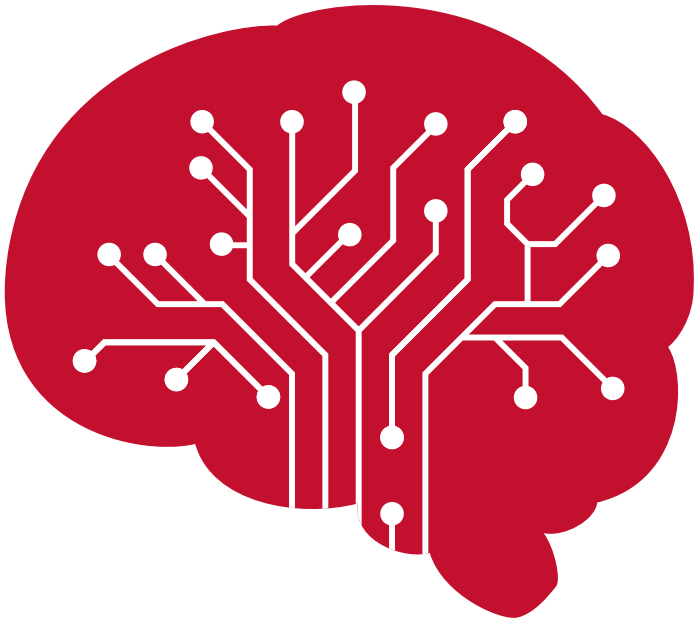
Role of attention mechanisms in listening

Barbara Shinn-Cunningham
Director, Neuroscience Institute



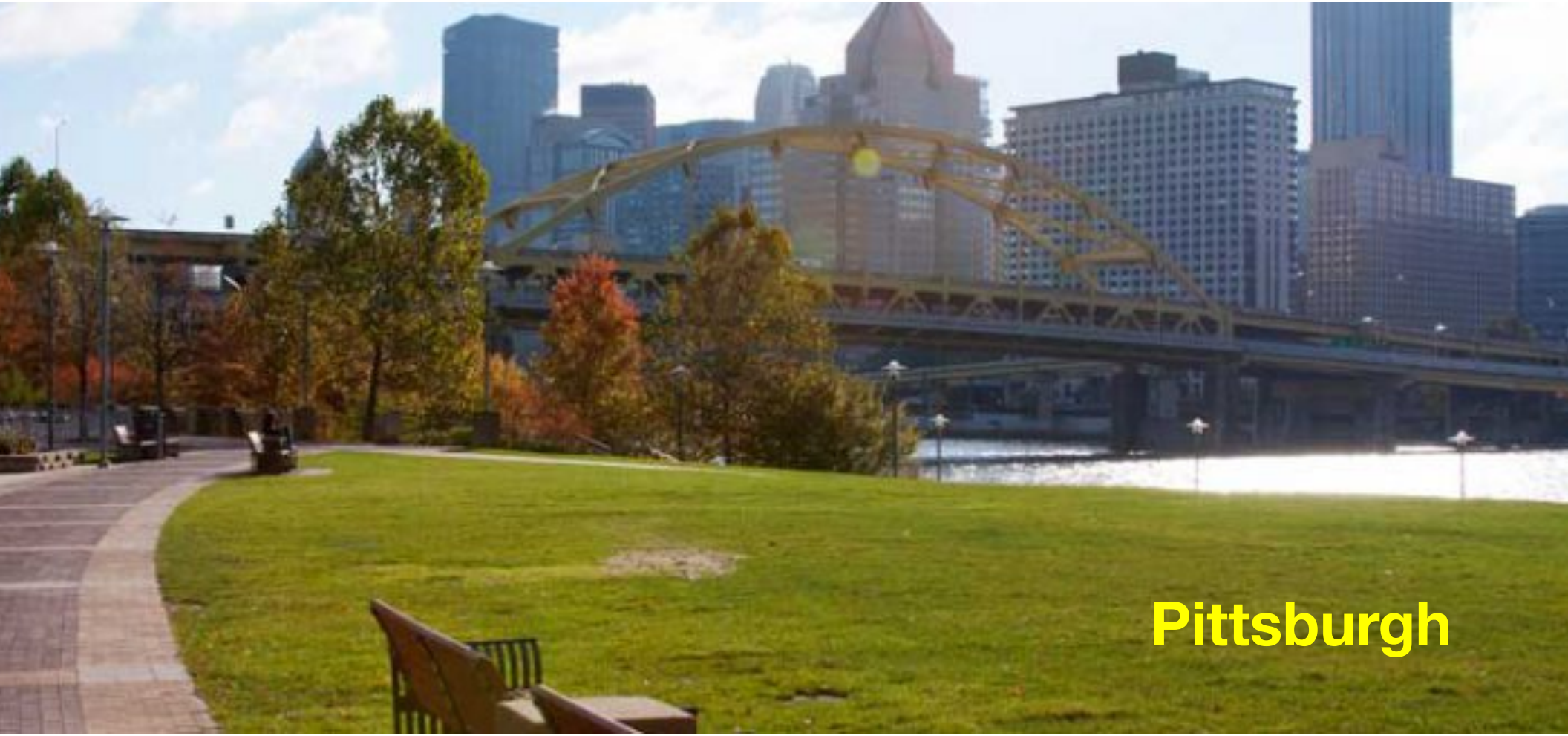
Carnegie Mellon University

What challenges auditory processing?

The cocktail party

Attention is necessary at the cocktail party— or when navigating busy streets

Attention is necessary at the cocktail party— or when navigating busy streets



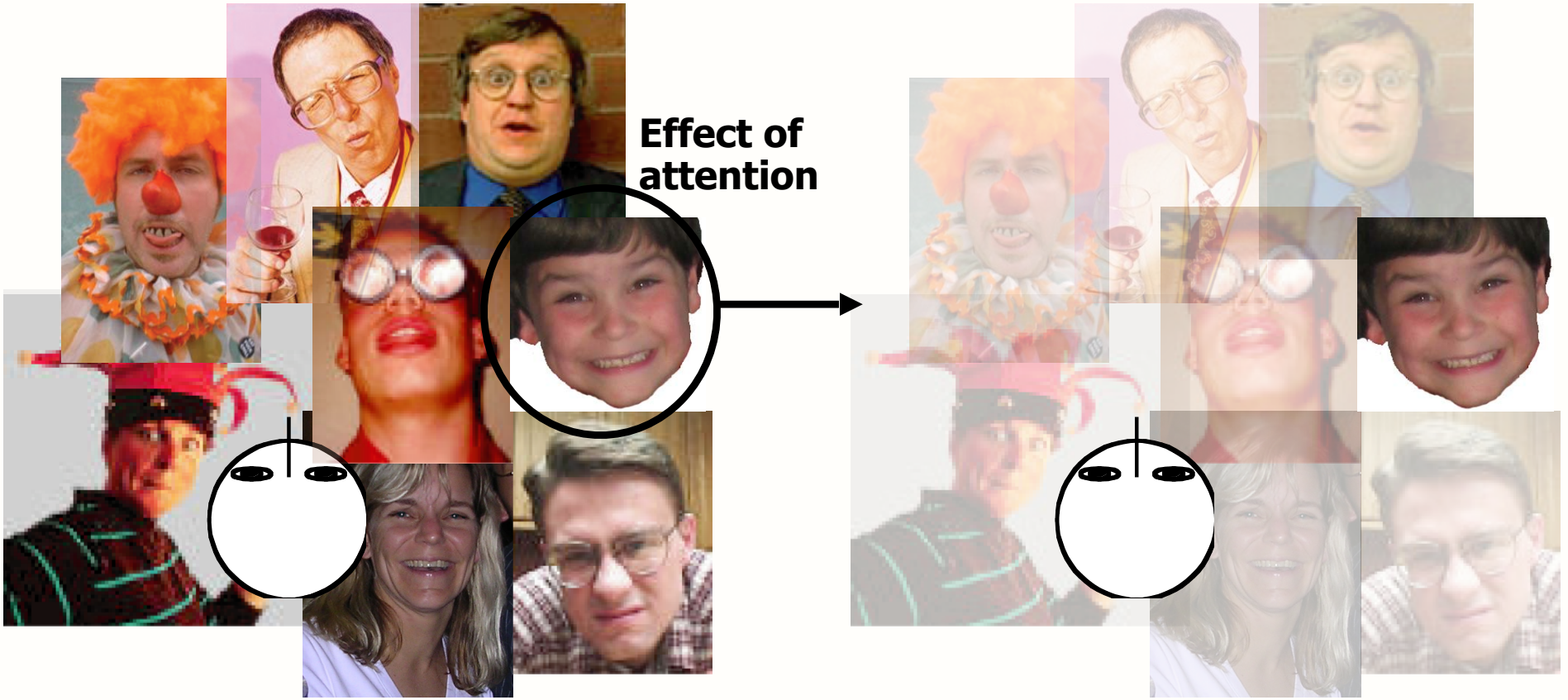
We can selectively listen even though sound adds before entering our ears

(Cocktail Party by SLAW, Maniscalco Gallery)

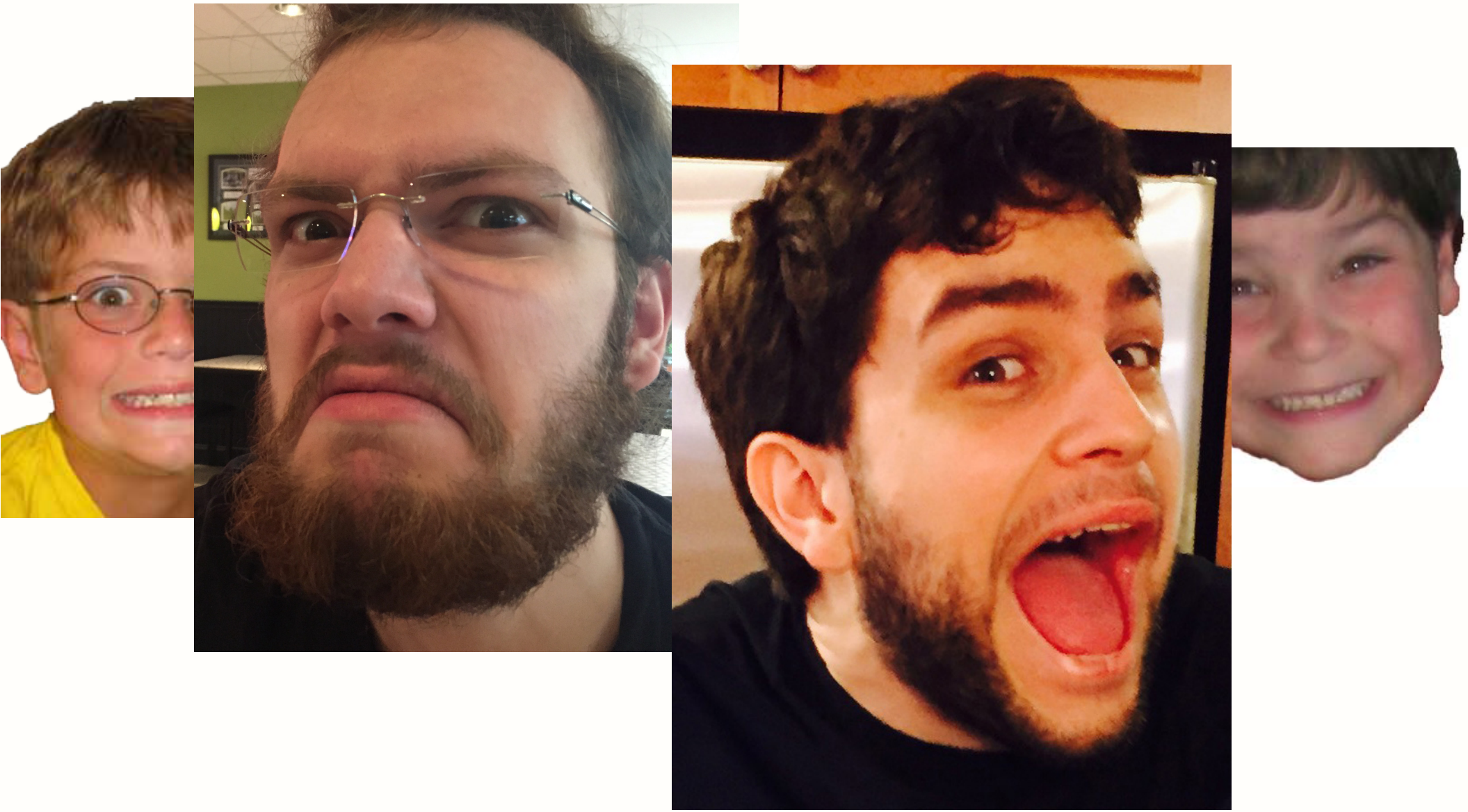
In everyday settings, competition for attention is often the factor limiting performance

?

