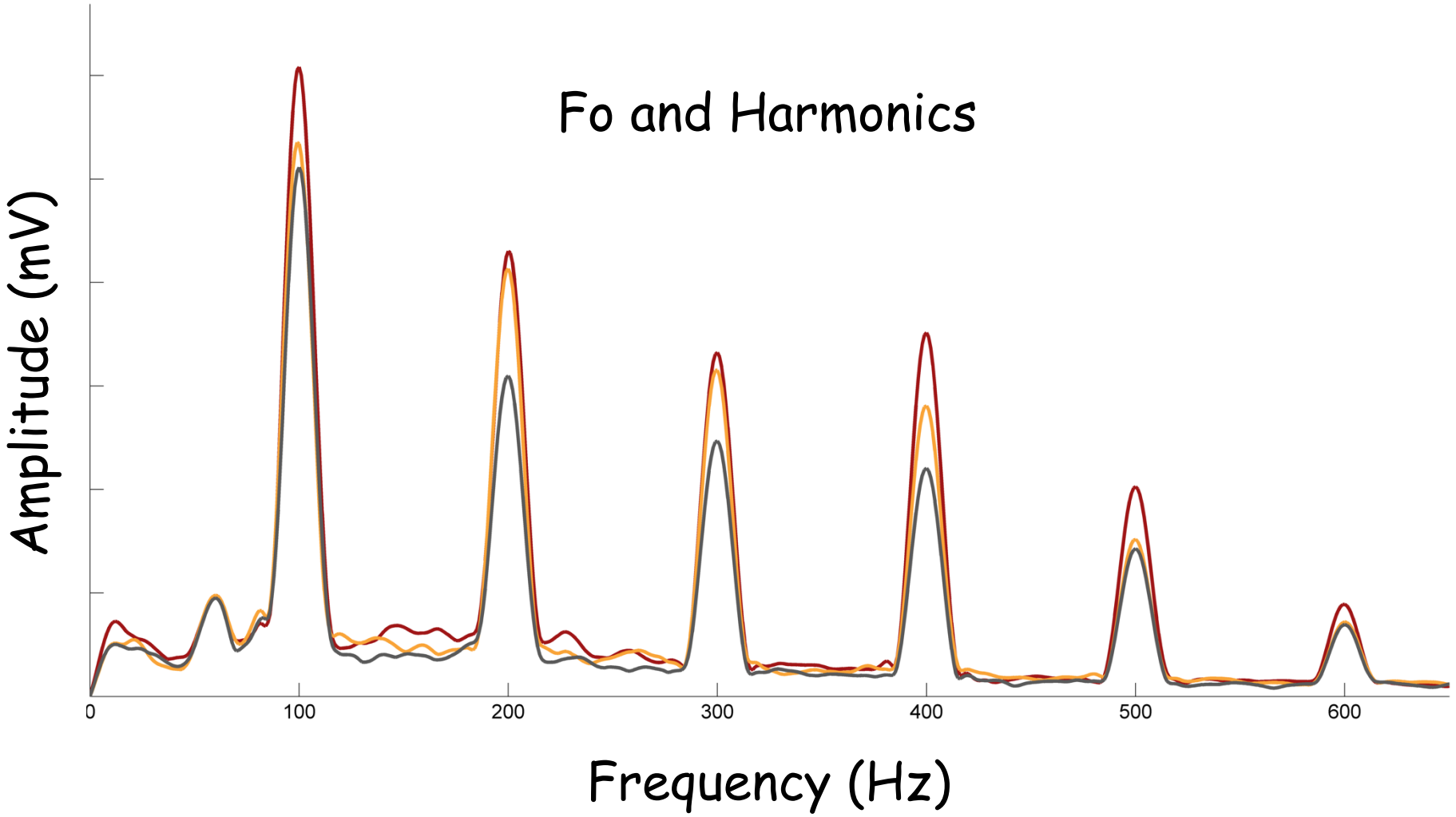
Non-musicians



F0 Harmonics

Strait et al., *Eur J Neurosci* 2009

Singers

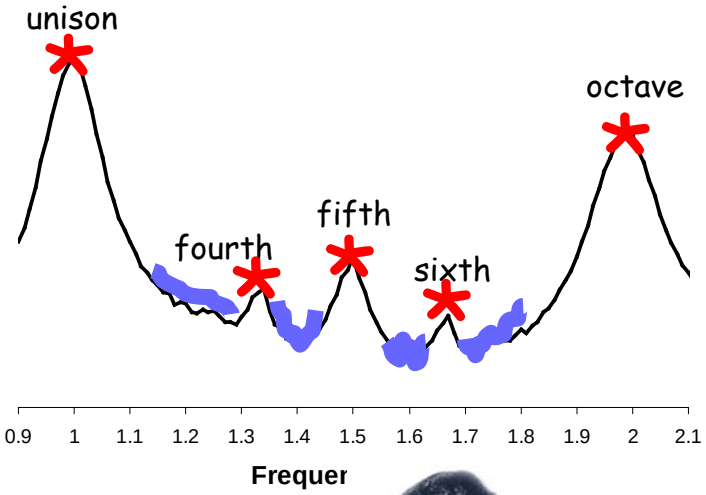


Slater...Kraus, Eur J Neurosci 2017

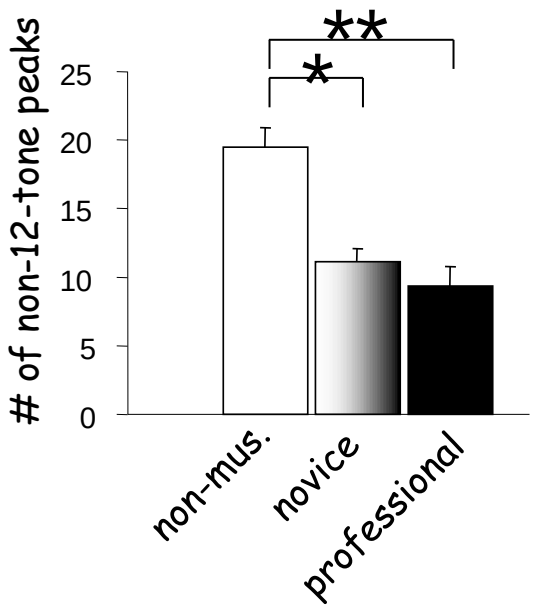
Speak and Sing well-known songs

Resonance Peaks Similar

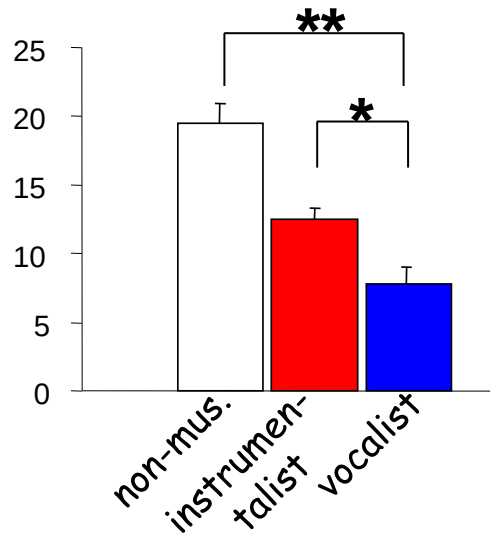
Singers less noise between resonance peaks



Experience level



Experience type



Stegemöller et al. 2003

Singers

..fine-tuning to align the voice with vast experience making music

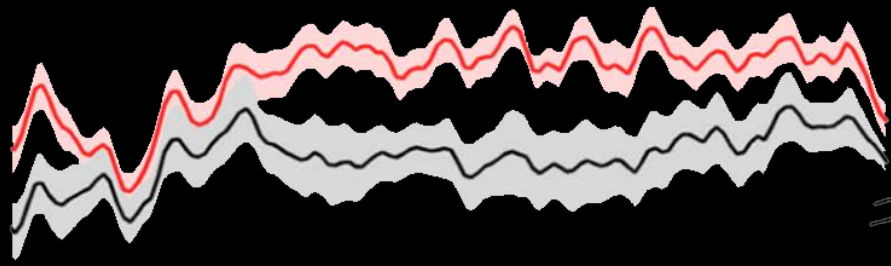
Sound-to-Meaning Connection

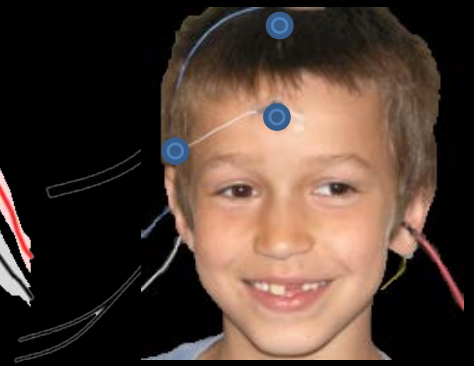
RHYTHM and LANGUAGE

BETTER LANGUAGE

Synchronizers

Non-synchronizers

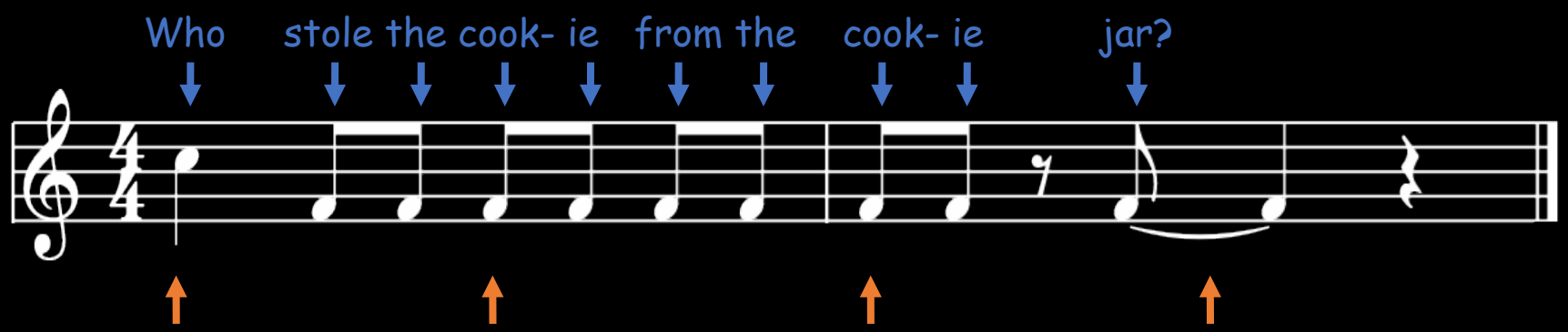




Woodruff et al. *PNAS* 2014; *Dev Cog Neuro* 2016

RHYTHM INTELLIGENCES

swing



Pattern

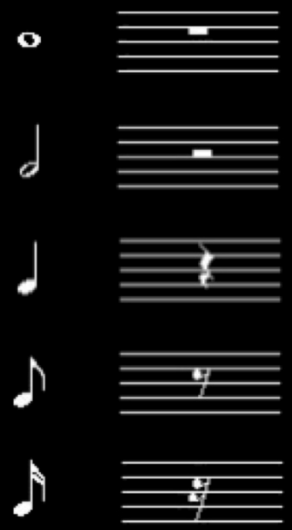
Beat (or Pulse)