Attention enhances the neural response to one source and suppresses others



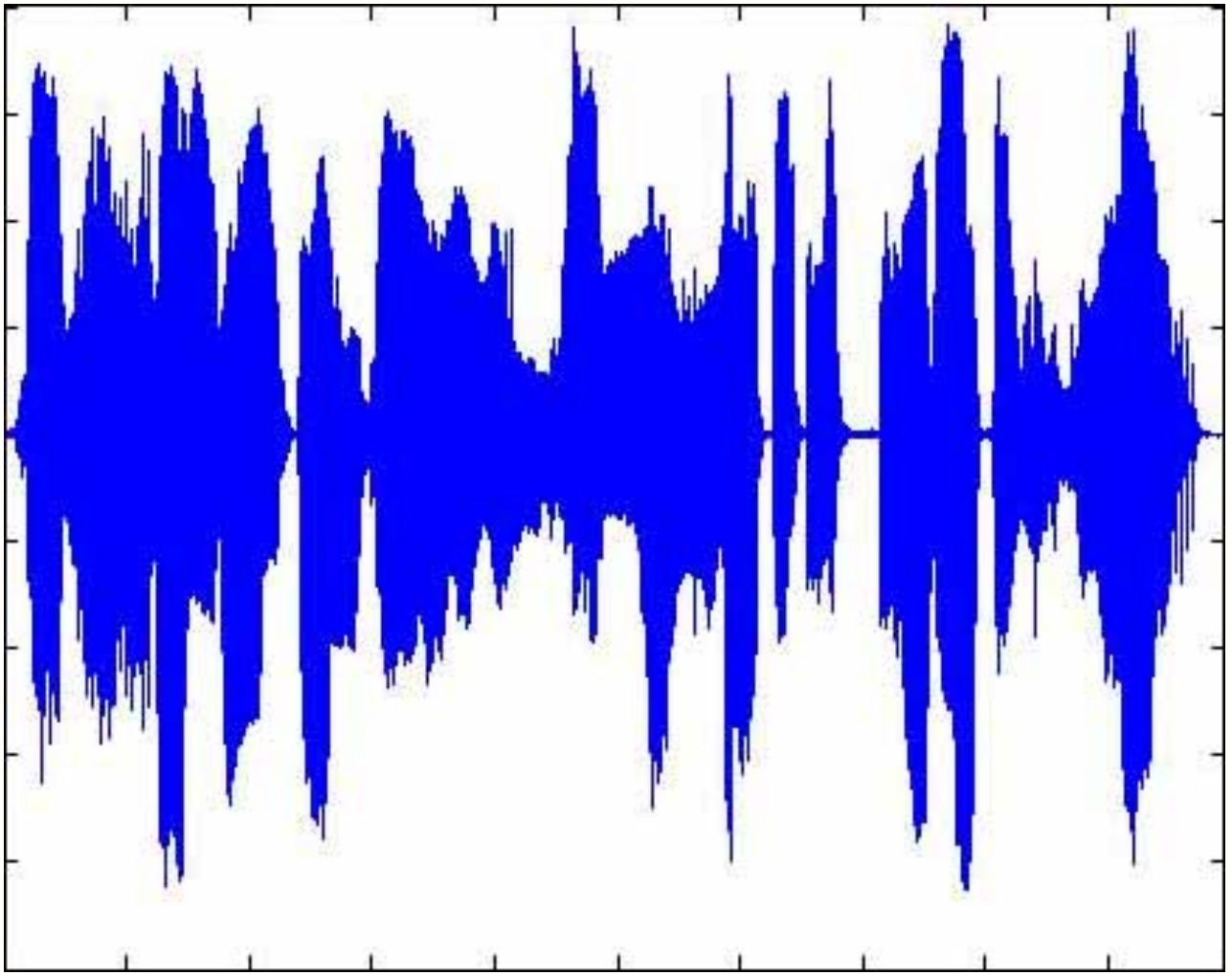
(I’ve been working on this a while…)



Attention operates on “objects,” formed by analyzing the scene

Selective attention requires you to know what to listen for…

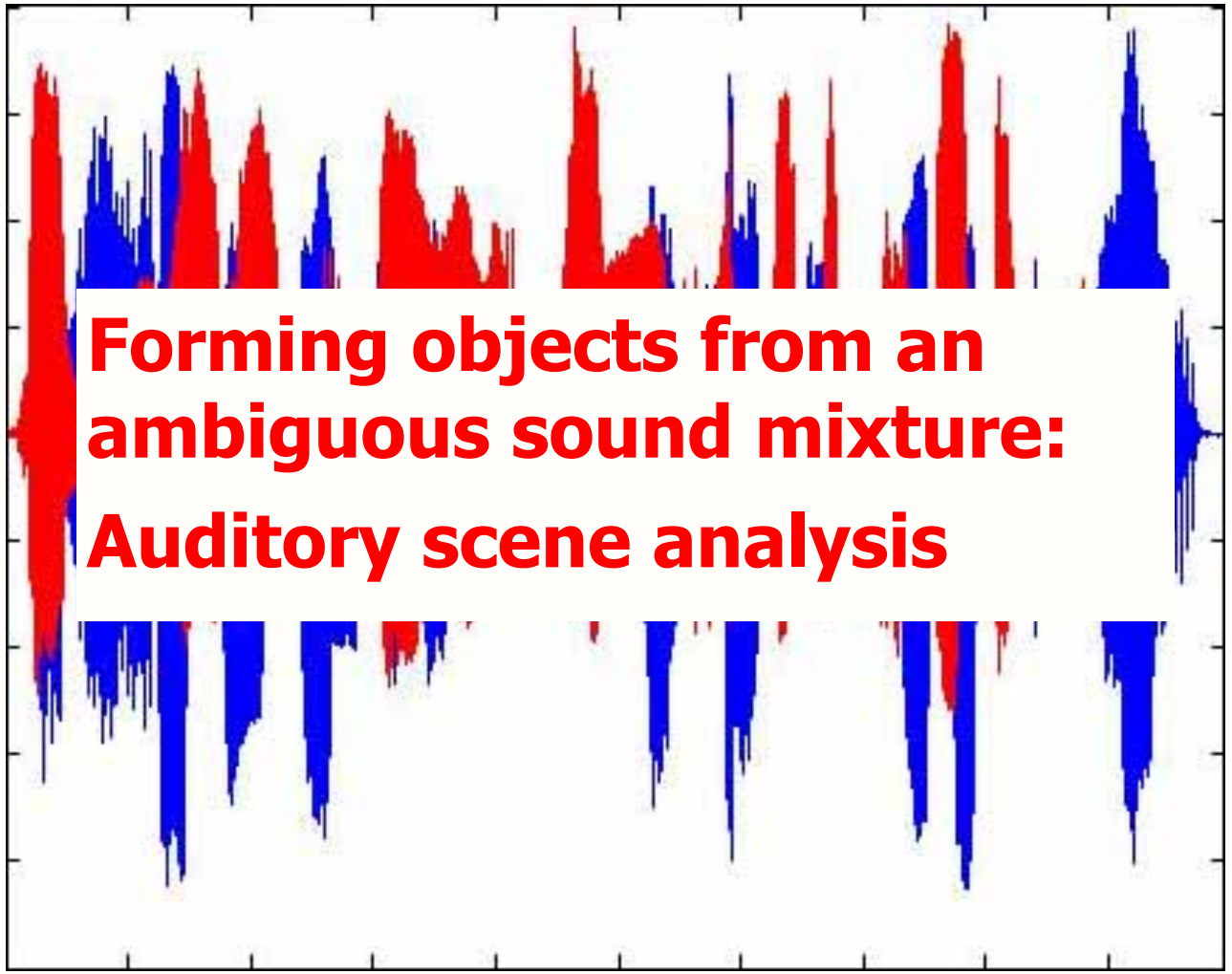
Listen to the sentence starting with "Her shaky…"



Selective attention requires objects to be perceptual segregated

Syllables form because of spectro-temporal structure

Need some feature or attribute to keep the different streams perceptually separate



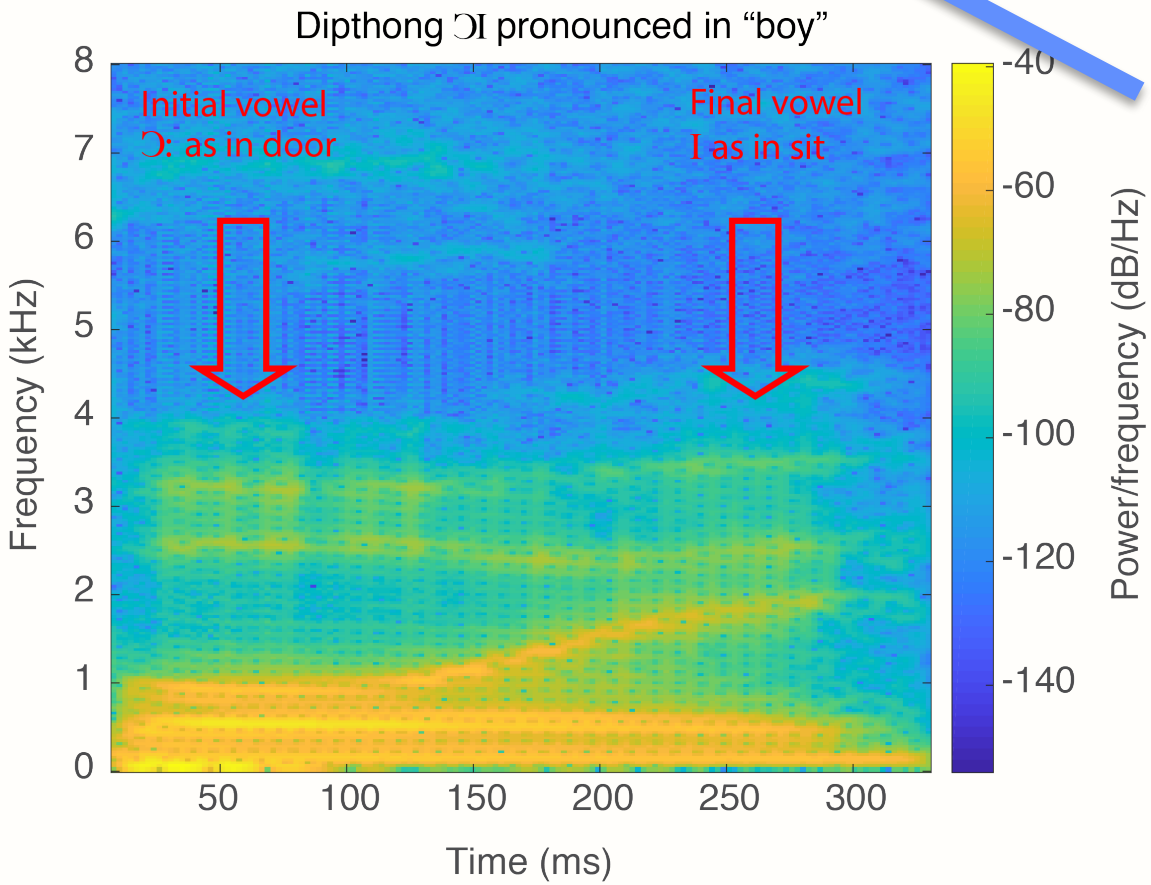
We solve auditory scene analysis by leveraging a priori knowledge

…an accomplishment only now being conquered by machines

“Syllables” are structured in time-frequency

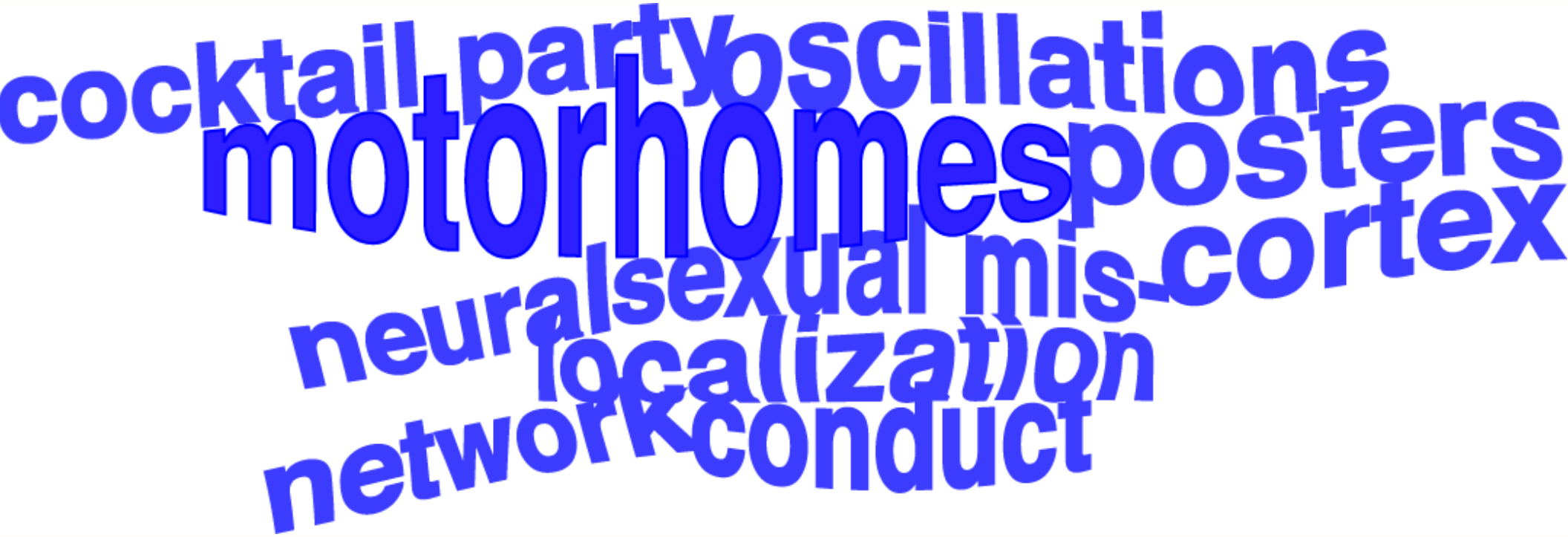
Our evolutionarily / experience-driven learning provides a priori information about sound structure

“Features” hardwired



Learned on line

If objects aren't perceptually segregated, selective attention fails



Shinn-Cunningham, TICS, 2008

Life is more interesting when you can segregate individual objects

Shinn-Cunningham, TICS, 2008

We process only one source at a time

Listen for the telephone number from the male, metallic voice

Because the male voice is distinct, there is little problem hearing out the number…

BUT WHAT WAS THE OTHER SIGNAL?

We process only one source at a time

HOLLOMAN AIR FORCE BASE, New Mexico

Credit: Reuters/Airman 1st Class Michael Shoemaker/USAF/Handout

We truly cannot process everything that is happening around us

Singapore Airlines flight SQ006

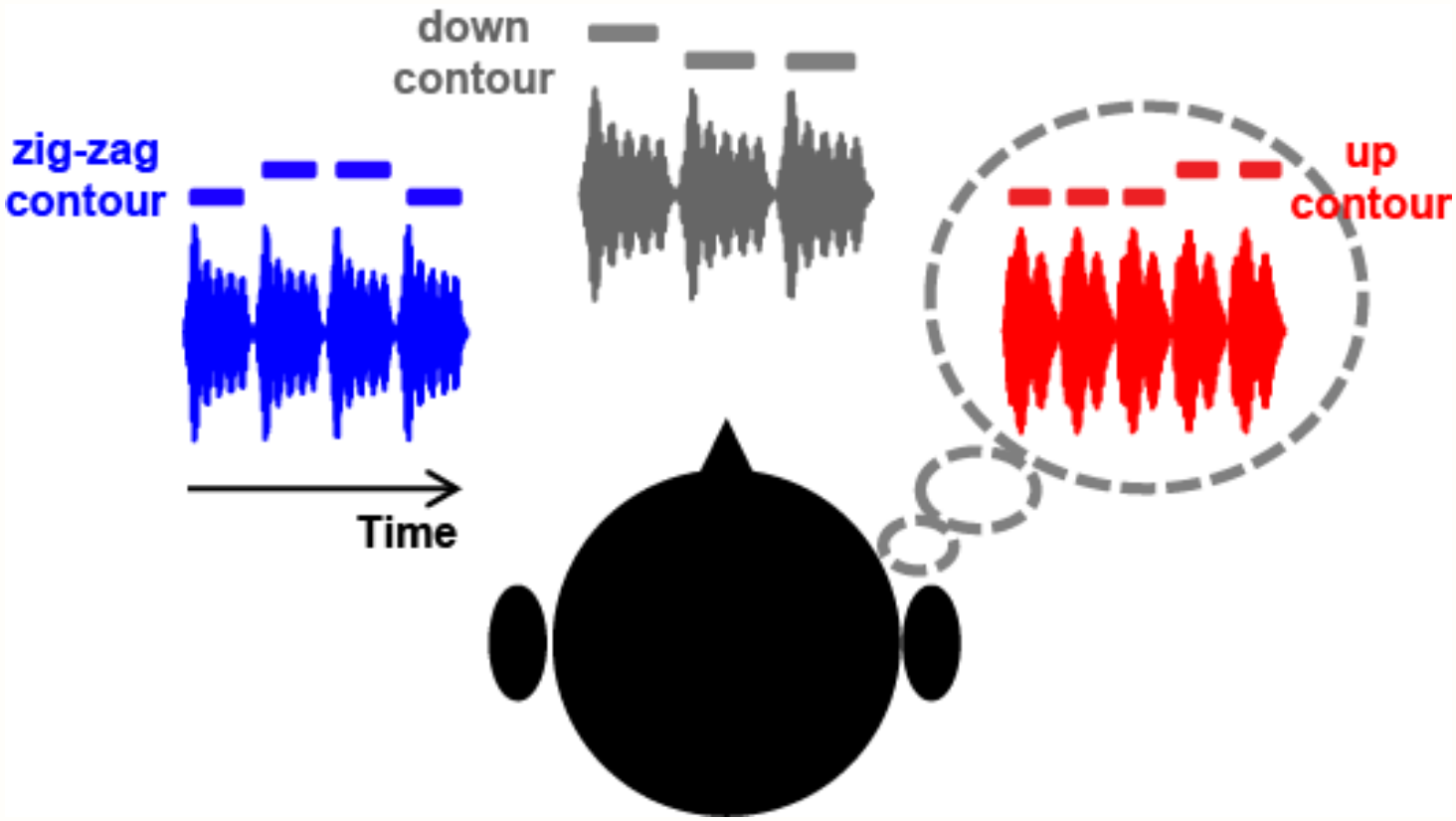
Interim Summary Part I

Auditory attention allows us to understand speech in noise (at the expense of missing other information)

Selective attention causes suppression of evoked sensory responses

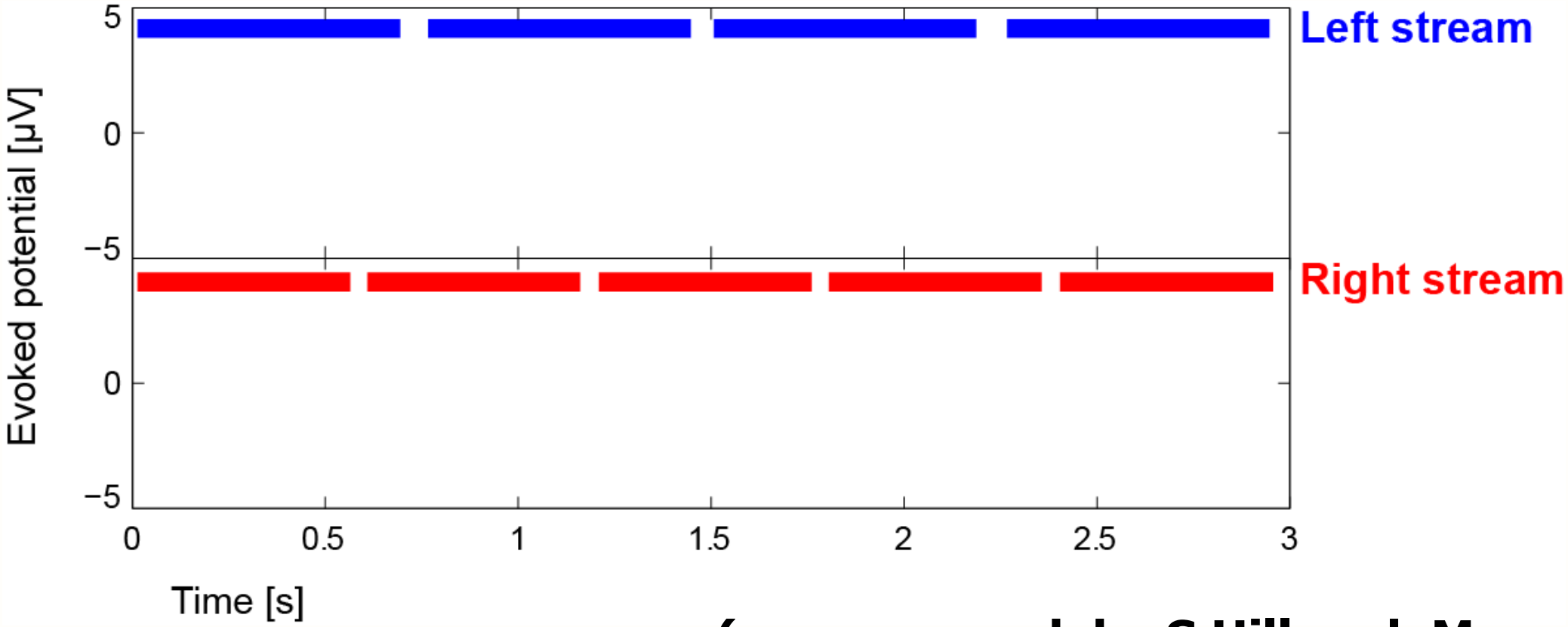
Measure cortical EEG during sustained attention to melodies

Focus on left or right and name pitch contour



Choi et al., Front. Neurosci., 2013

Attentional effects are so strong they can be seen using noninvasive EEG



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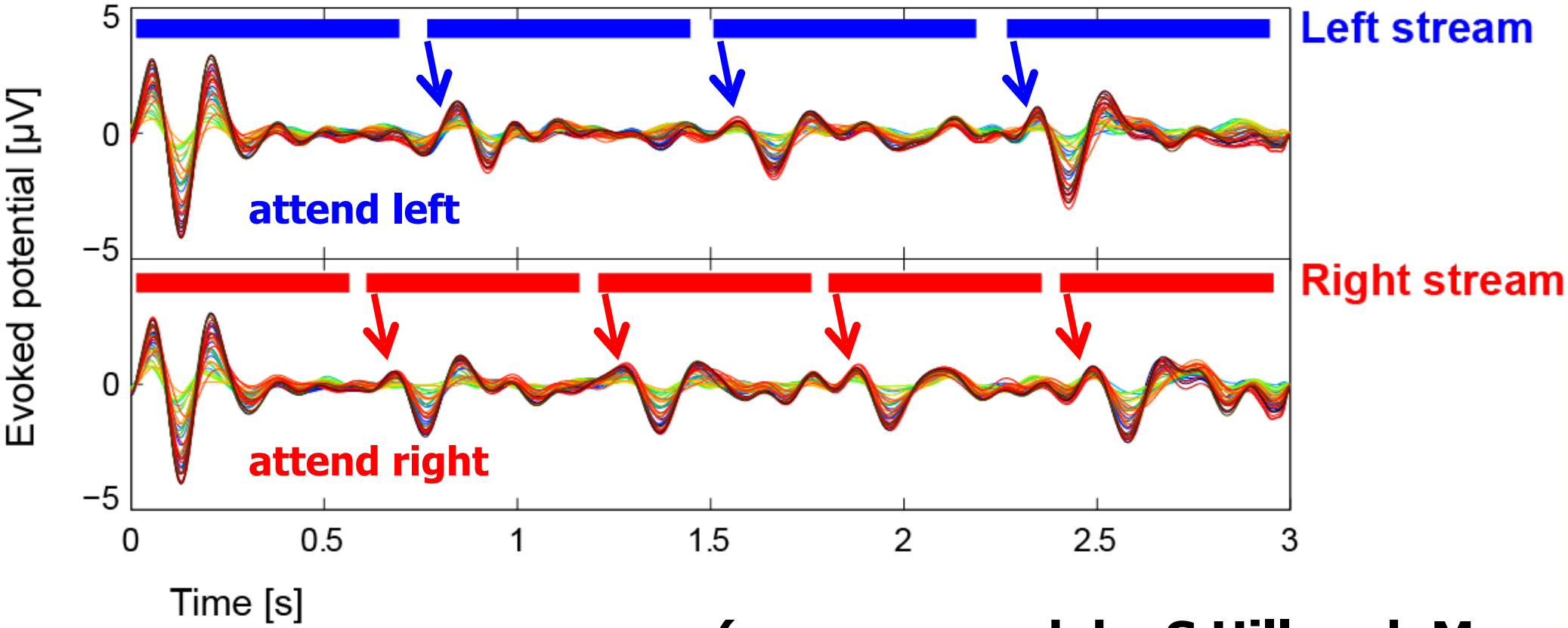