Beat

3/4 **1**-2-3 **1**-2-3

4/4 **1**-2-3-4 **1**-2-3-4

Pattern



NEURAL TIME SCALES

Beat-keeping

microseconds

milliseconds

Pattern production

milliseconds

seconds

RHYTHM FRAMEWORK

BEET: Beat Engages Exquisite Timing

PLUM: Pattern Learning Unlocks Memory

Beat-keeping

Microsecond brain activity

language

Pattern production

Second brain activity

memory

Interactive metronome

Kraus, *Hearing Journal*, 2021

RHYTHM CONNECTS US

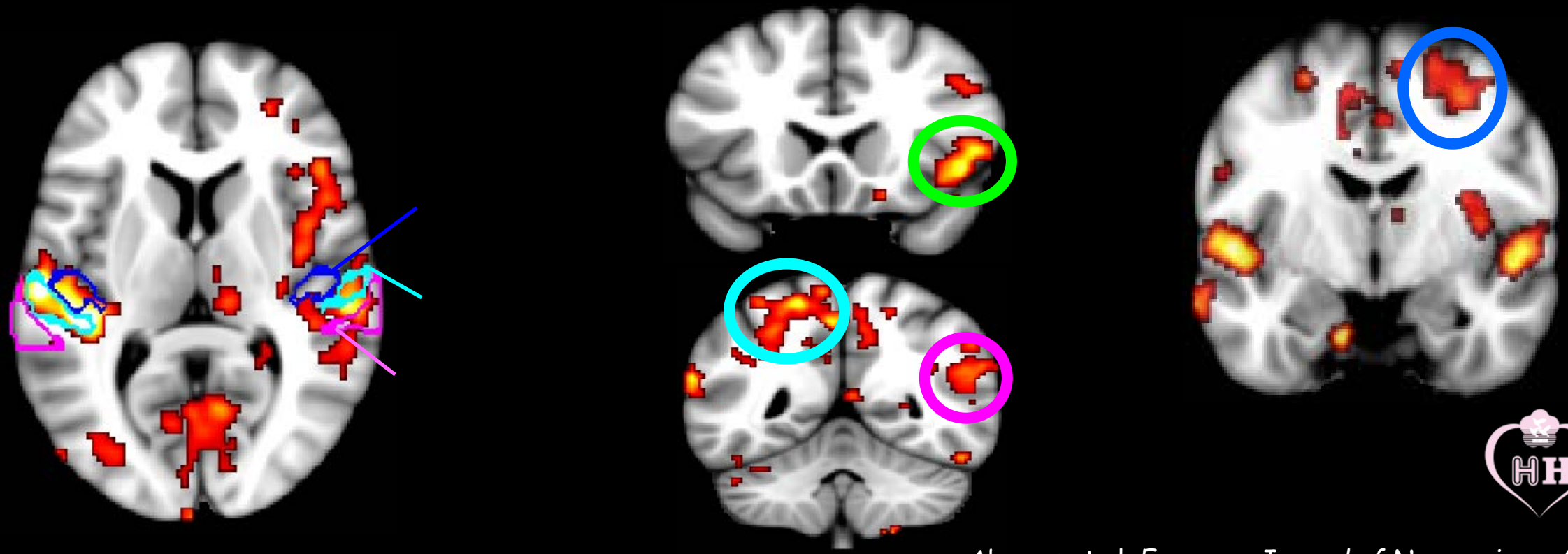
SOCIAL BONDING

Inter-personal brain synchrony during a musical experience

Auditory Cortex

Fronto-parietal

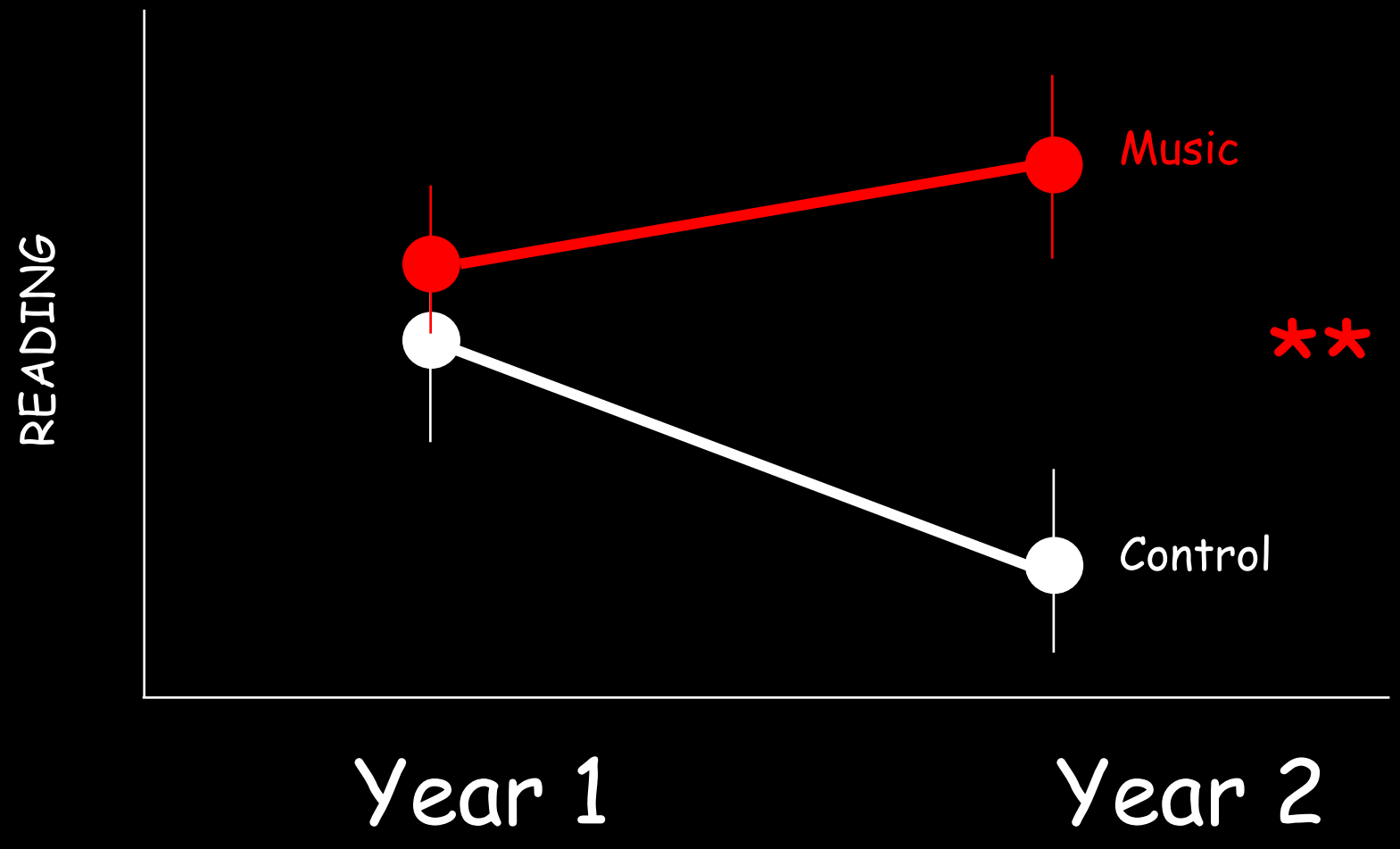
Motor Cortex



Abrams et al. *European Journal of Neuroscience* (2013)