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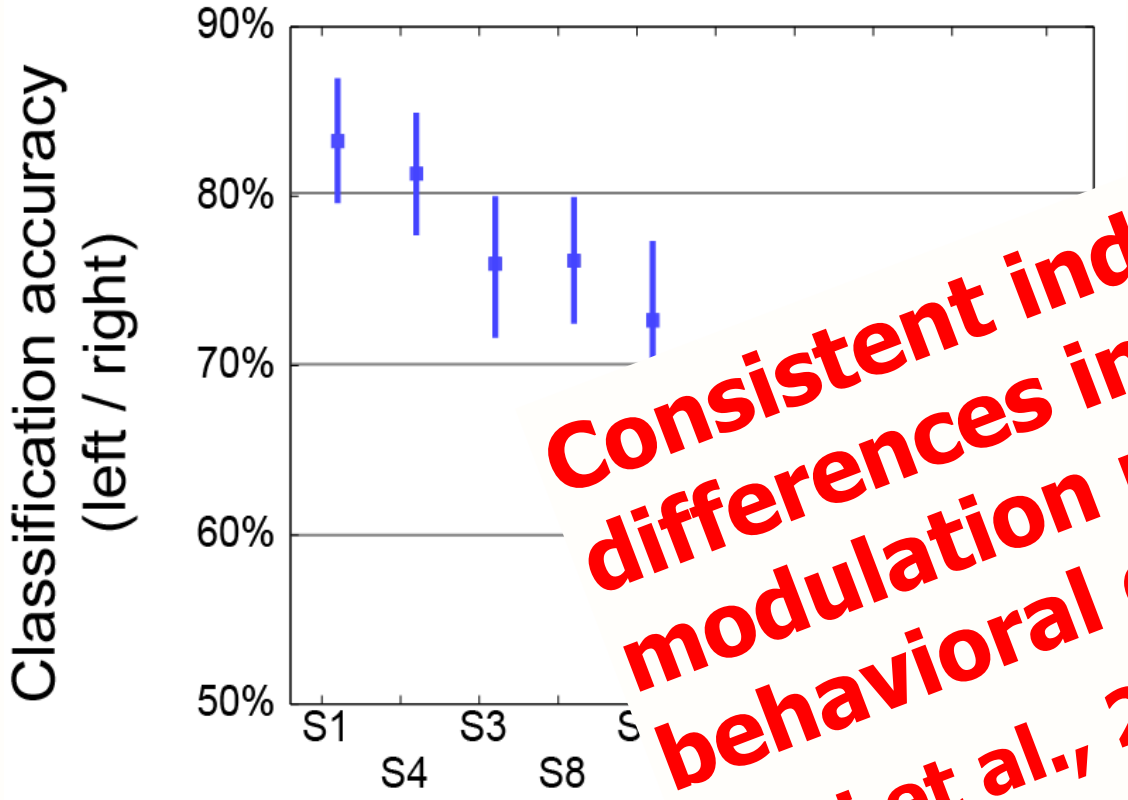
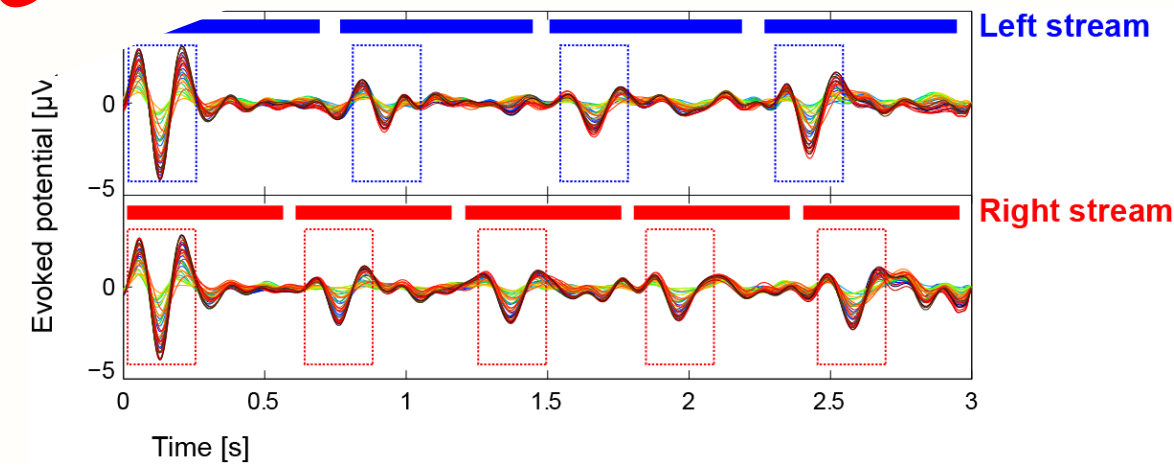
Can accurately classify direction of attention from single trial



Consistent individual differences in top-down modulation reflect behavioral differences

Choi et al., 2014, Hear Res.

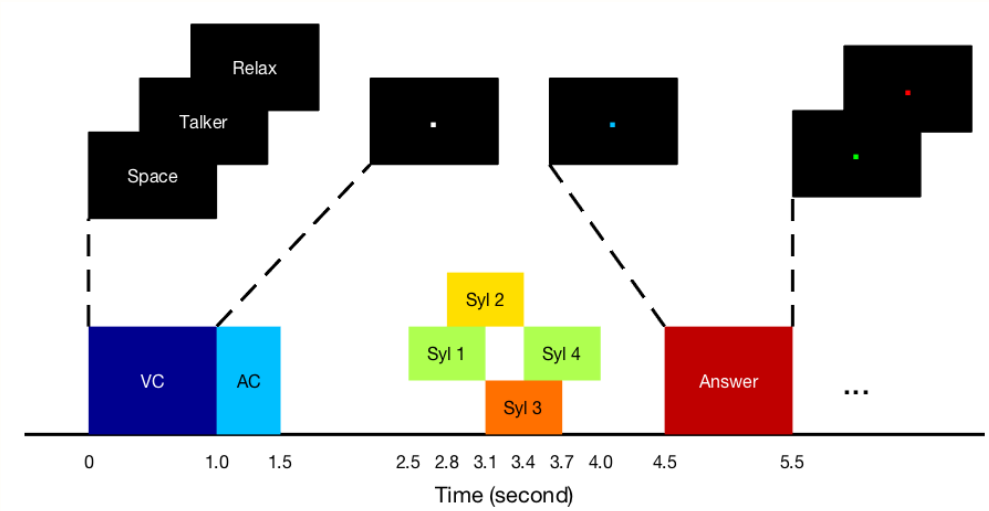


Choi et al., Front. Neurosci., 2013

EEG responses can also be used to differentiate between forms of attention

Winko An
(BU -> CMU)

Decoding differences in attentional control



Attend to an syllable, either based on location or talker identity (or ignore)…

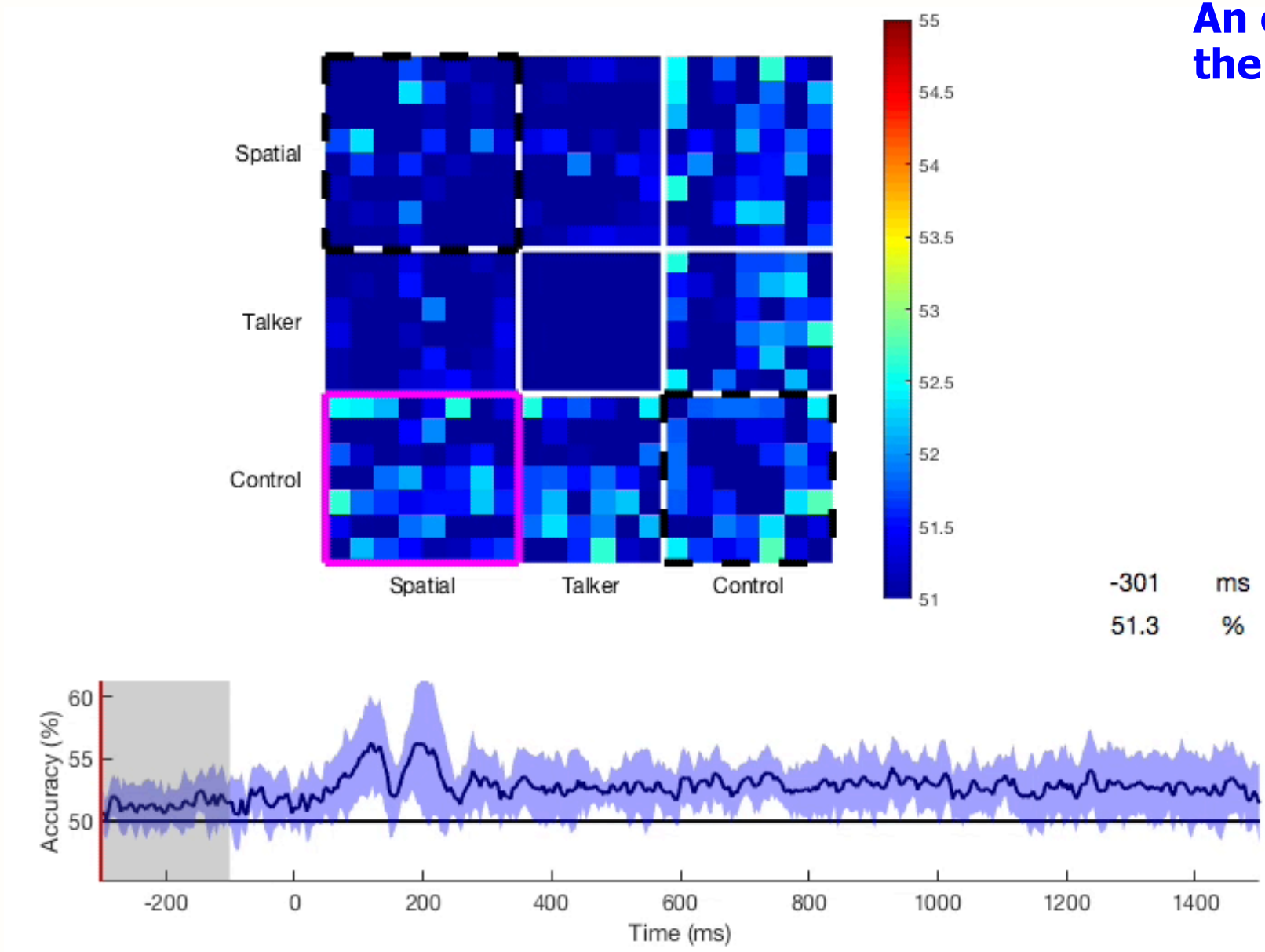
… for a hierarchical set of conditions

An et al., in the works

Condition	Task	Target	Masker	Extra cue
1	Spatial	L90	L30	Different gender
2	Spatial	L90	L30	Same gender
3	Spatial	L90	R90	Different gender
4	Spatial	L90	R90	Same gender
5	Spatial	R90	R30	Different gender
6	Spatial	R90	R30	Same gender
7	Spatial	R90	L90	Different gender
8	Spatial	R90	L90	Same gender
9	Talker	Male	Female	Same side 90
10	Talker	Male	Female	Same side 30
11	Talker	Male	Female	Opposite side 90
12	Talker	Female	Male	Same side 90
13	Talker	Female	Male	Same side 30
14	Talker	Female	Male	Opposite side 90
15	Control	L90	L30	Different gender
16	Control	L90	L30	Same gender
17	Control	L90	R90	Different gender
18	Control	L90	R90	Same gender
19	Control	R90	R30	Different gender
20	Control	R90	R30	Same gender
21	Control	M/F	F/M	Same side 90

Evoked responses at onsets reveal form of attention (including direction)

An et al., in the works

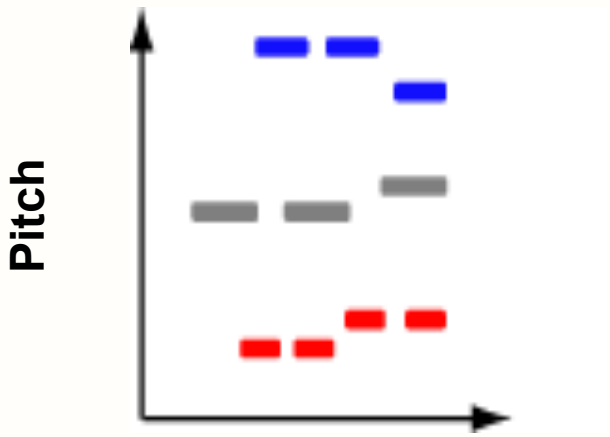


Blast-exposured veterans cannot selectively attend

Scott Bressler

Inyong Choi

Similar melody task

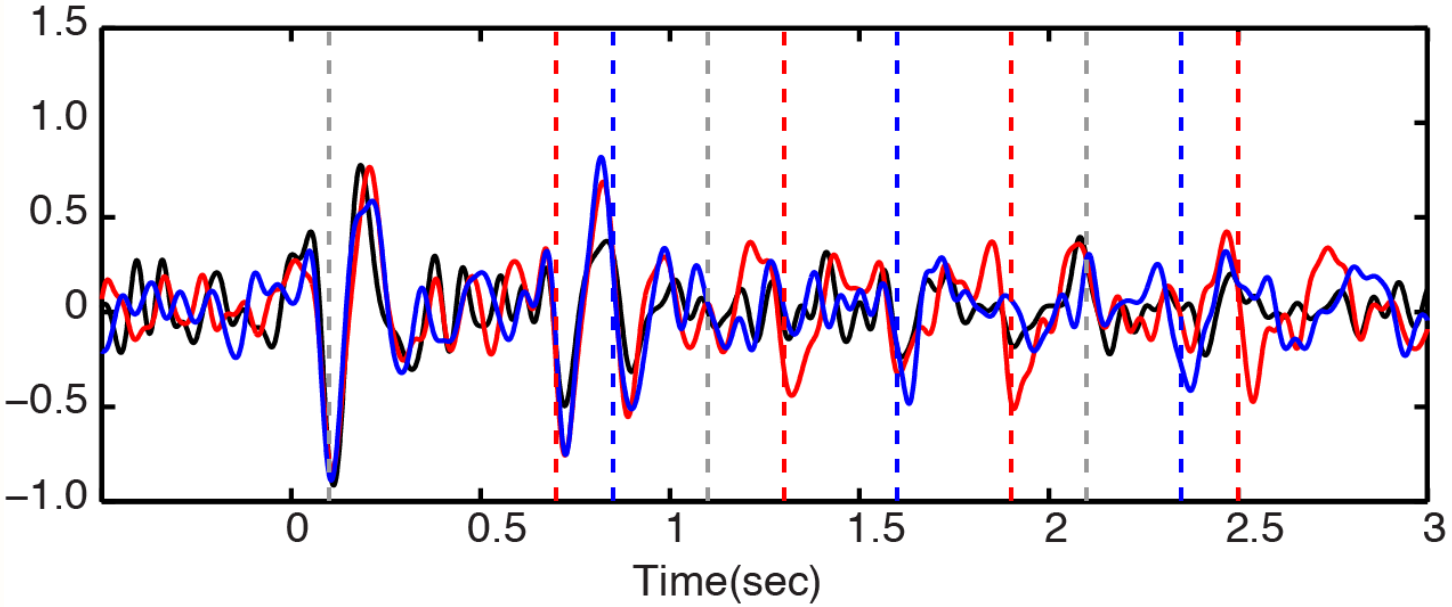


- 3 concurrent melodies
- Attend left or right (2/3 of trials)
- Do not respond (1/3 of trials)

… and test veterans with mTBI

Bressler, in the works

Attention modulates ERPs in controls

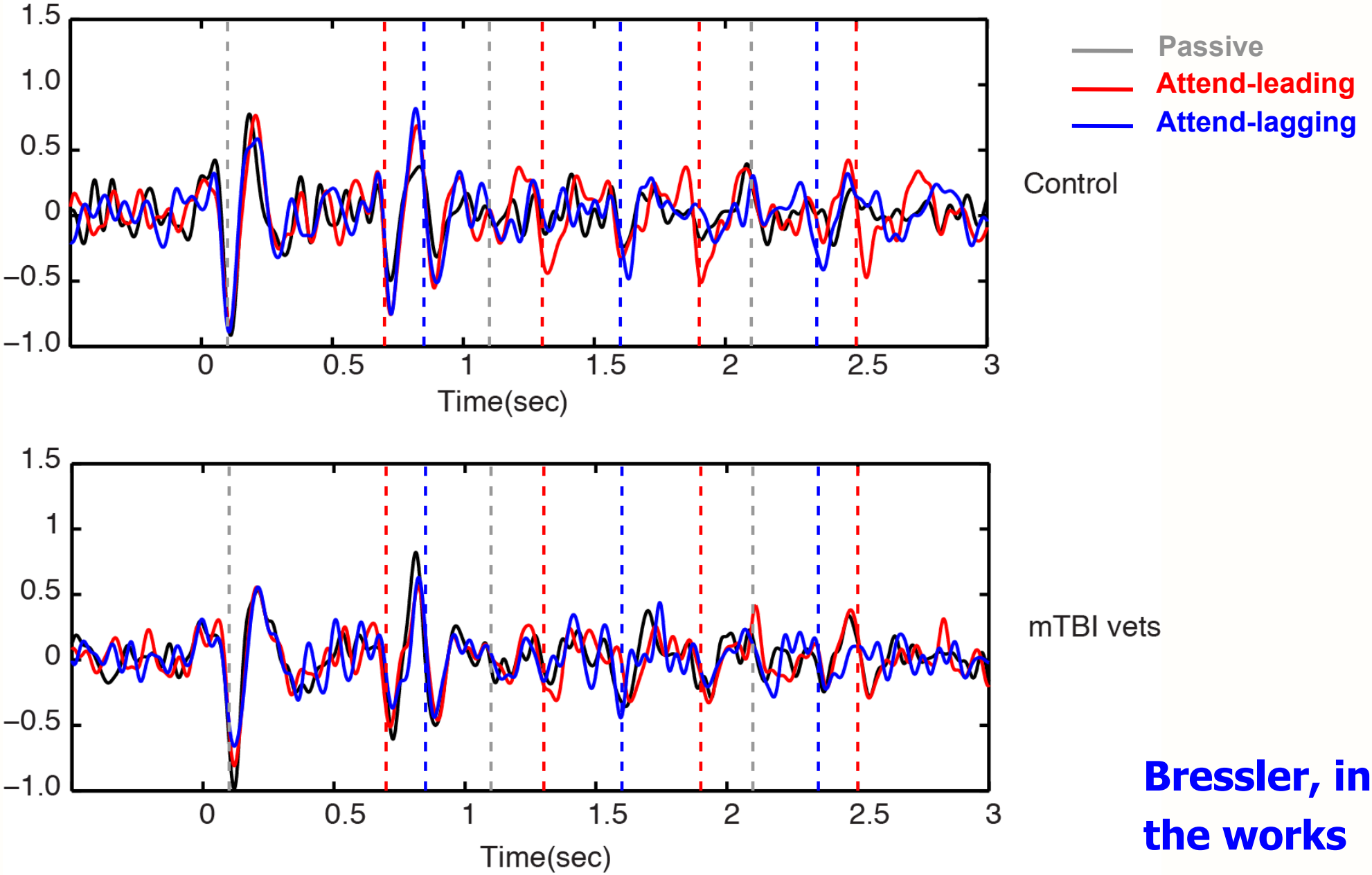


Passive
Attend-leading
Attend-lagging

Control

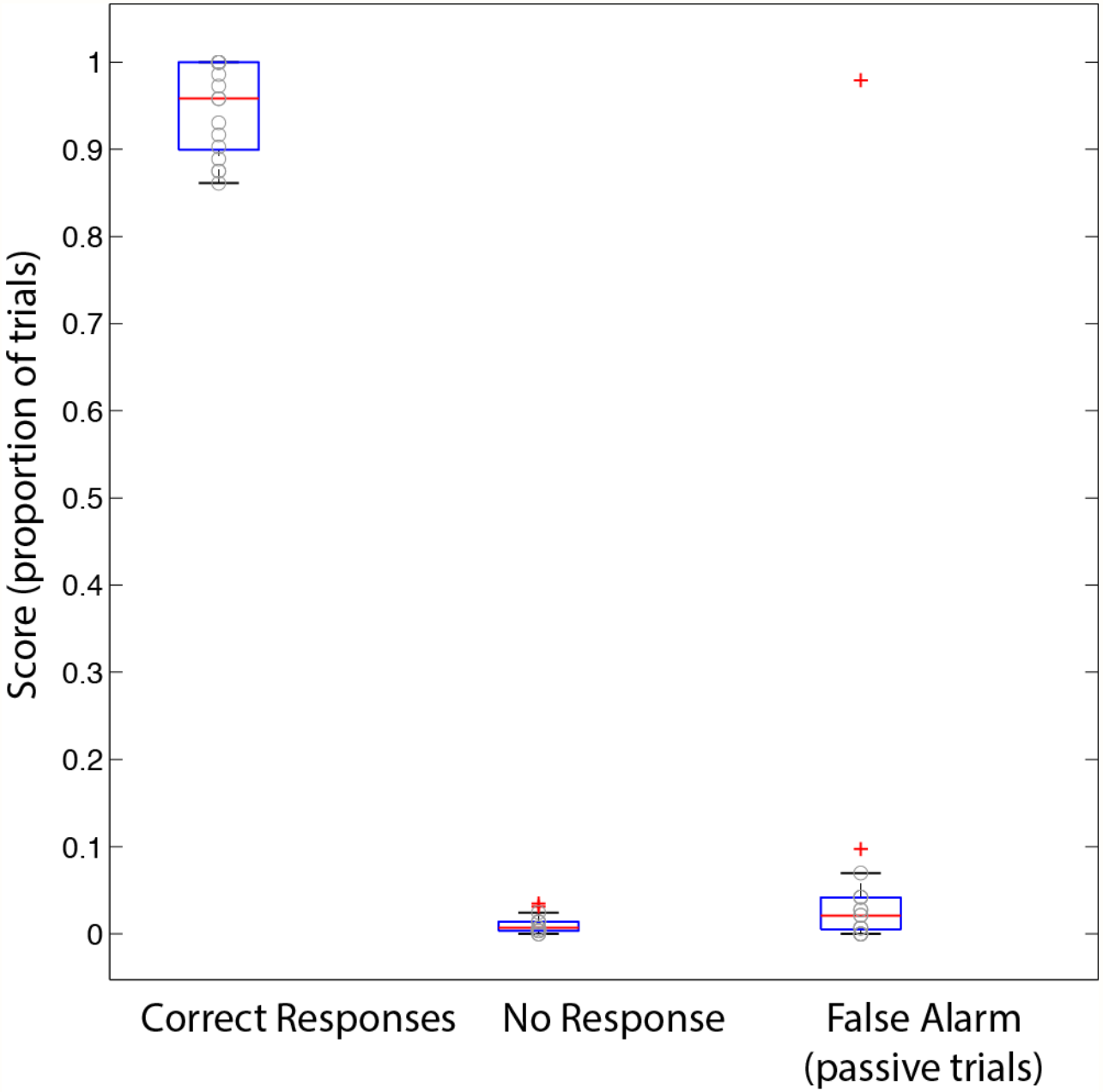
Choi et al., Hearing Res, 2014

Attention modulates ERPs in controls– but not in vets



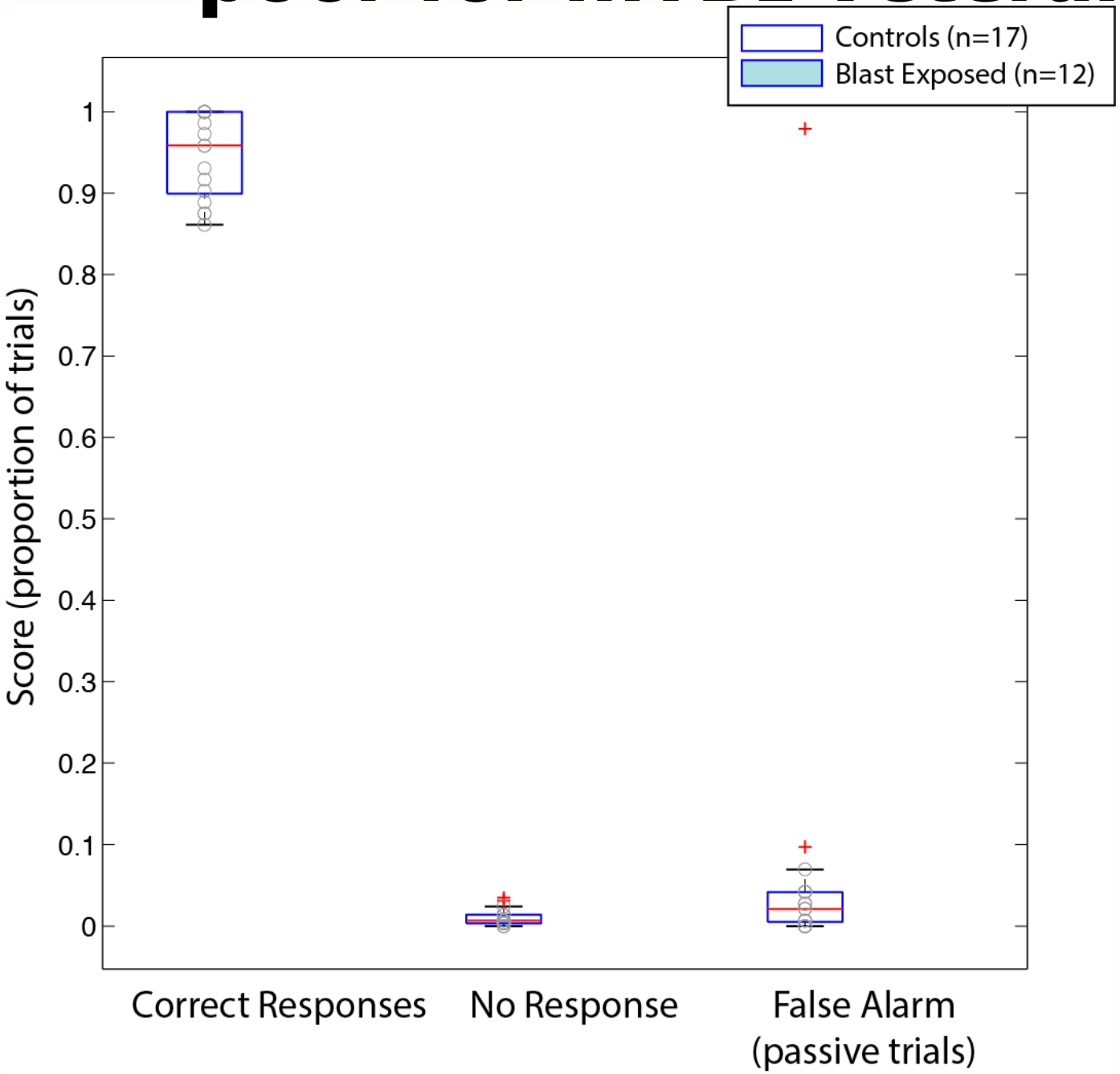
Bressler, in the works

Controls perform well, respond properly, and inhibit responses



Choi et al., Hearing Res, 2014

Every aspect of performance poor for mTBI veterans



Bressler, in the works

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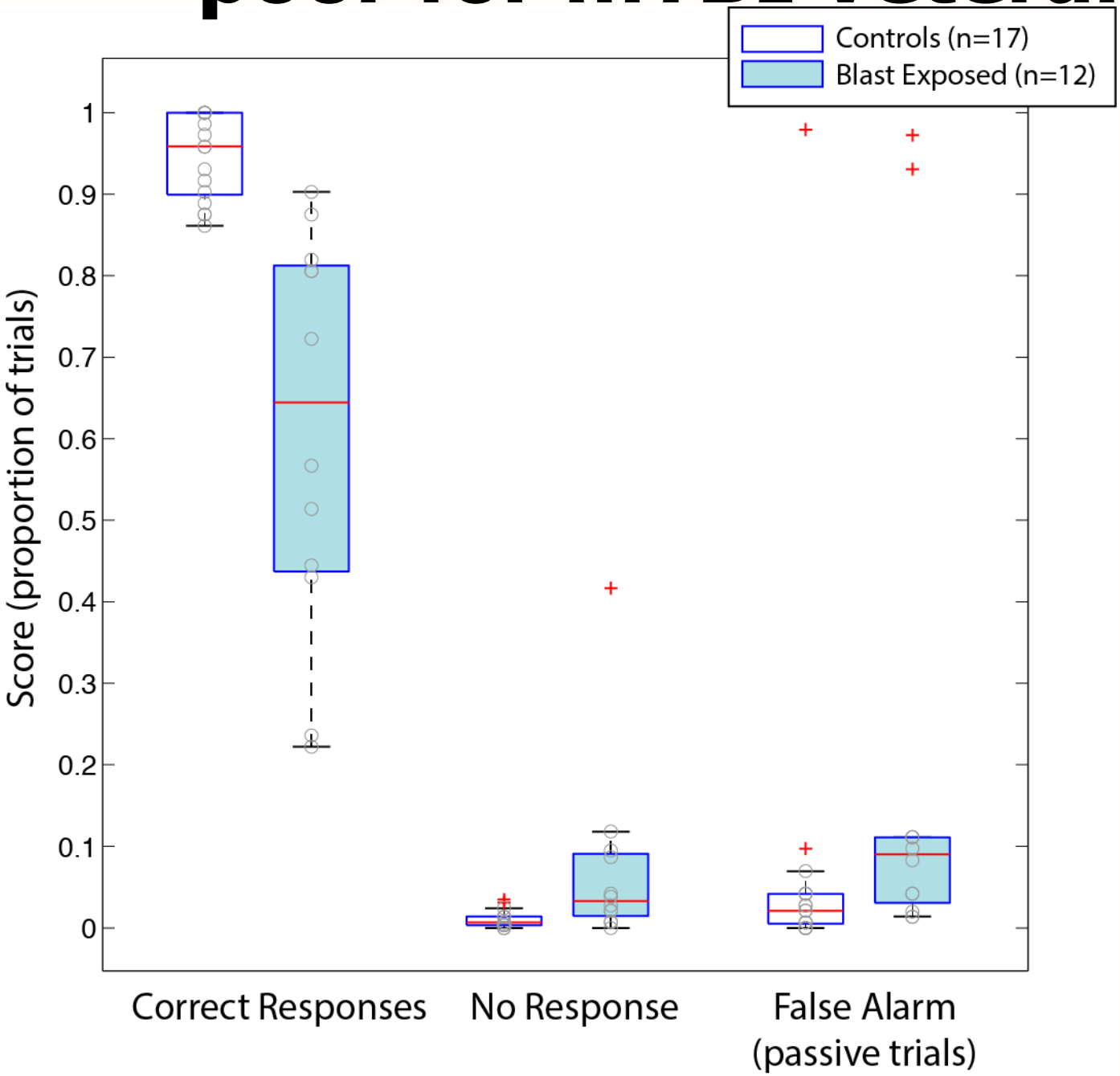


Bressler, in the works

Summary Part I