MUSIC EDUCATION

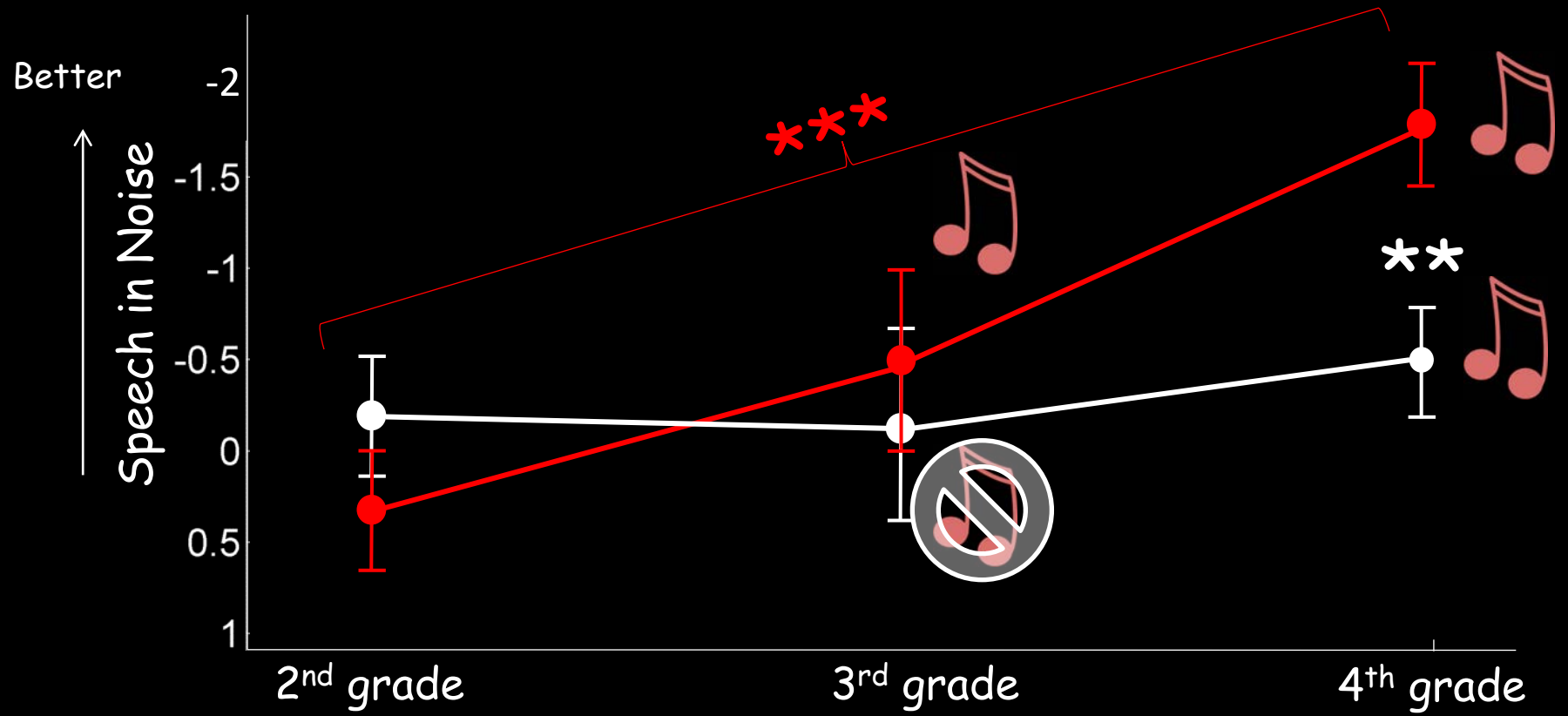
Reading



Achievement Gap

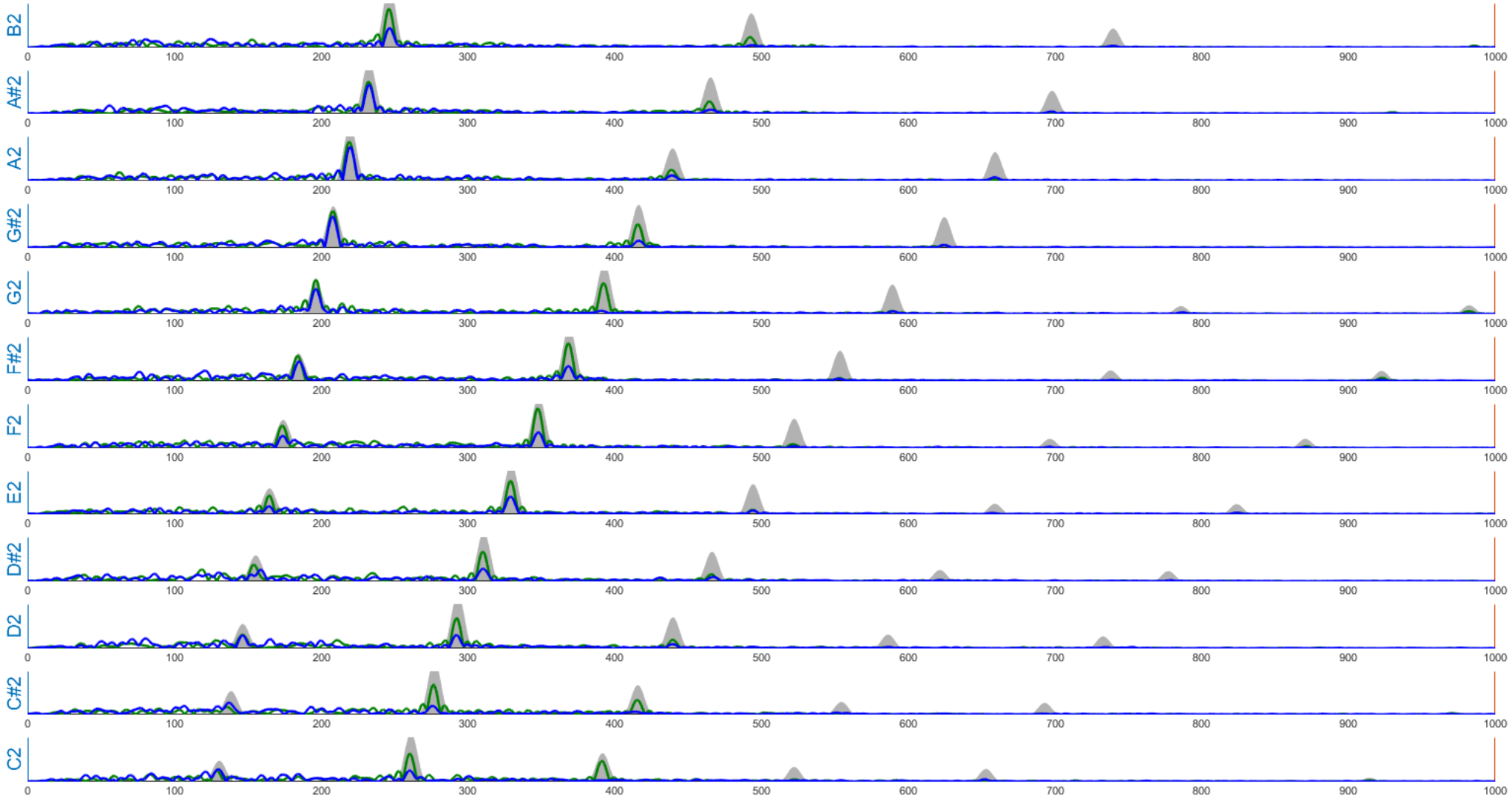
Slater et al., *Plos 1*, 2014

Hearing in Noise



Slater…Kraus, *Beh Brn Res*, 2015

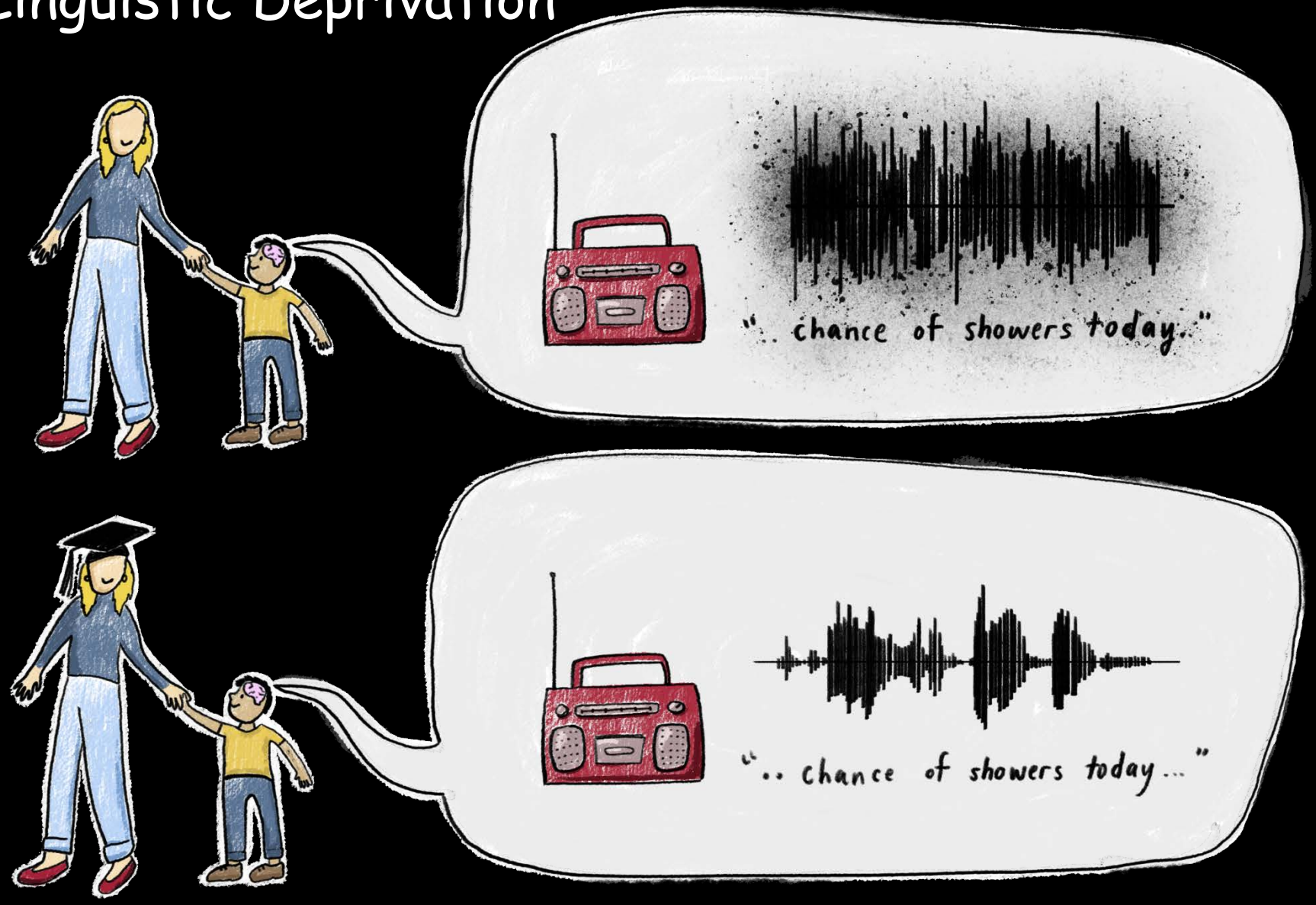
Nonmusician



Musician

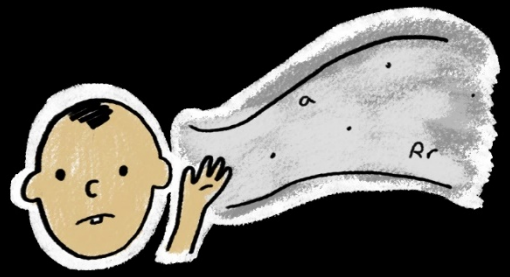
SOUND-TO-MEANING CONNECTION

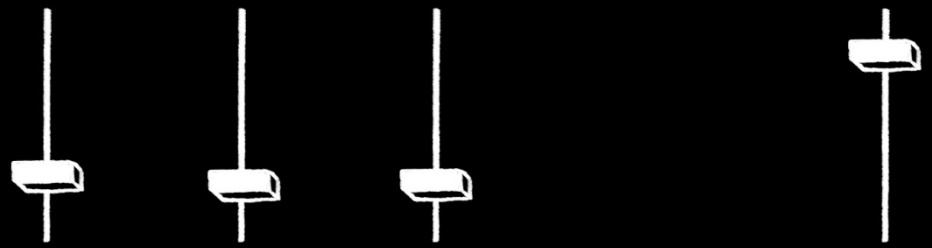
Poverty - Linguistic Deprivation

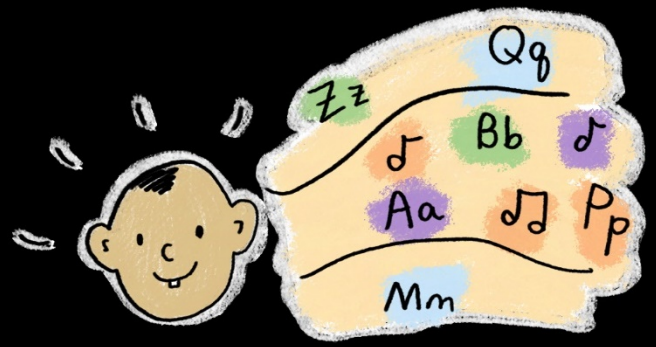


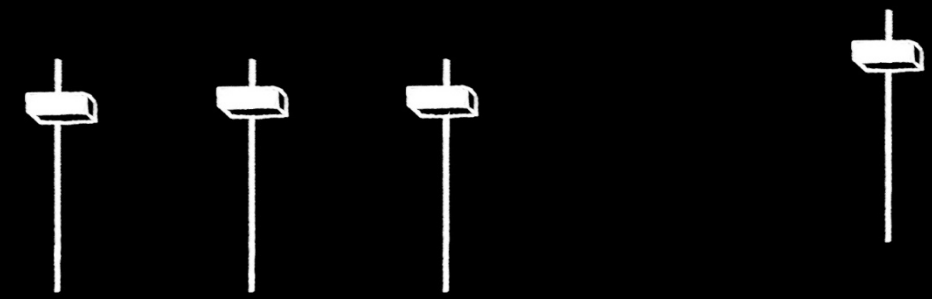
Skoe et al., *J Neurosci*, 2013

Poverty - Linguistic Deprivation









Harmonics Timing Stability Neural Noise

review: Kraus & White-Schwoch, *Neuroscientist*, 2016

Krizman et al. *Dev Sci*, 2016

It Takes Time to Shape the Brain

in-and after-school

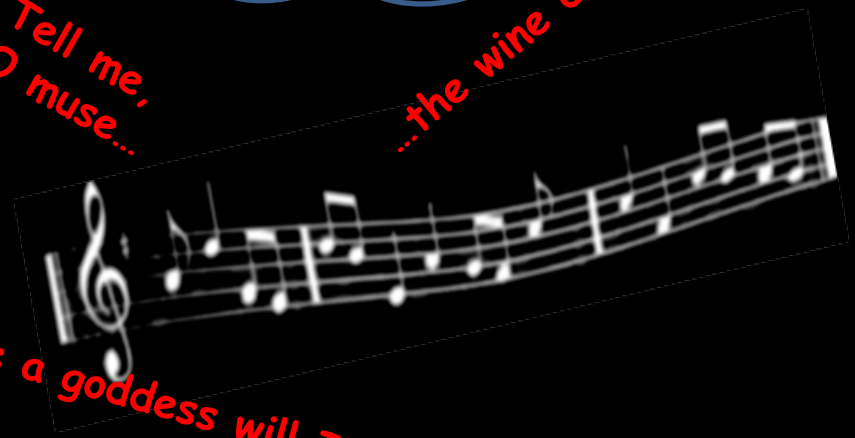
lifelong impact

Music and Memory

Bards..

Tell me, O muse...

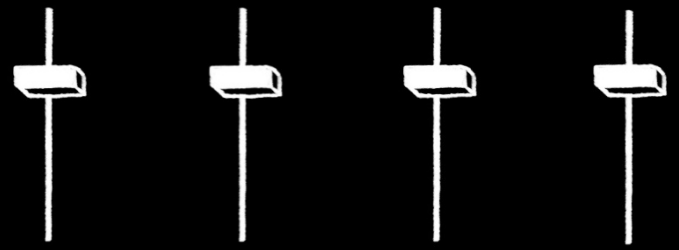
...the wine dark sea...

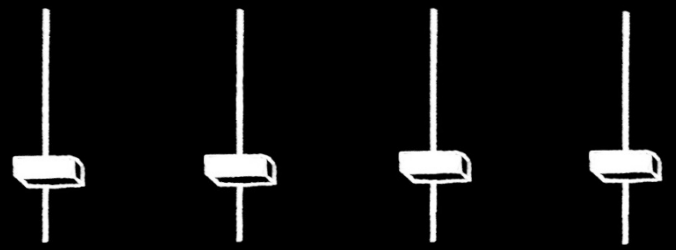


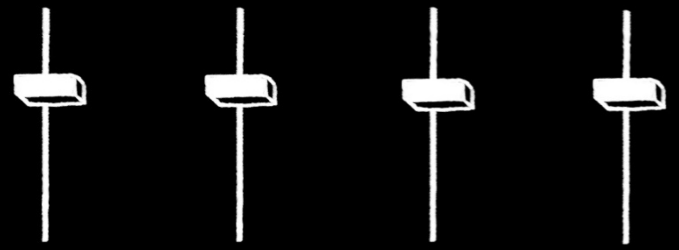
... as a goddess will I pray to thee...