Auditory attention allows us to understand speech in noise (at the expense of missing other information)

Attention changes in what information is represented in auditory cortex (for those who can control it)

Selective attention ability varies even in ~~"normal-hearing" listeners~~

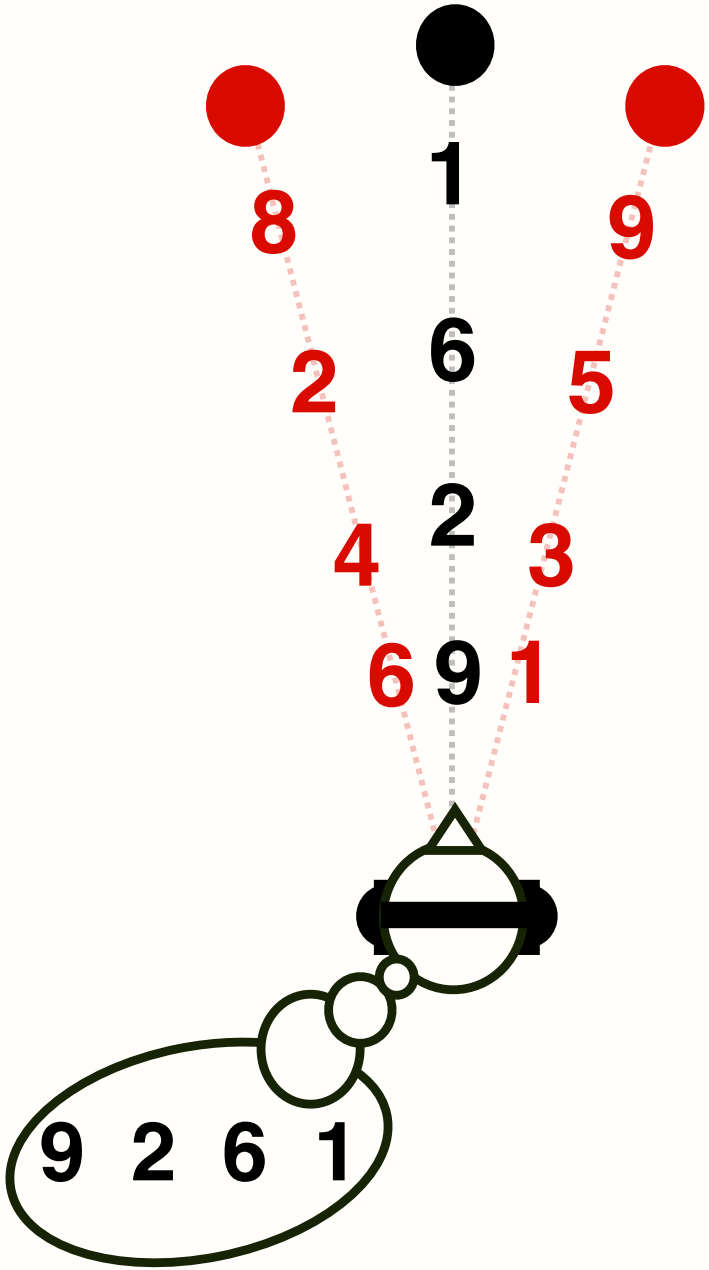
listeners with normal hearing thresholds

Dorea Ruggles

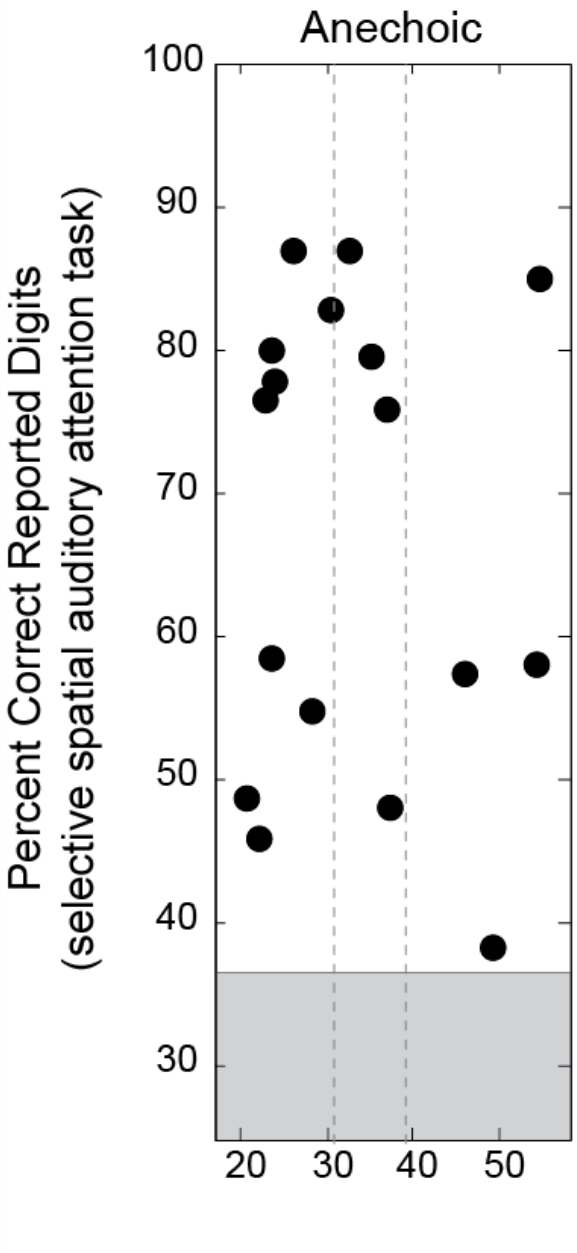
Test supra-threshold attention ability

Three streams of four digits

Only distinguishing characteristic of target: direction (center)



Probability of correct answer varies from chance to ~90%

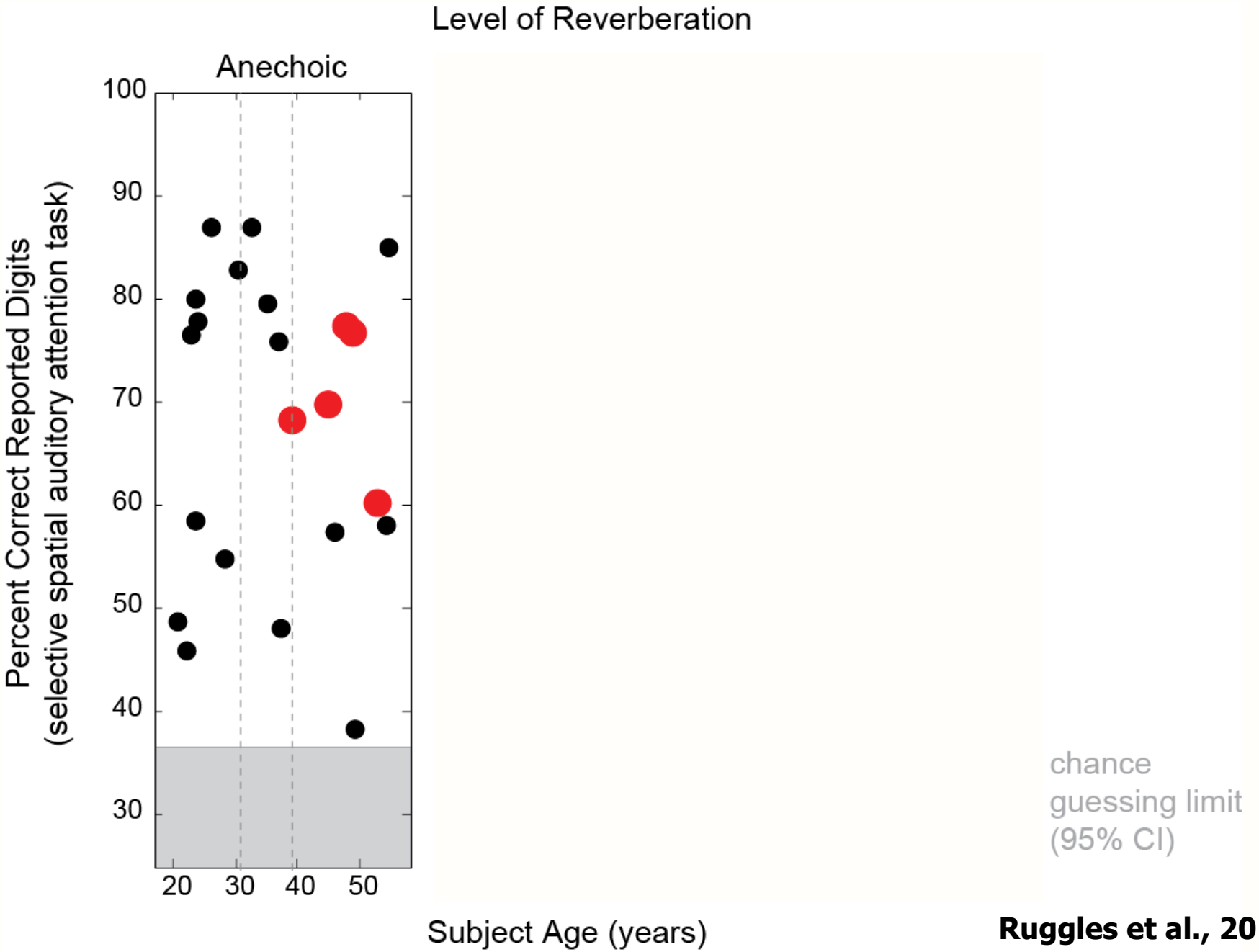


Age not a factor

chance
guessing limit
(95% CI)

Ruggles and Shinn-Cunningham, 2011

Recruit extra older listeners



Ruggles et al., 2012

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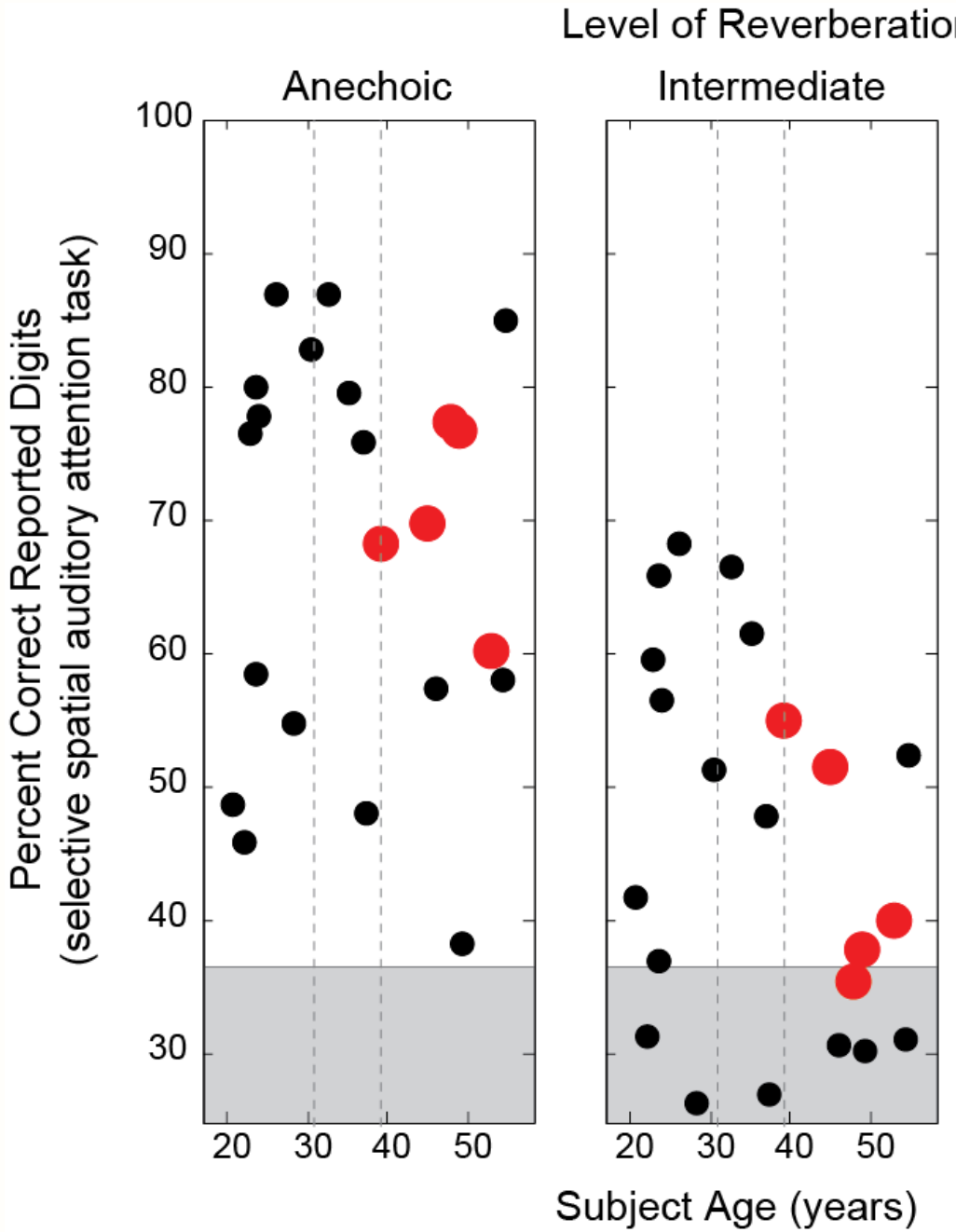

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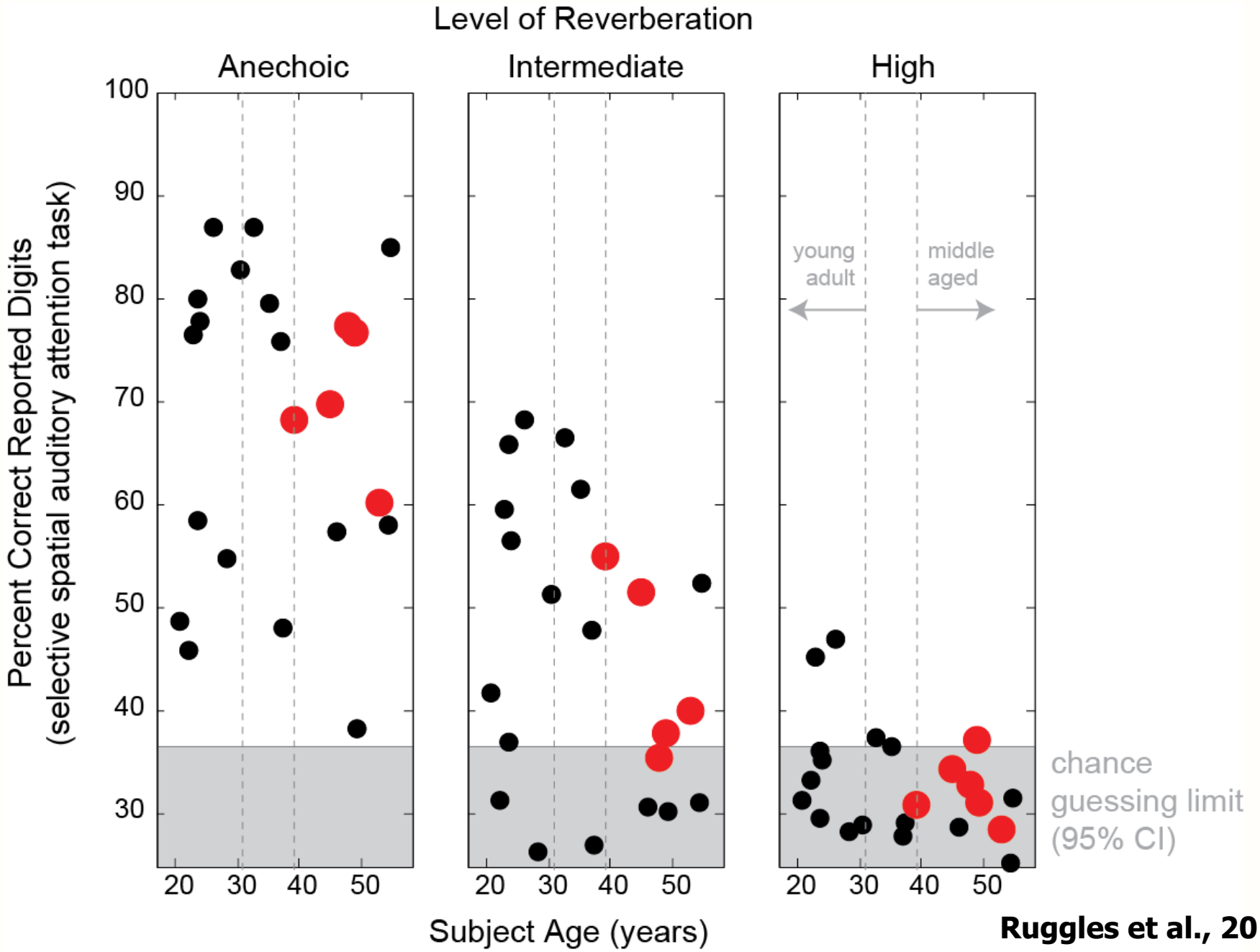

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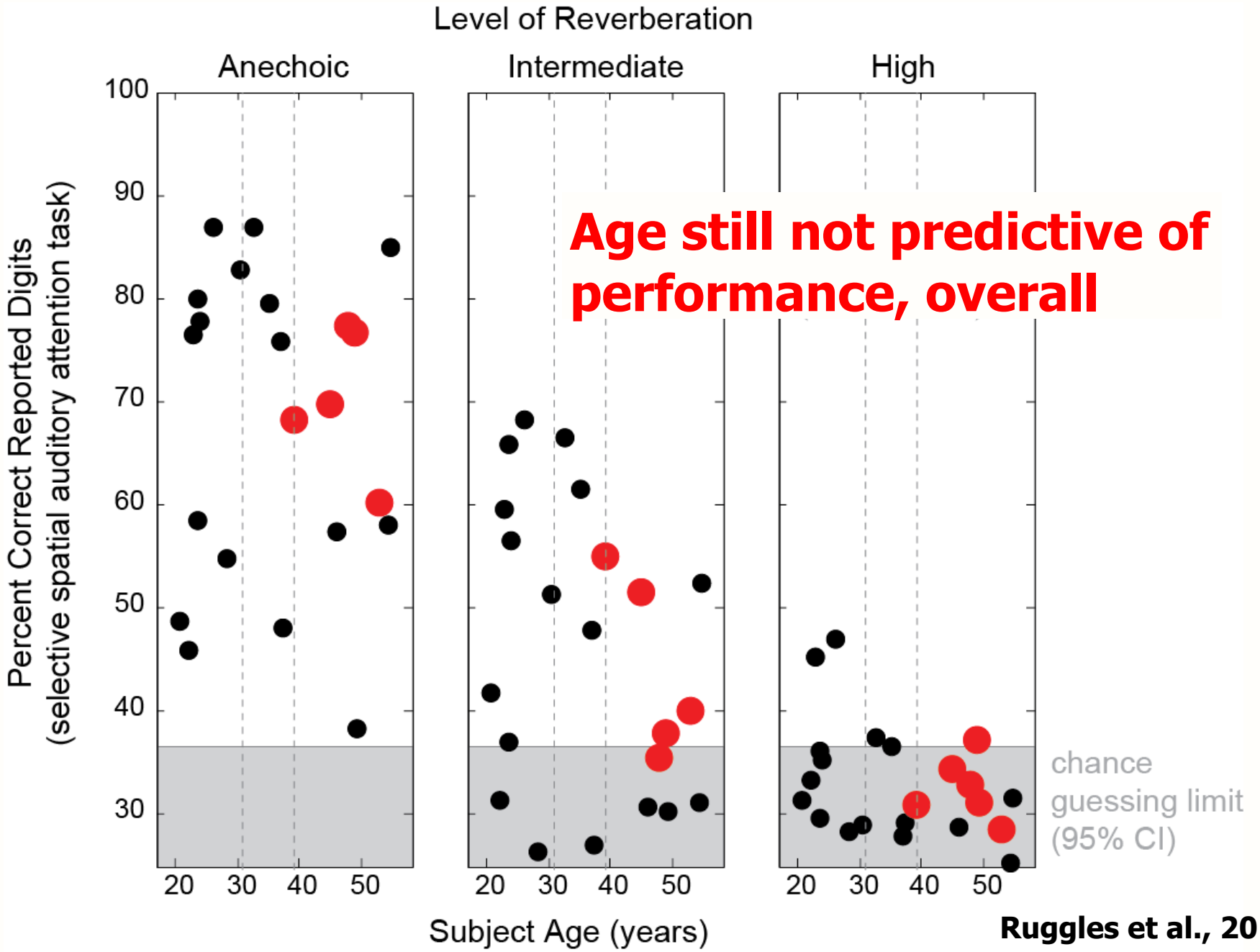

Ruggles et al., 2012

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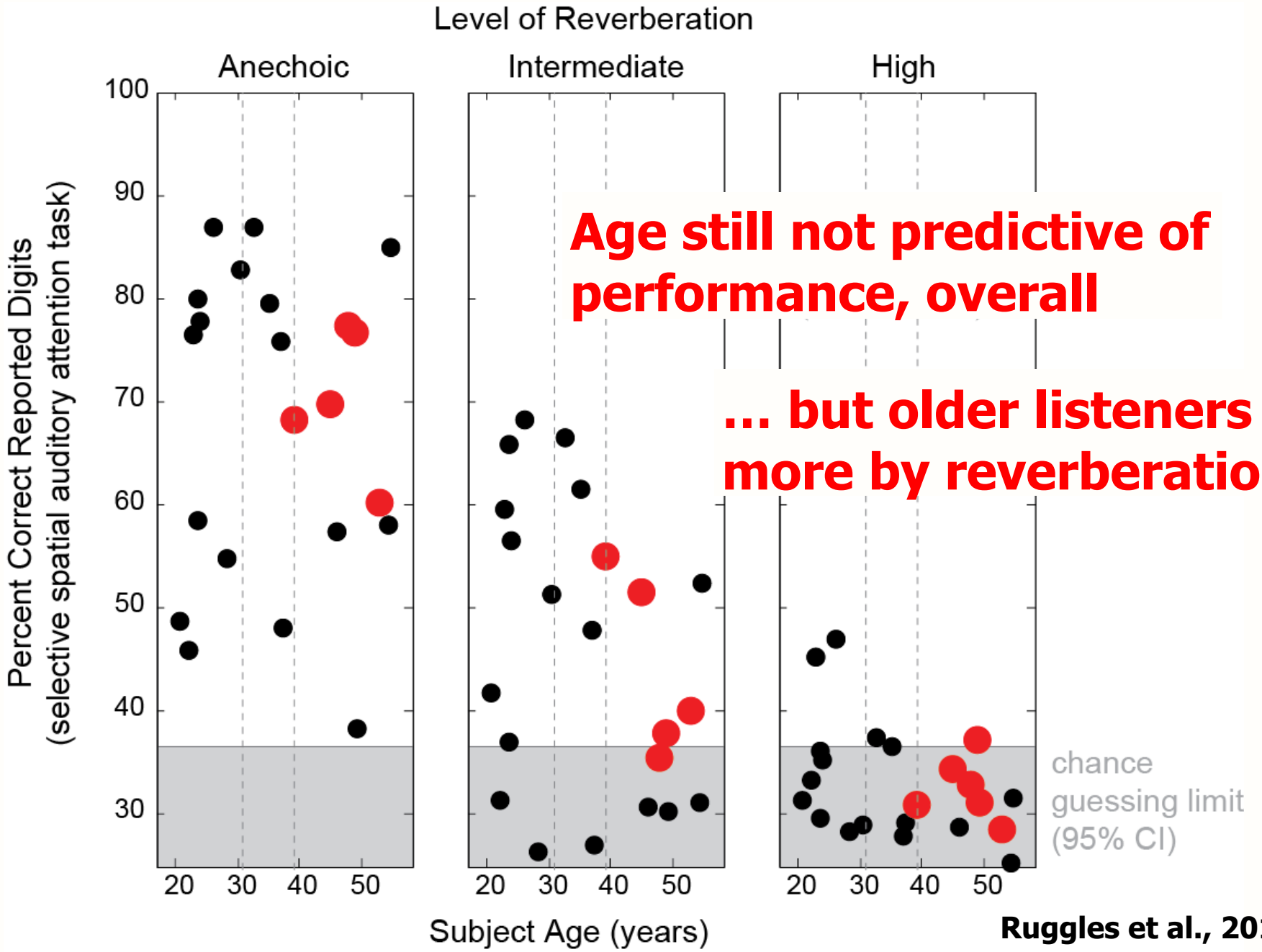