AGING

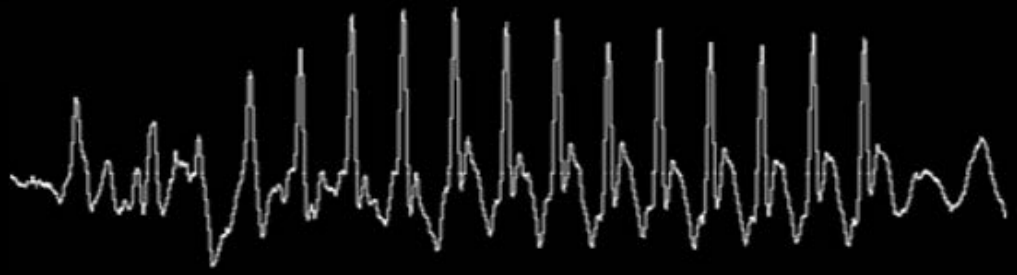
Music and the Sound Mind

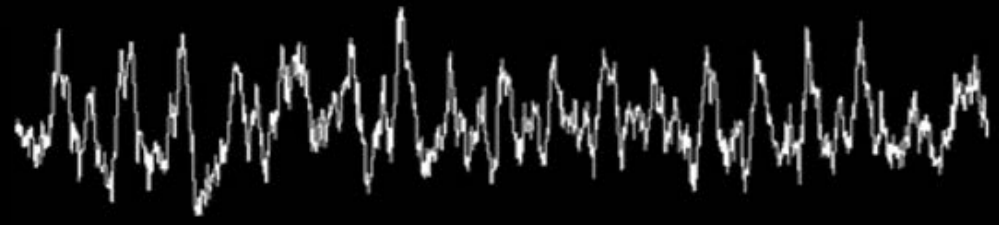


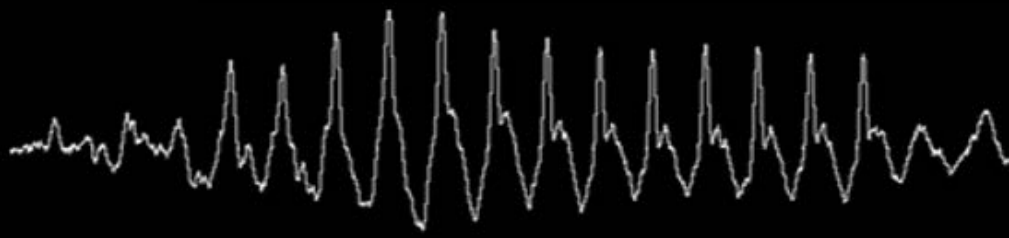




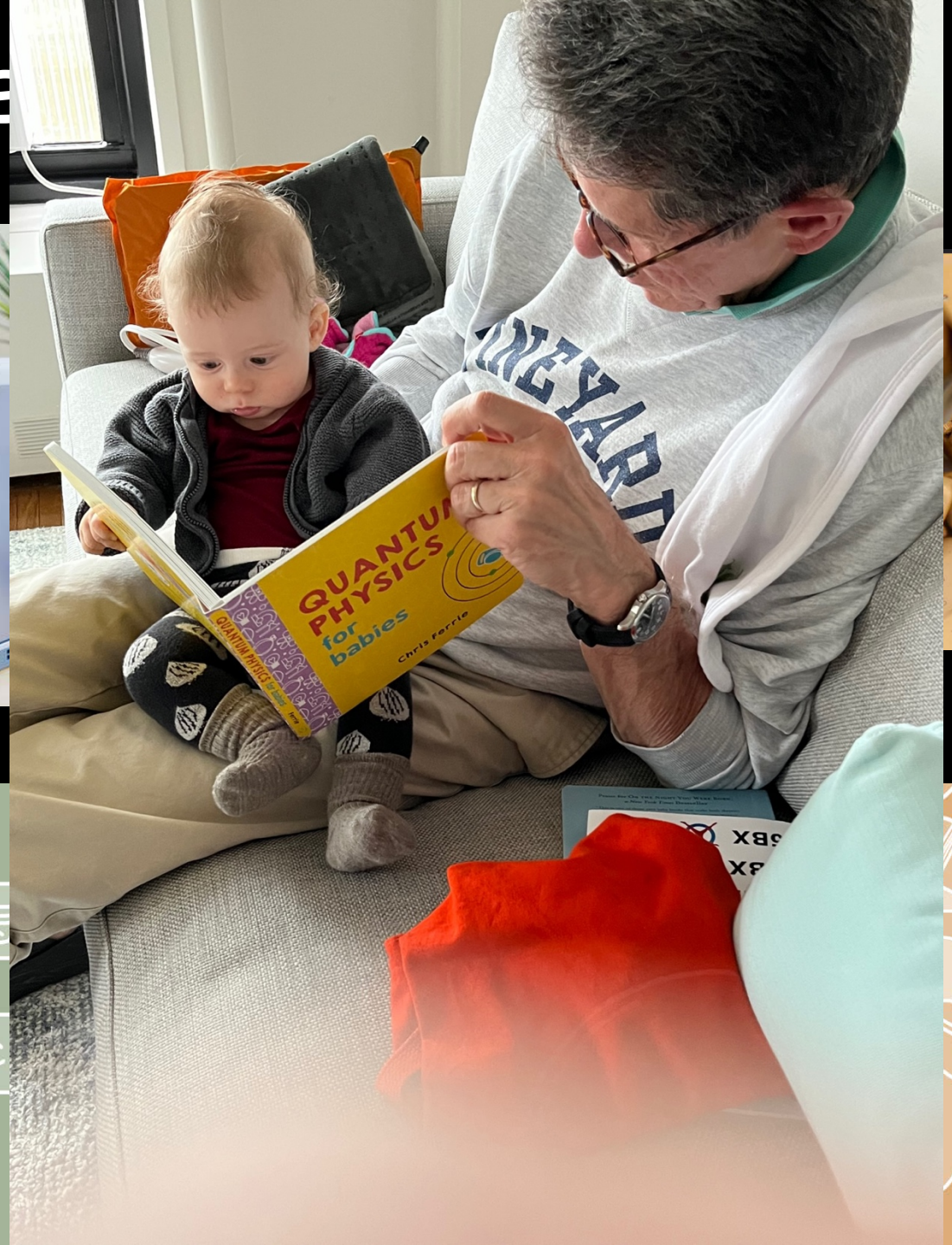
Harmonics Consistency FM Sweeps Timing





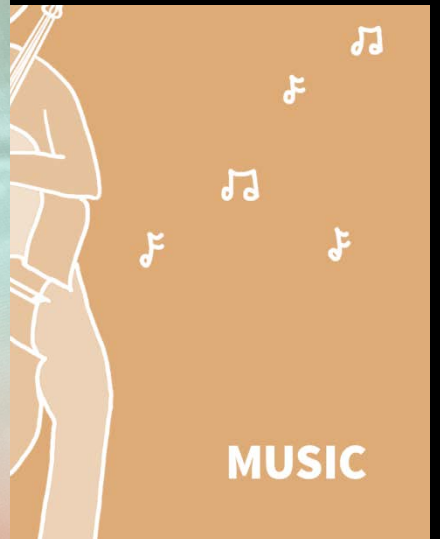


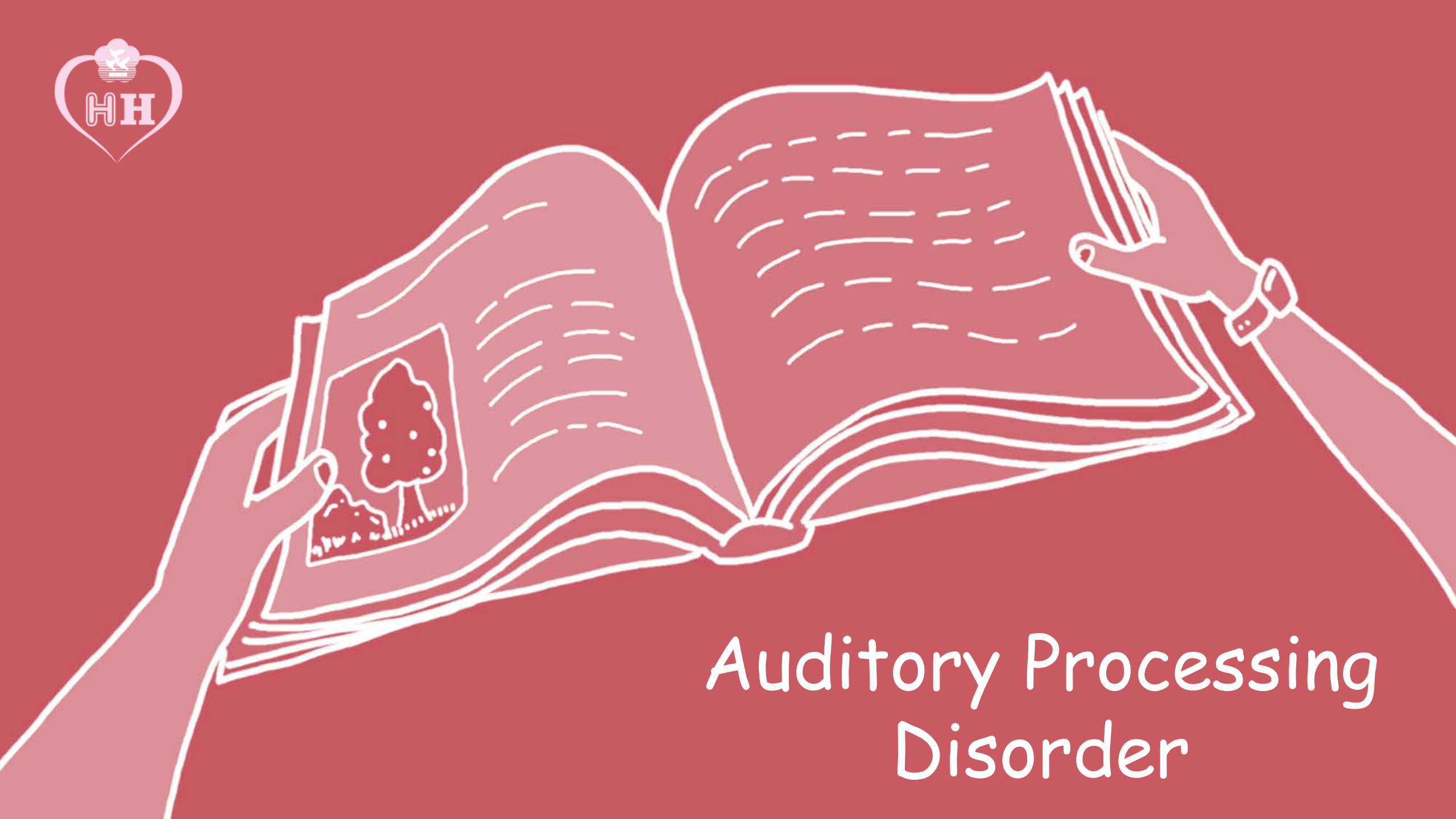
STRENGTHE


QUANTUM
PHYSICS
for
babies
Chris Ferrie


STARKEY
HEARING
FOUNDATION


你 怎
Bien, grac

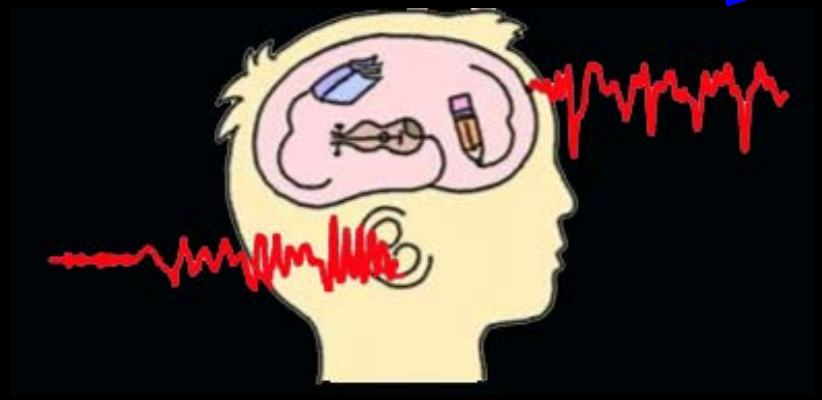

MUSIC



Auditory Processing Disorder

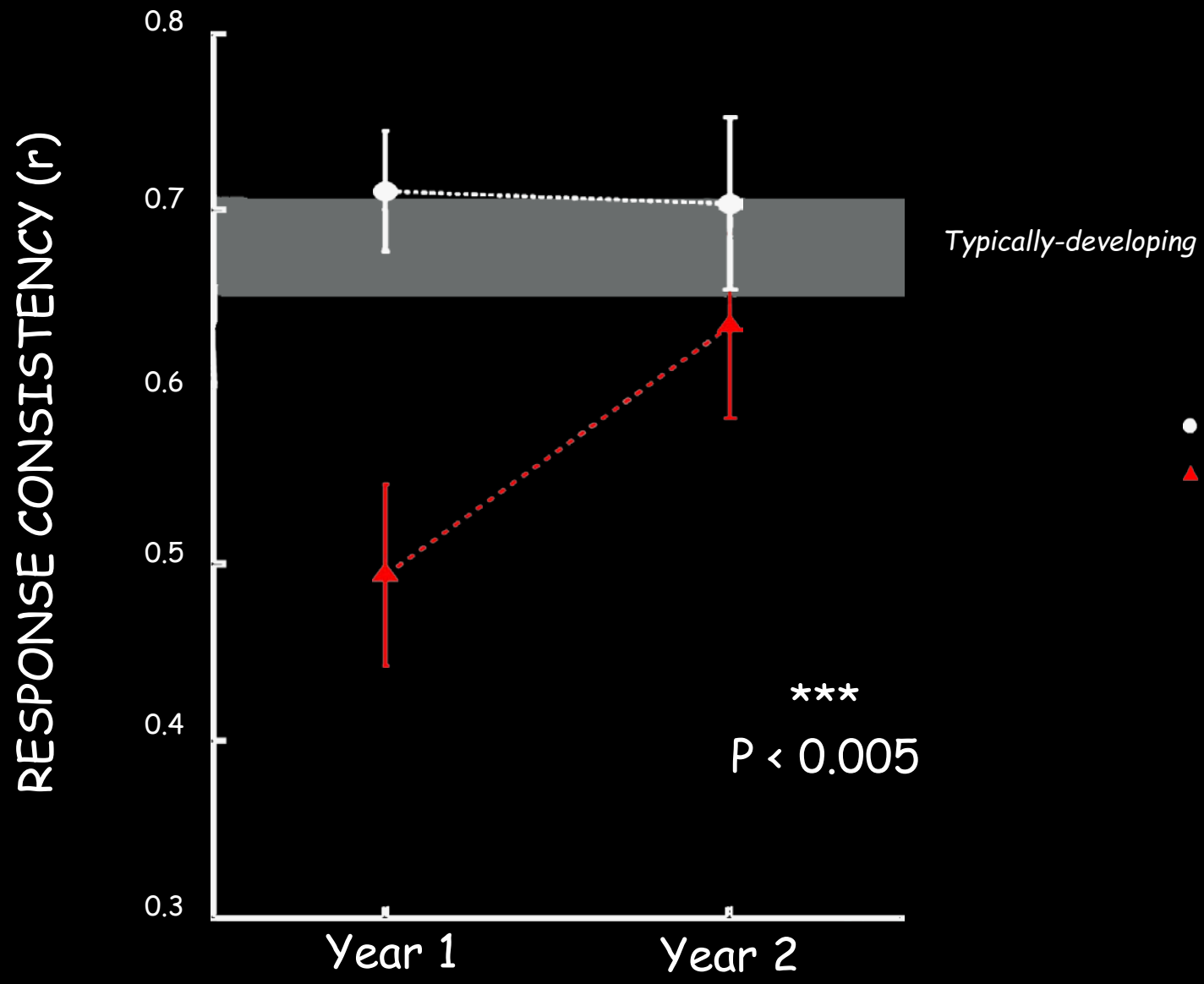
classroom FM listening device

.... 'hearing aid'



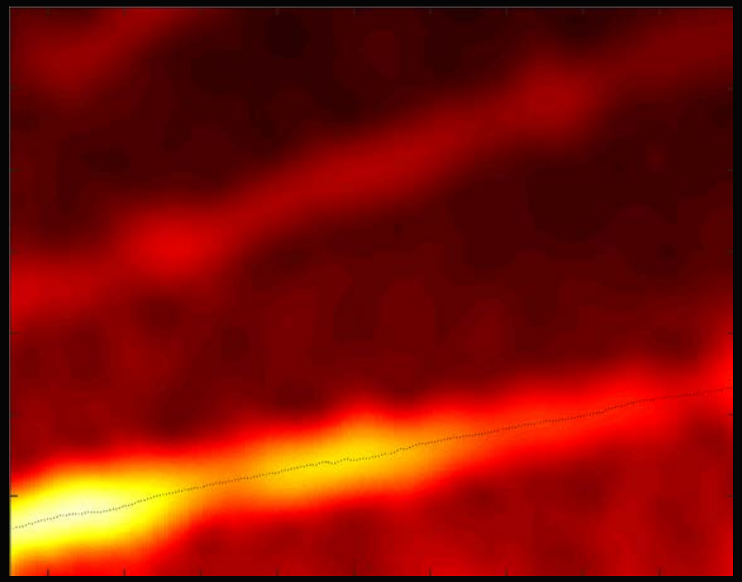
School year

classroom FM listening device

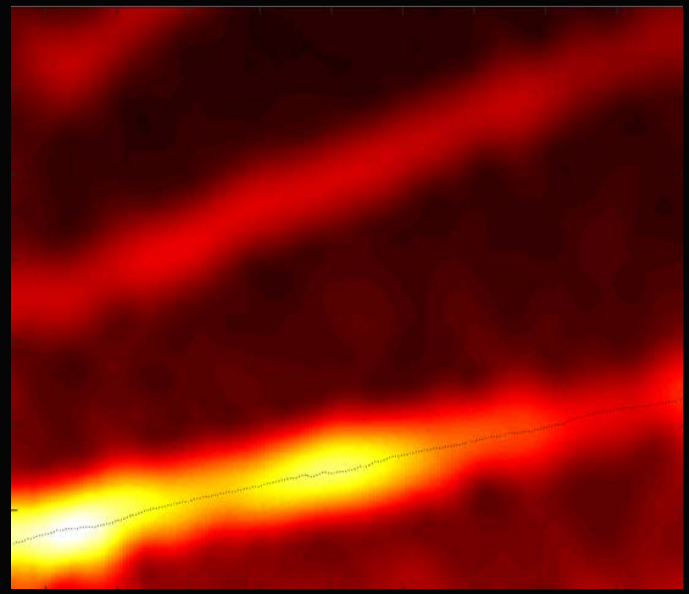


Autism – Pitch tracking

ASD



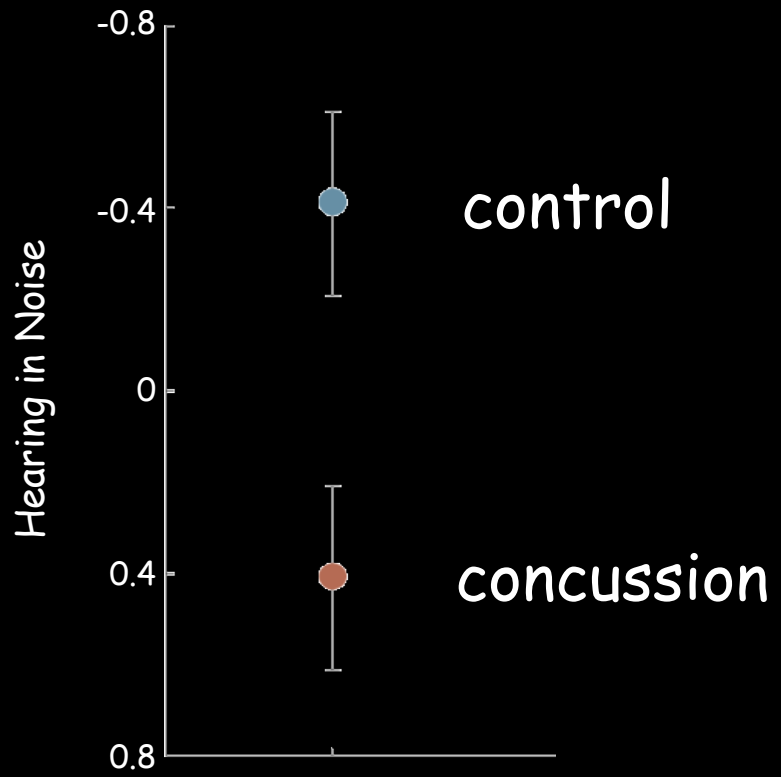
Control



Concussion Disrupts the Hearing Brain

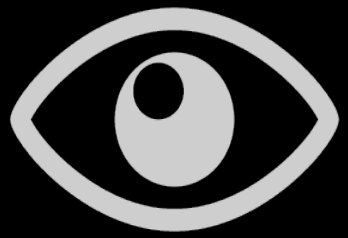
Concussion Disrupts the Hearing Brain

HEARING IN NOISE



Thompson, Kraus, LaBella et al. *Brain Injury*, 2018

Auditory System Makes Unique Contribution



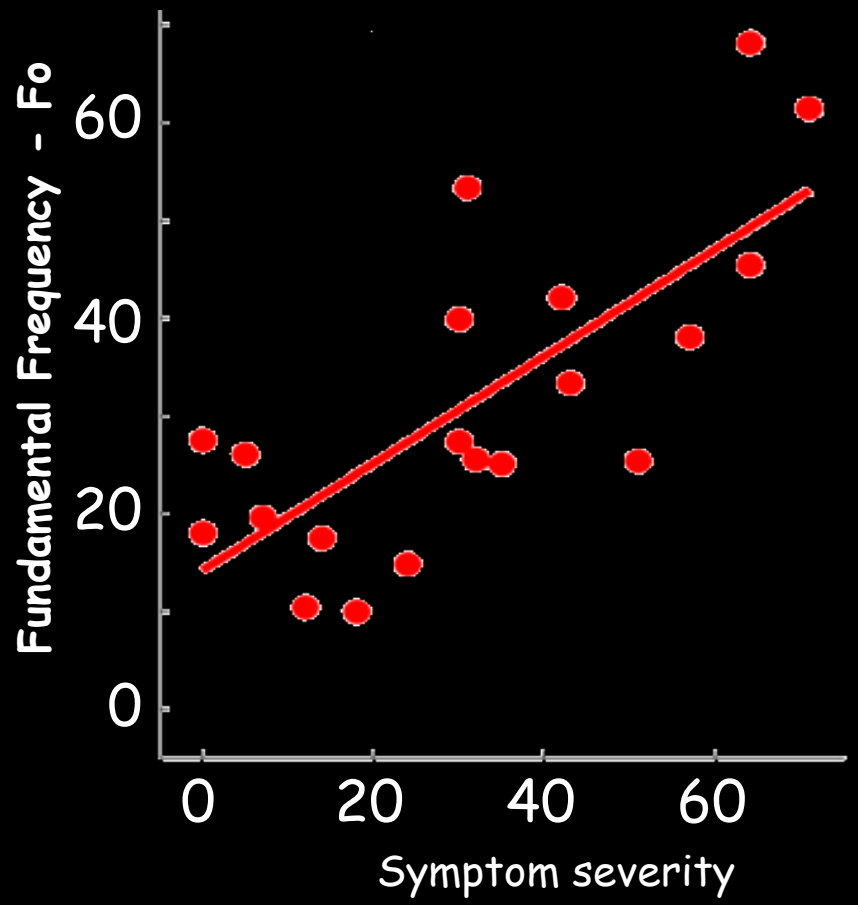
Vision
King Devick

Auditory
FFR

Vestibular
BESS

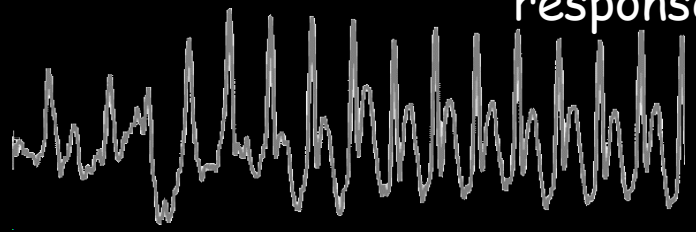
LaBella, Kraus, et al. (2018) *AMSSM Abs*

FFR tracks with symptom severity

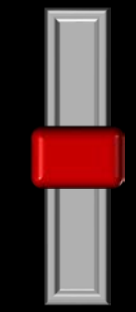


Kraus....LaBella *Nature*, Sci Rep, 2016

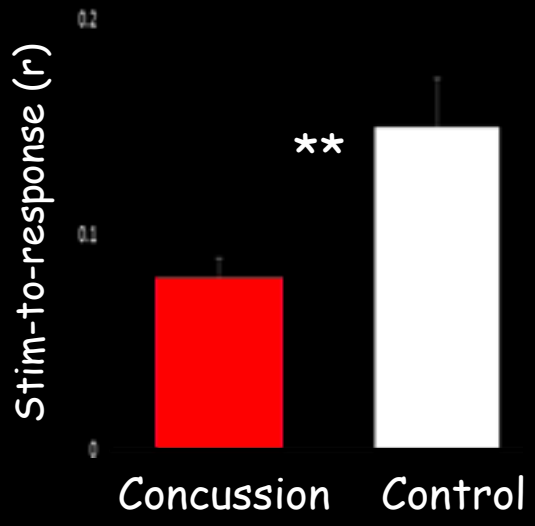
FFR is Slower, Smaller, and Less Accurate in Children with a Concussion



0 50 100 150 ms

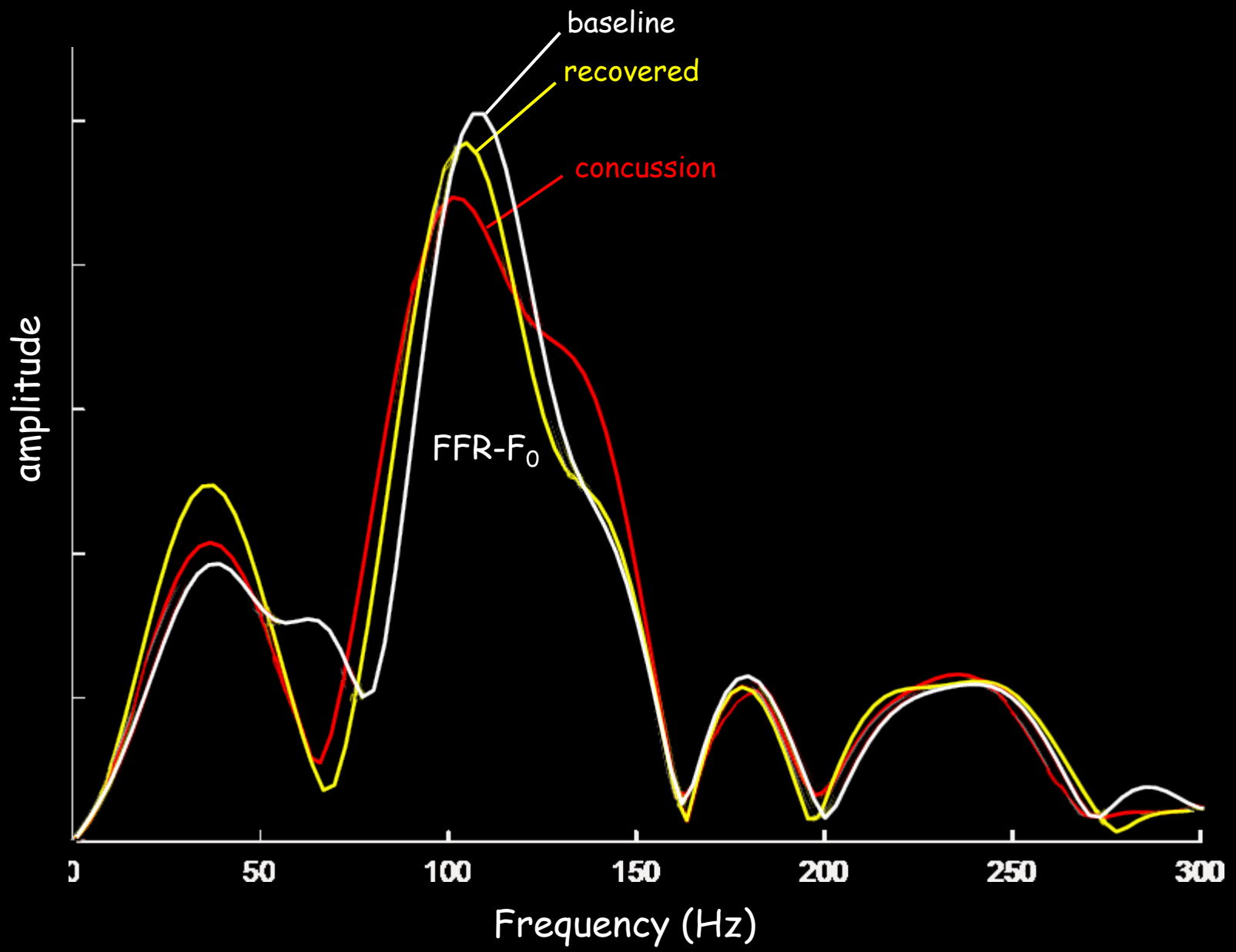


Timing

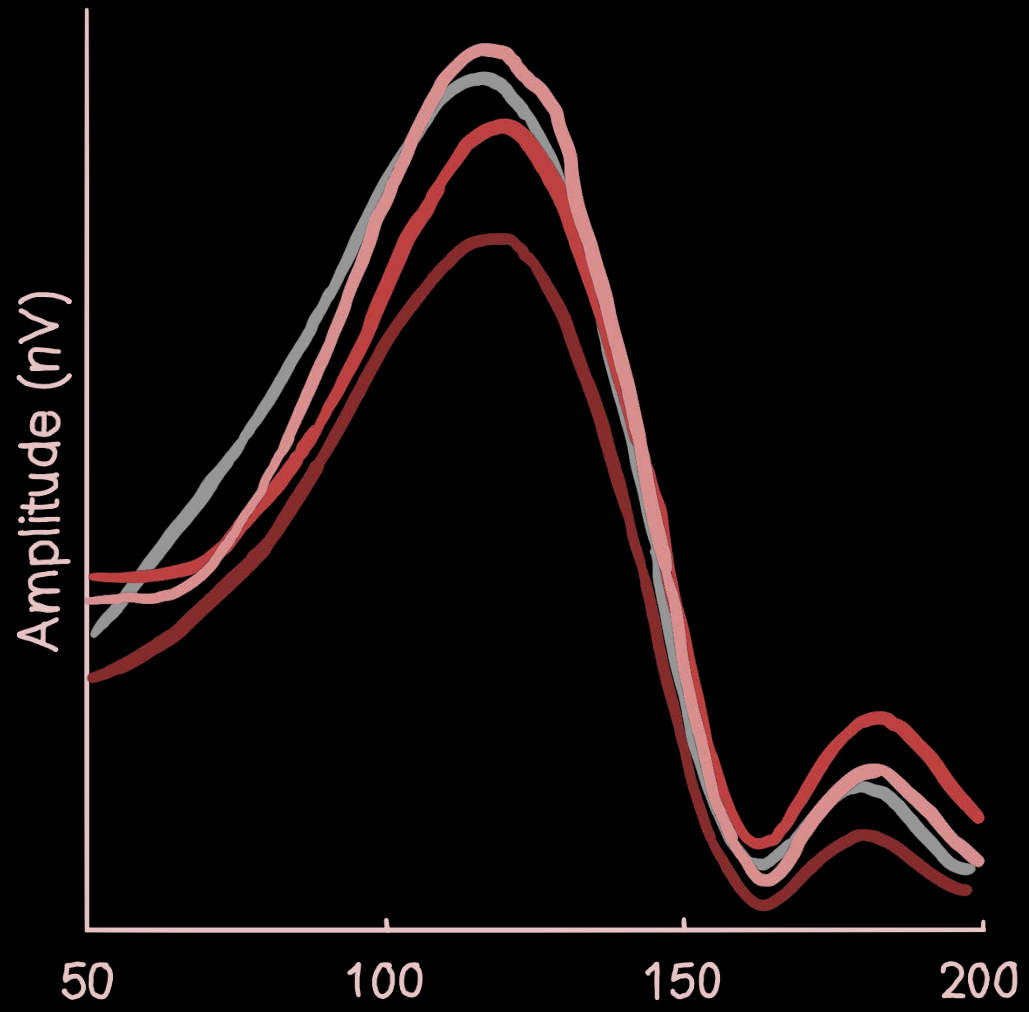


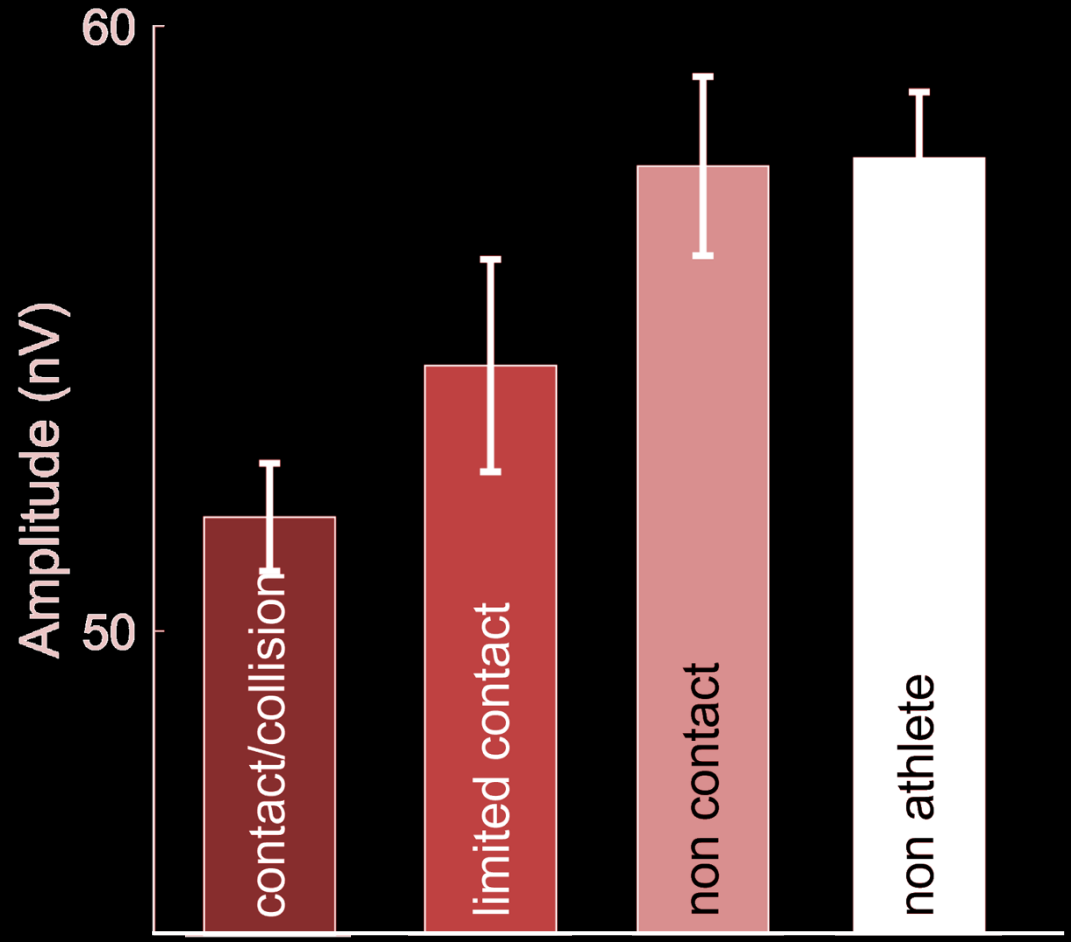
Kraus....LaBella *Nature*, Sci Rep, 2016

Tracking Recovery



Subconcussion and the Sound Mind





Concussion Disrupts the Hearing Brain

Hearing in Noise
Sound Processing in the Brain
    slower, smaller, and less accurate
    tracks with symptom severity

Track Concussion Recovery
Return-to-Play Decisions

Subconcussion

Can Rhythm Help Concussion Recovery?

- Concussed children perform poorly on rhythm tasks

- Performance on IM relates with FFR metrics of voice pitch (Fo), timing, and consistency

Play Sports for a Quieter Brain

THE NEW YORK TIMES, TUESDAY, DECEMBER 24, 2019

Well

PHYS ED | GRETCHEN REYNOLDS

The Quiet Focus of the Athlete

The brains of fit, young players block extraneous noise and attend to important sounds.

TOP ATHLETES' BRAINS are not as noisy as yours and mine, according to a fascinating new study of elite competitors and how they process sound. The study finds that the brains of fit, young athletes dial down extraneous noise and attend to important sounds better than those of other young people, suggesting that playing sports may change brains in ways that alter how well people sense and respond to the world around them.

For most of us with normal hearing, of course, listening to and processing sounds are such automatic mental activities that we take them for granted.

But "making sense of sound is actually one of the most complex jobs we ask of our brains," said Nina Kraus, a professor and director of the Auditory Neuroscience Laboratory at Northwestern University, who oversaw the new study.

Sound processing also can be a reflection of broader brain health, she said, since it involves so many interconnected areas of the brain that must coordinate to decide whether any given sound is familiar, what it means, if the body should respond and how a particular sound fits into the broader orchestration of other noises that constantly bombard us.

For some time, Dr. Kraus and her collaborators have been studying whether some people's brains perform this intricate task more effectively than others. By attaching electrodes to people's scalps and then playing a simple sound, usually the spoken syllable "da," at irregular intervals, they have measured and graphed electrical brain wave activity in people's sound-processing centers.

And they have found interesting variations in proficiency. The brains of trained musicians, for instance, tend to show greater spikes in processing activity when they hear the "da" than do the brains of other people, indicating that learning and practicing musicianship also hones and refines the portions of the brain that process sound.

More recently, Dr. Kraus and her collaborators began to explore whether the reverse might also be true and that some experiences might blunt sound processing. In par-

abilities of 495 Division 1 male and female athletes at the school, as well as another 500 students who weren't athletes.

The athletes played sports ranging from football to track, some involving tackling and similar contact and others little contact but considerable exertion. Dr. Kraus and her colleagues began testing them at the start and end of their competitive seasons and after any suspected concussions, with a plan to compare the readouts after heavy training and injuries and look for patterns.

That study is continuing, but Dr. Kraus realized in the meantime that she possessed a wealth of baseline data about the brains and sound-processing abilities of fit, young athletes and other students. She could crosscheck their brain wave readouts, she thought, and see if the athletes, when healthy, processed sounds differently than the other students.

So, for the new study, which was published this month in Sports Health, she did just that. And she found that the athletes did hear and make sense of sounds differently than most of us.

According to their electrical readouts, almost all of them attended to specific, specified sounds better than the other students.

"Basically, their brains were quieter," Dr. Kraus said.

Some of the athletes' acoustic agility most likely developed during years of attending to crucial sounds despite clatter, Dr. Kraus said. "You have to be able to hear the coach yelling something or what a teammate is saying," she said. "Brains change in response to that kind of repeated experience," and the sound-processing components within the brain strengthen.

But many of the athletes played sports that, typically, are not noisy, she points out. Cross-country running and golf, for instance, most likely demand less sound filtering during most practices and competitions than a sport like football or basketball. But the university's runners and golfers had brains just as quiet as those of linemen.

For them, "fitness and regular movement of the body also change the brain," Dr. Kraus said. And sports that seem quiet can still demand a focus on subtle sounds and signals like the whoosh of a breeze through branches alerting golfers and runners to wind speed or a creak in a joint that could warn of early injury.

Over all, the results suggest that being active, whether as part of a team or on yo

Typical

Athlete

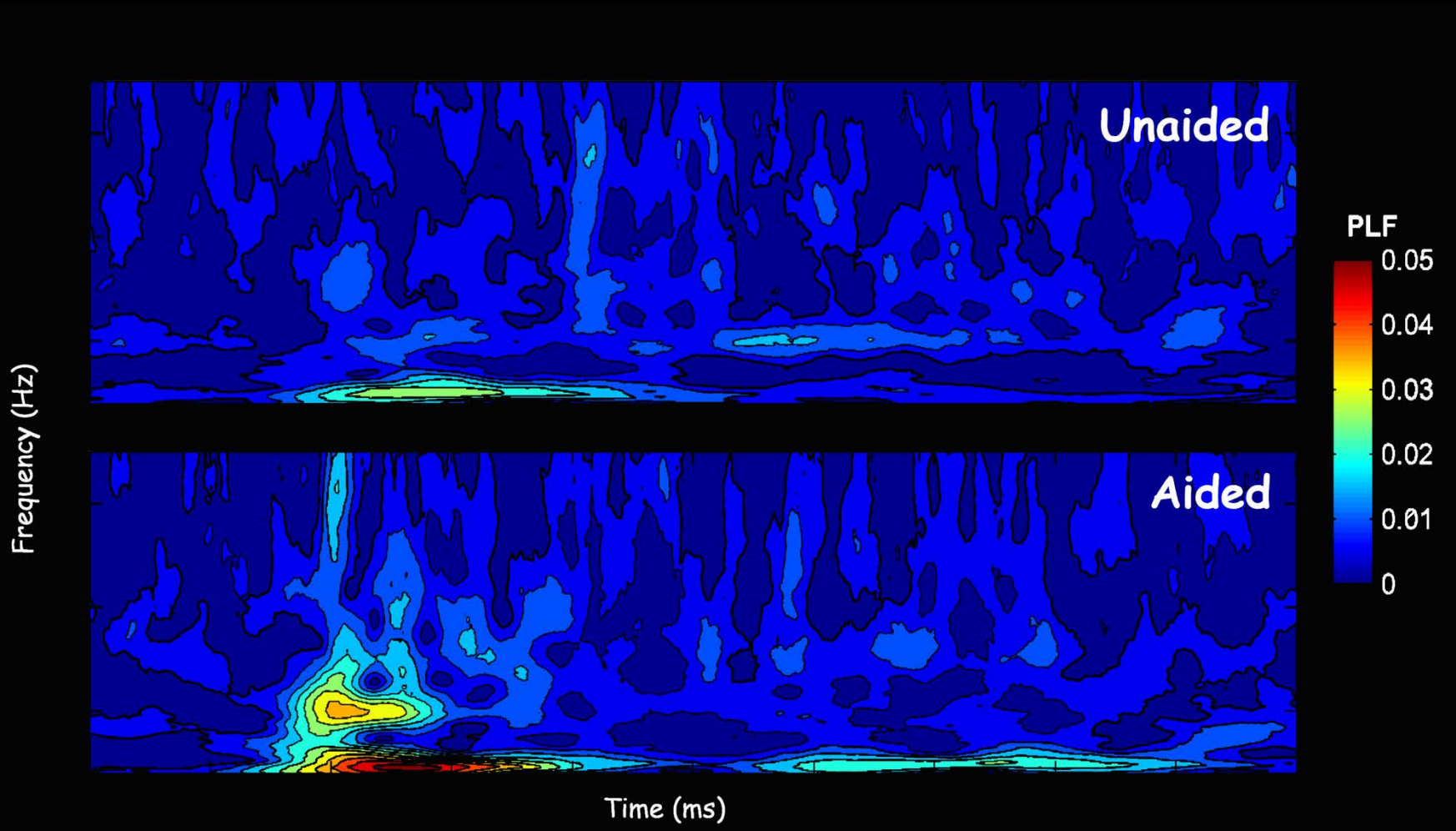
Musician
Bilingual

Krizman et al. *Sports Health*. (2019)

Hearing Loss and the Sound Mind

.....Spotlight on Music

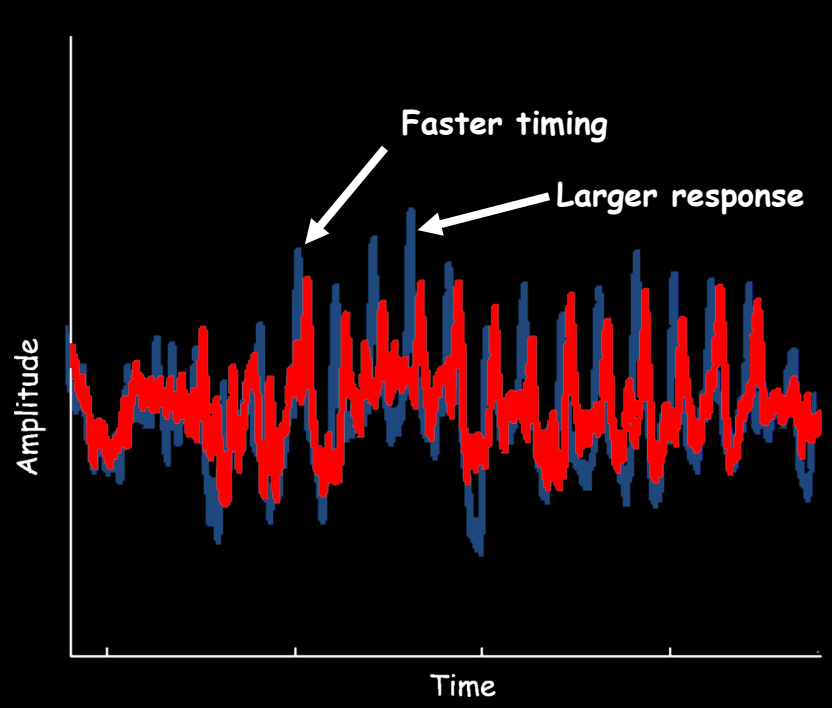
Hearing aids and the Sound Mind

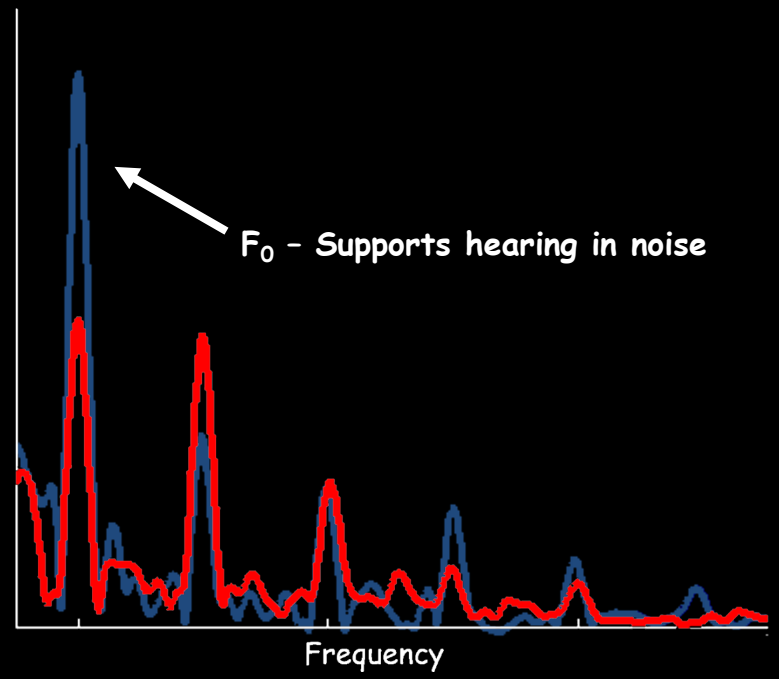


Amplification boosts neural synchrony

Anderson et al. Ear Hear 2019

Hearing aids and the Sound Mind





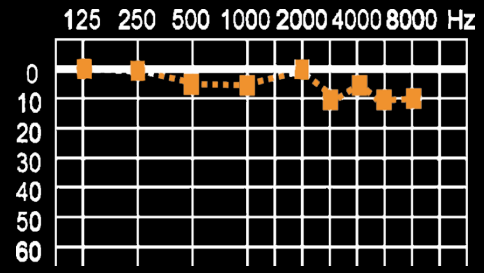
Hearing Aid Setting #1
"These aren't working anymore..."

Hearing Aid Setting #2
"I can't remember the last time
I heard so well in a restaurant!!"

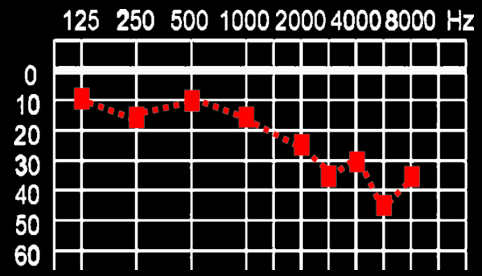
Anderson & Kraus 2013 *Int J Otolaryngol*

Hearing Loss and the Sound Mind

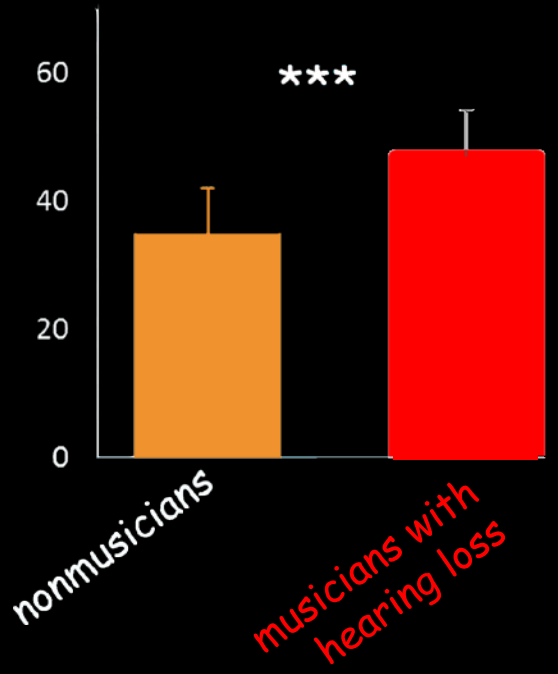
nonmusician



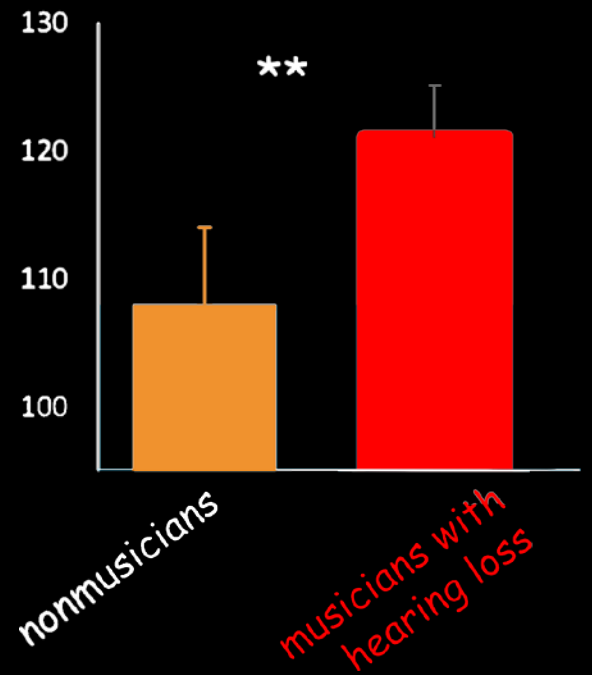
musician



speech in noise



auditory working memory



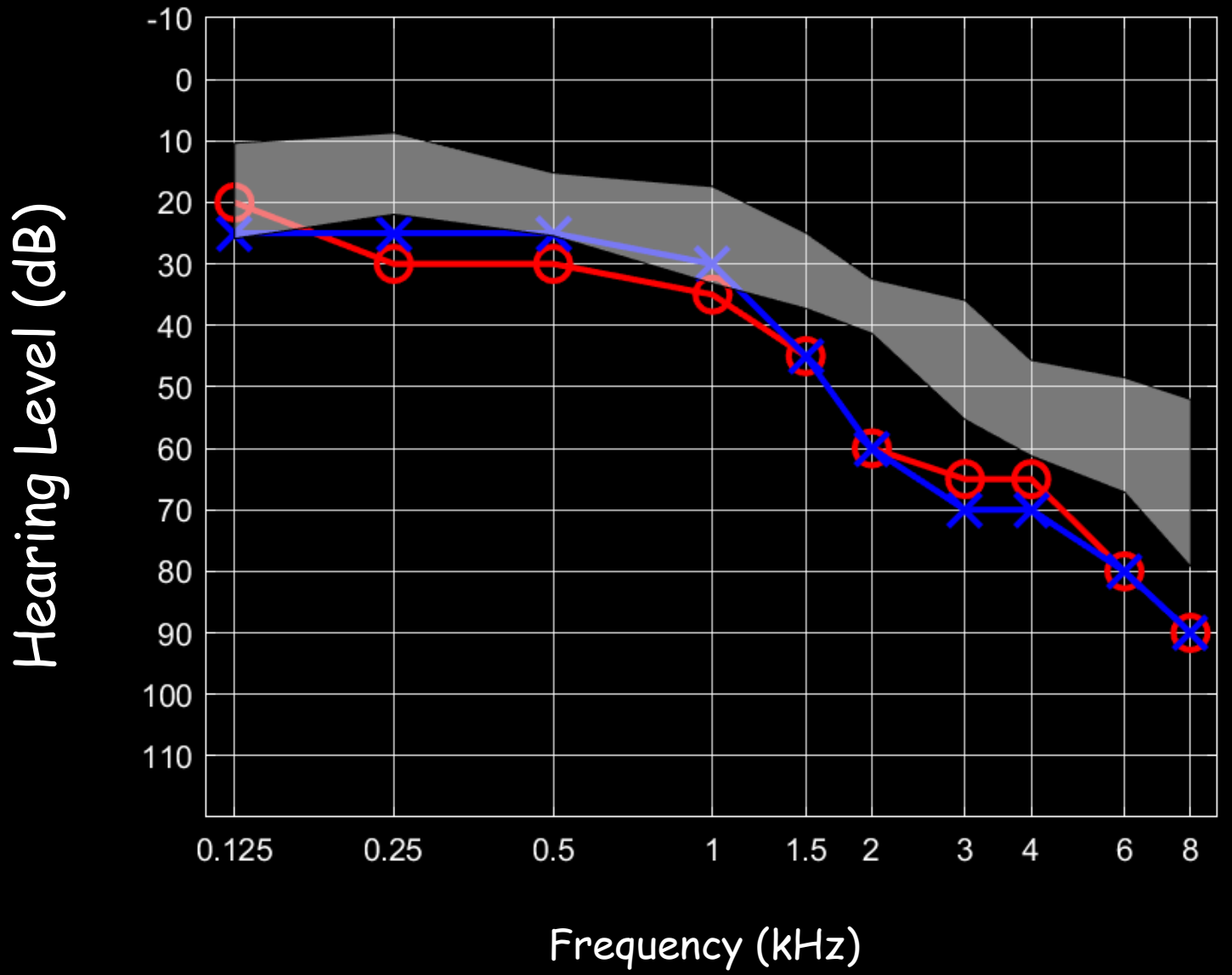
MUSIC more than meets the ear

84 y Musician

hearing loss since his 20's

Bobby Lewis

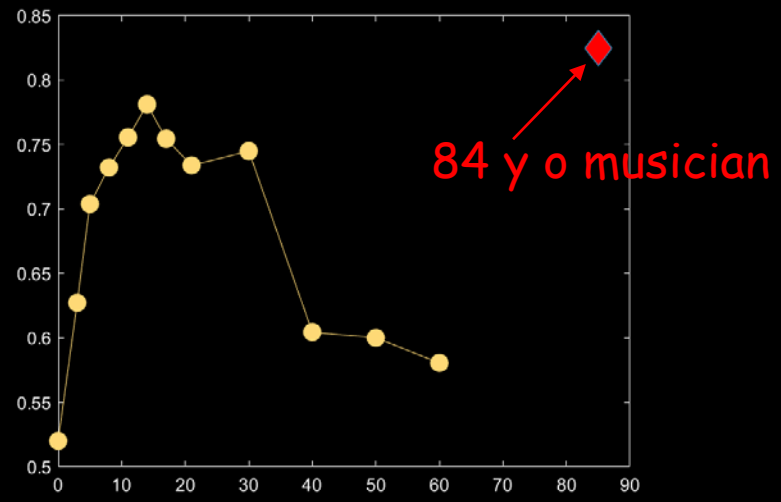
Hearing Loss and the Sound Mind



Bobby Lewis

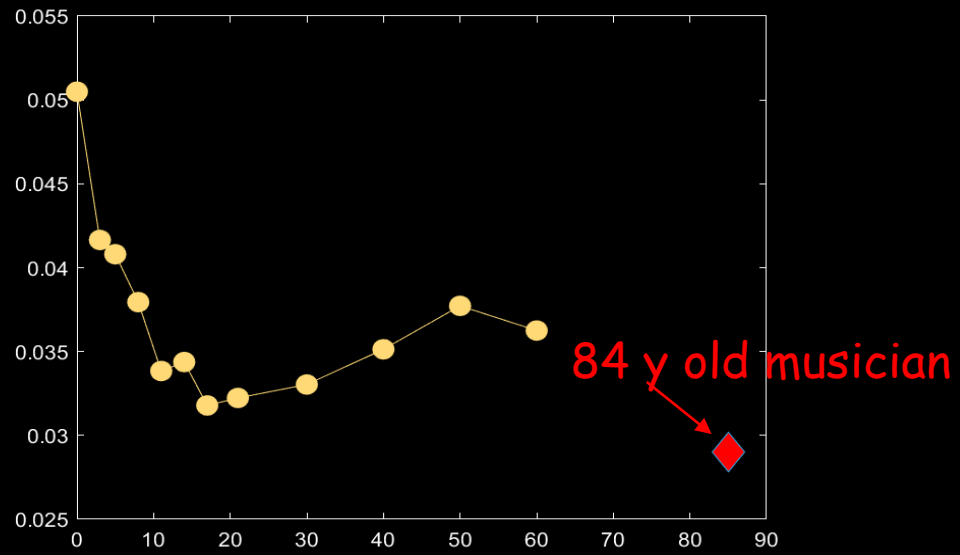
Hearing Loss and the Sound Mind

Neural Consistency



Age

Neural Noise



Age

— lifespan norms

Skoe et al, 2015. Cereb Cortex

HEARING AIDS, COCHLER IMPLANTS

AND THE BRAIN KEYBOARD

brainwolts

We wondered how his brain responded to the sounds he heard via his implant.

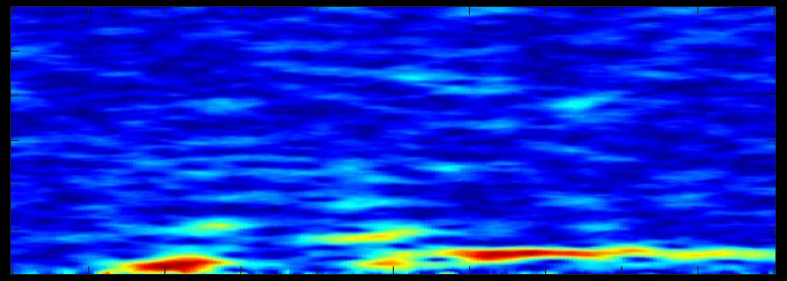
FFR testing at Brainvolts…
Six similar speech syllables (da, ba, du…)

Does his auditory brain differentiate the sounds like a person with normal hearing?

"MH"

Representative male 40-something response for reference

da-low



ba

da-falling

da-rising

phaselocking

da high

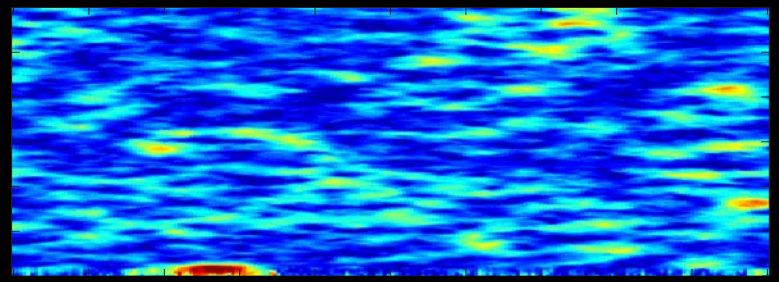
du

Frequency

Time

MH

da-low



ba

da-falling

da-rising

phaselocking

da high

du

Frequency

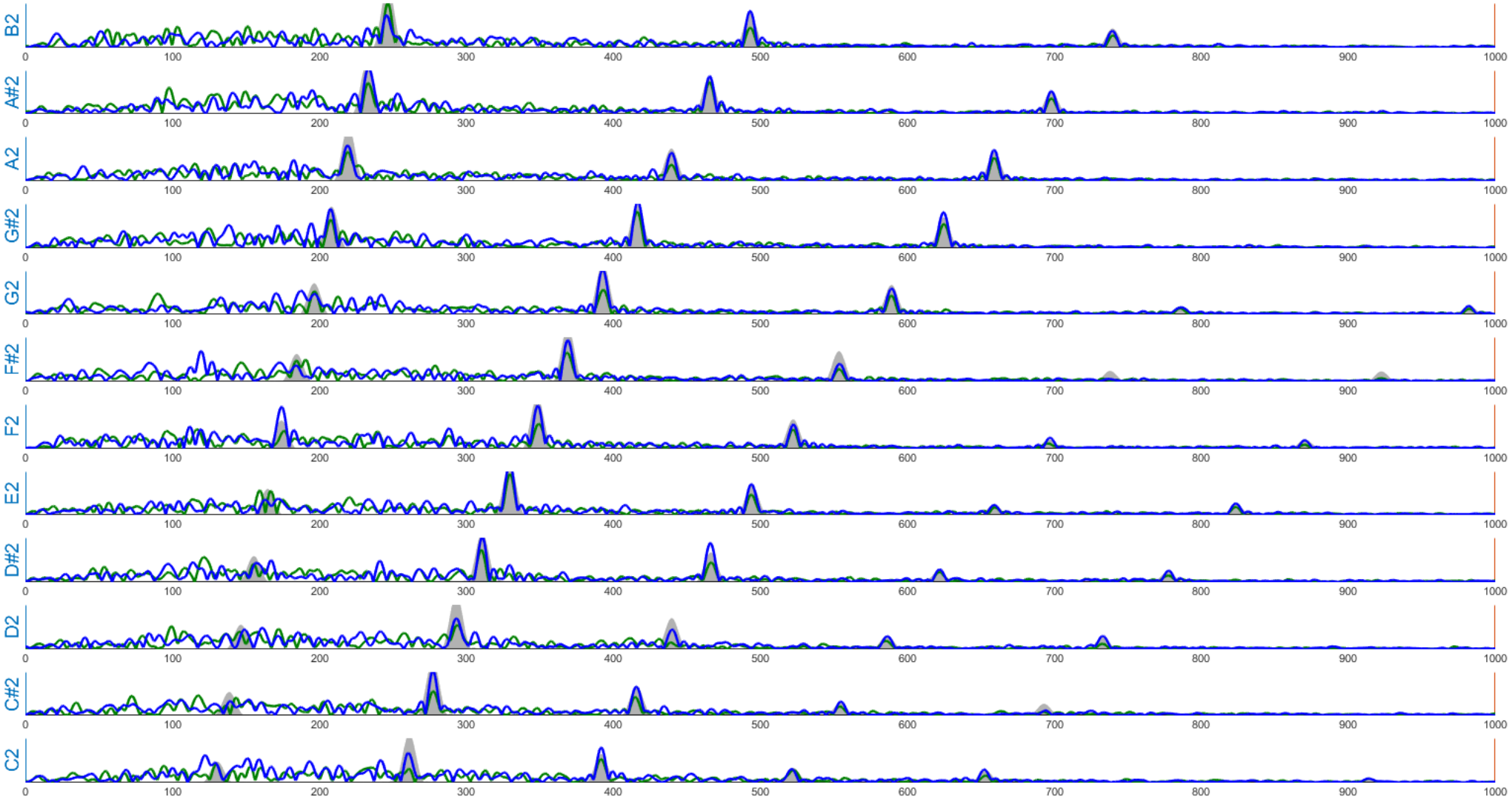
Time

Unaided

Hearing aid

Unaided

Hearing aid



Hearing Loss and the Sound Mind – Food for Thought

Hearing is a felt sense

Stimulation of fingertips enhances *auditory* perception

Auditory pathway responds to touch

Helen Keller learned to speak through touch

The deaf are super-touchers

Musicians control tone of their instrument with tactile feedback

Deaf can hear musical timbre, pitch, duration, loudness with vibrotactile stimulation alone

.. supplementary vibrotactile cues enhance talker-specific information, such as talker identify, gender, age

Hearing Loss and the Sound Mind – Food for Thought

vibration - cilia

Its no coincidence the nervous system is derived from the skin (ectoderm) the counterpart of a humans' cell membrane.

Sensory organs are only part of the picture. We sense with brain, body and mind.

Hearing Health

....our vision

Is sound getting in?

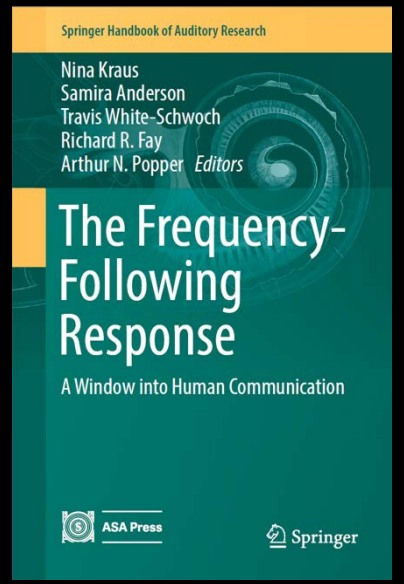
audiometry

How well does a listener use sound?

Speech in noise Quicksin, HINT

Auditory working memory

Attention



How well is sound processed by the brain?

PERSONAL TRAINER

audiologist
music therapist
MUSIC TEACHER

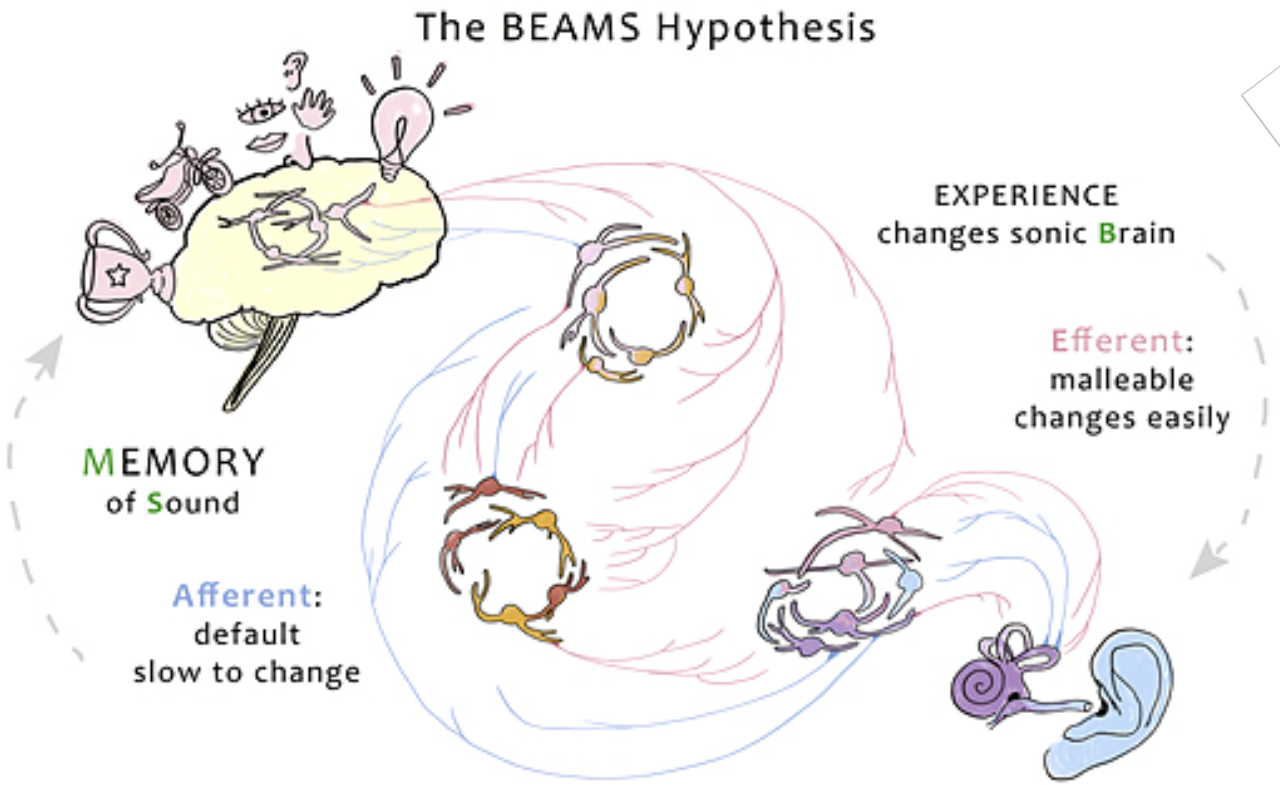
Neural Plasticity Over one's Life Time:

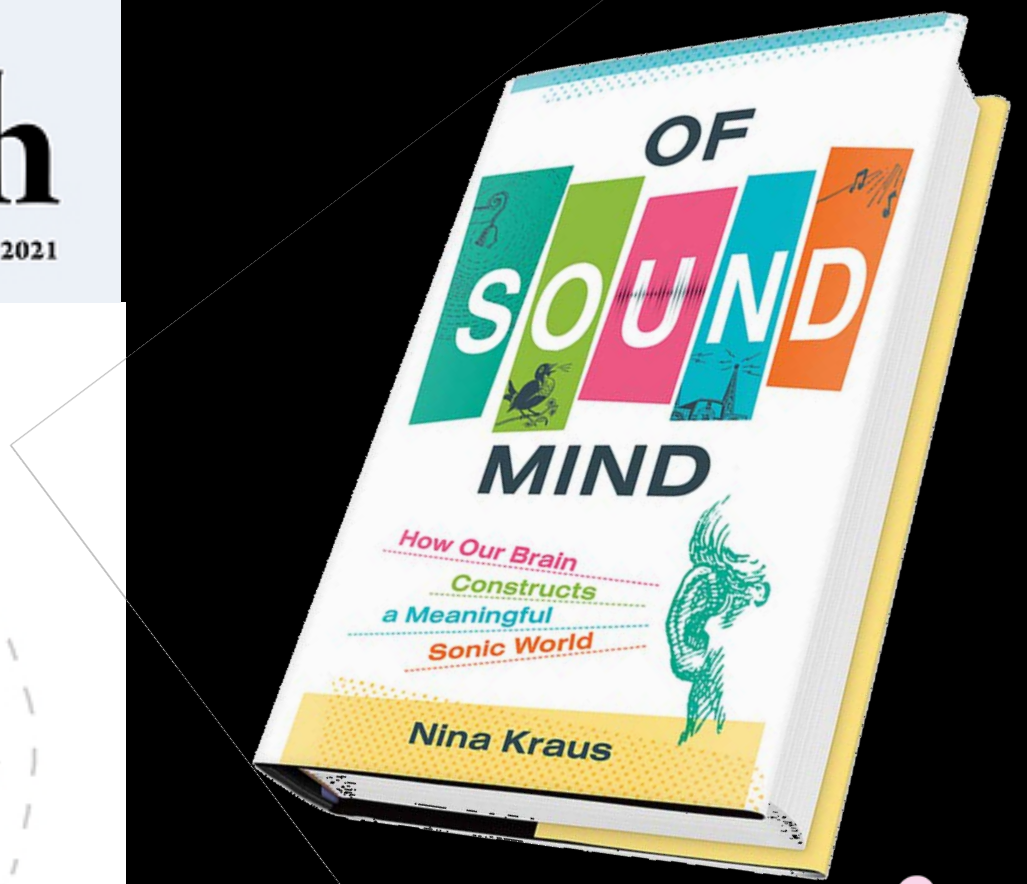
The BEAMS Hypothesis

ISSN 0378-5955

Hearing Research

Volume 407, August 2021

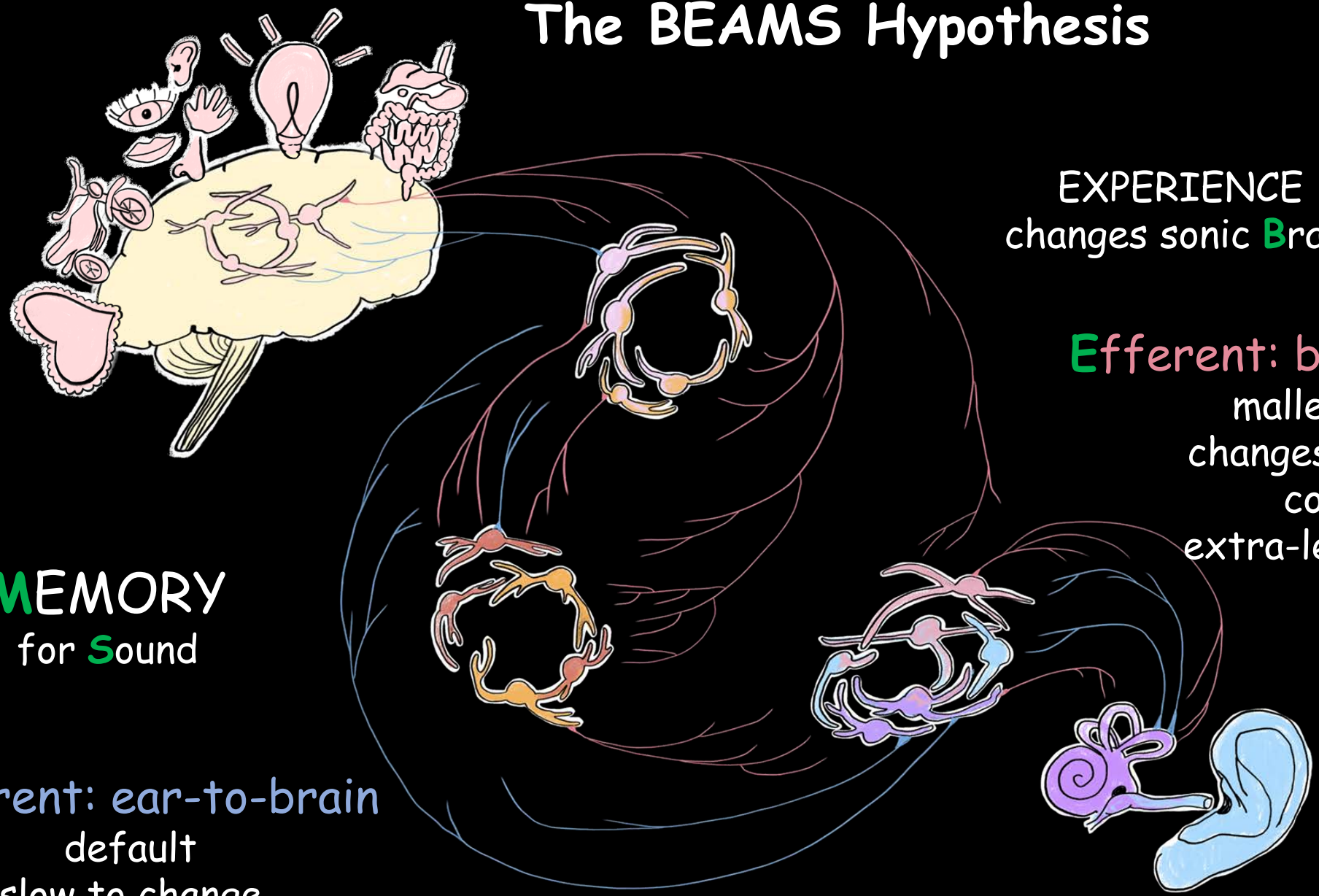




The BEAMS Hypothesis - Lite

Lloyd Dangle

The BEAMS Hypothesis



EXPERIENCE
changes sonic **B**rain

Efferent: brain-to-ear
malleable
changes easily
conscious
extra-lemniscal

MEMORY
for **S**ound

Afferent: ear-to-brain
default
slow to change
unconscious
lemniscal

Kraus *Hearing Research*, 2021

Brain - organ of prediction

...depends on memory

We integrate sensory information with hormonal states, inherited predispositions, cultural preferences, and our experiences.

do it again

re-focus neuroplasticity:
how we spend our time over the life span

STABILITY

Wisdom

- insight from African drumming

"SAFE" NOISE

anxiety/stress

ability to focus

SUMMING UP

Our life in sound shapes sound processing in the brain

Sound Connects Us

Ambassadors of the Sound Mind

CALL TO ACTION……

IT TAKES A COMMUNITY

FREQUENCY FOLLOWING RESPONSE WORKSHOP 2024 CHICAGO

June 12-14
2024

The Wirtz Center Chicago

We hope you will join us for the

FFR Workshop 2024

held in downtown Chicago. The two days of presentations, discussions, and posters will culminate with an architectural boat tour along the historic Chicago River.

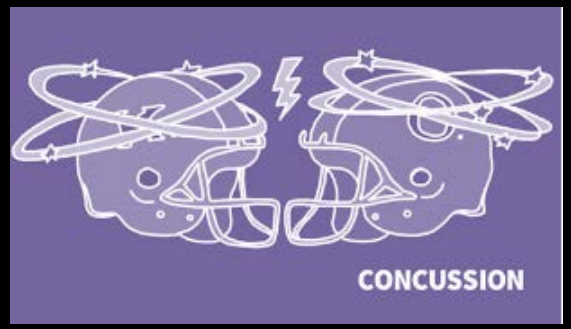
For more information including **abstract submission** and **registration**, please visit

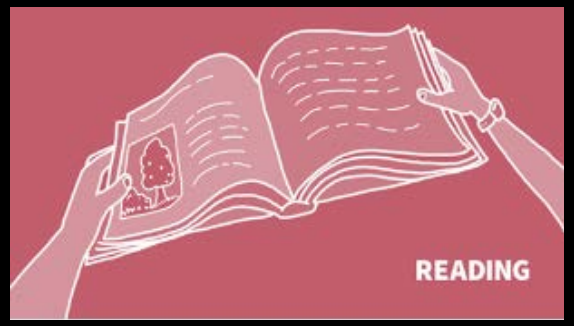
https://ffrworkshop.northwestern.edu/

brainvolts

www.**brainvolts.northwestern.edu**

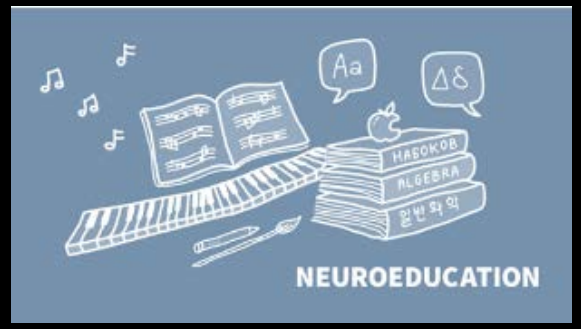
nkraus@northwestern.edu





NIH
National Institutes of Health

NAMM Foundation



NOCSAE

NORTHWESTERN UNIVERSITY 1851