Age still not predictive of performance, overall

… but older listeners hurt more by reverberation

Ruggles et al., 2012

In animals, noise exposure and aging lead to loss of auditory nerve fibers

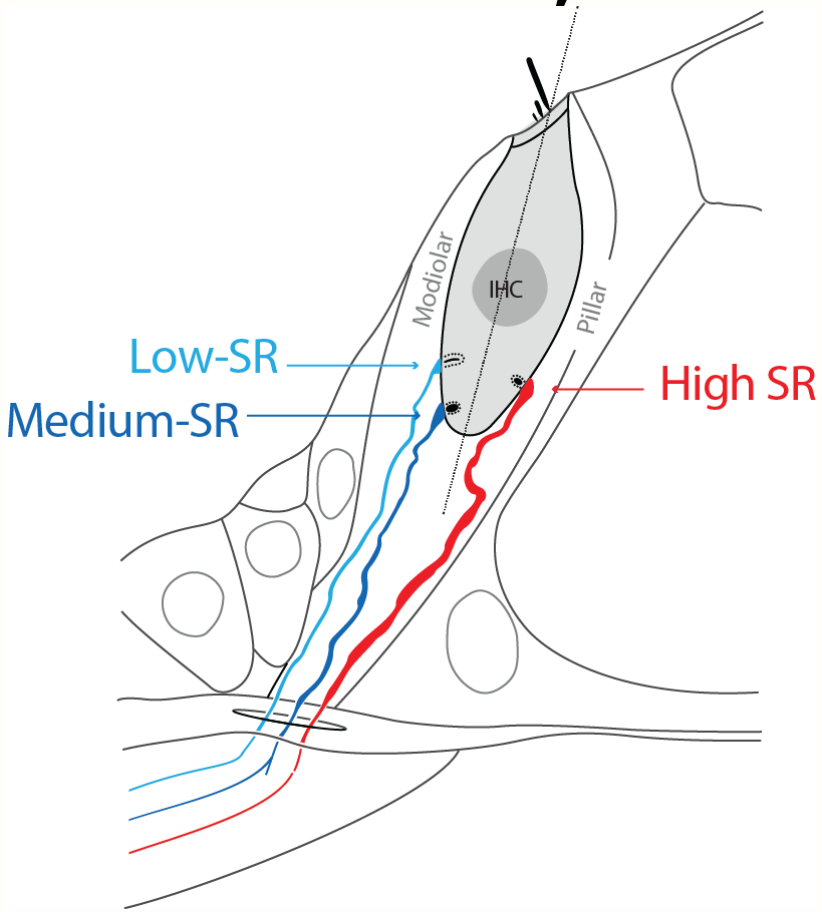
In animals, noise exposure and aging lead to loss of auditory nerve fibers

"Hidden hearing loss"
Auditory neuropathy
Synaptopathy

Nerve fiber loss occurs before cochlear function is damaged

Kujawa and Liberman, J Neurosci, 2009:

No permanent threshold shifts, but nerve loss



Nerve fiber loss occurs before cochlear function is damaged

Kujawa and Liberman, J Neurosci, 2009:

No permanent threshold shifts, but nerve loss

From the same group, and others:

Starts with synaptopathy (death of synapses, which are what cause neurons to fire)

Synaptopathy leads to neuropathy (death of nerve fibers, which convey sound to the brain)

Neuropathy occurs with aging, even without noise

Noise speeds up aging process of nerve loss

“Normal hearing” is defined by detecting, not identifying sound

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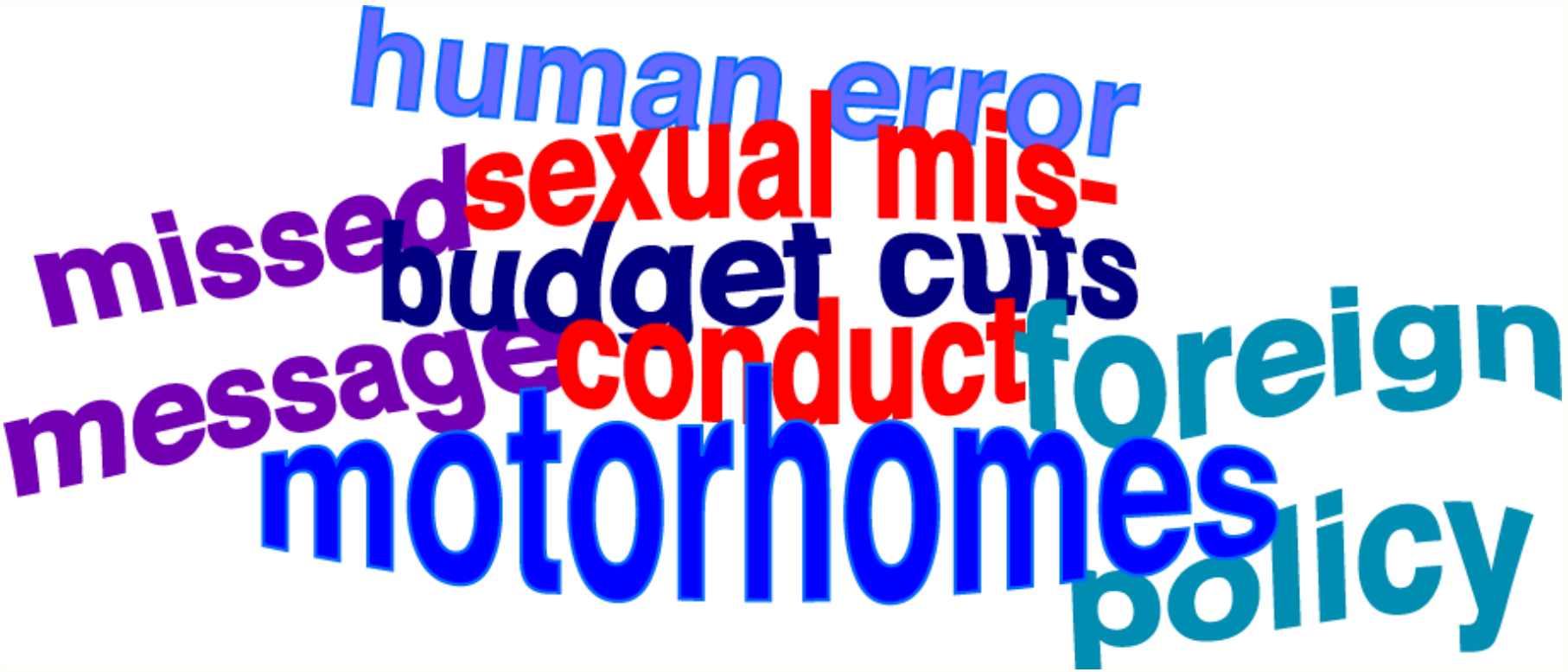


Normal cochlear function does not mean good supra-threshold hearing

(perception of sound at levels above threshold)

Hari Bharadwaj

Large cohort of listeners with normal cochlear function

Thresholds within 15 dB HL up to 8 kHz

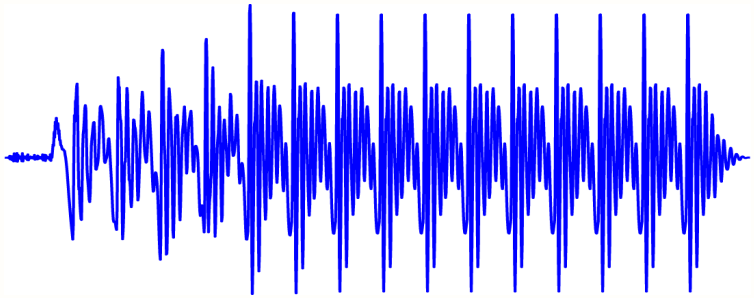
Normal compressive growth of cochlear input-output (distortion product otoacoustic emissions)

Normal psychophysical tuning width

Residual differences in cochlear metrics are unrelated to supra-threshold hearing abilities

Bharadwaj et al., 2015

Brainstem EEG measures reveal spectro-temporal encoding
(Frequency Following Response: FFR)



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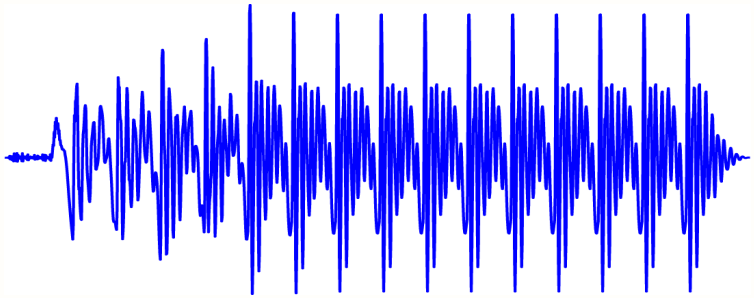
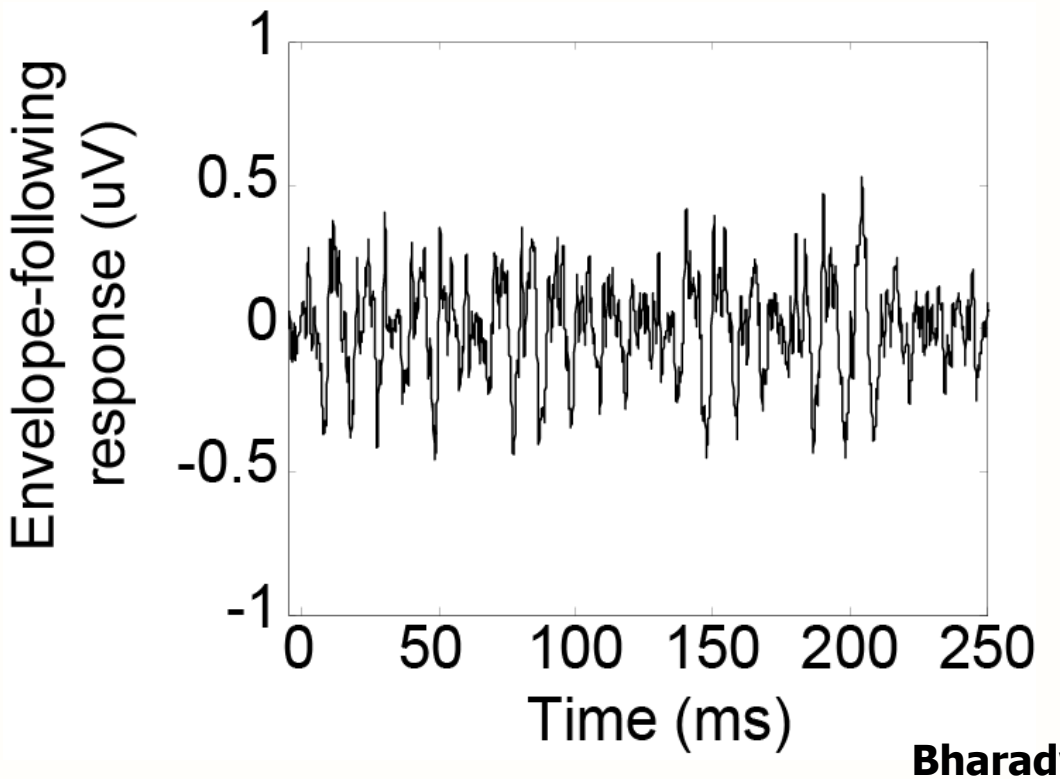
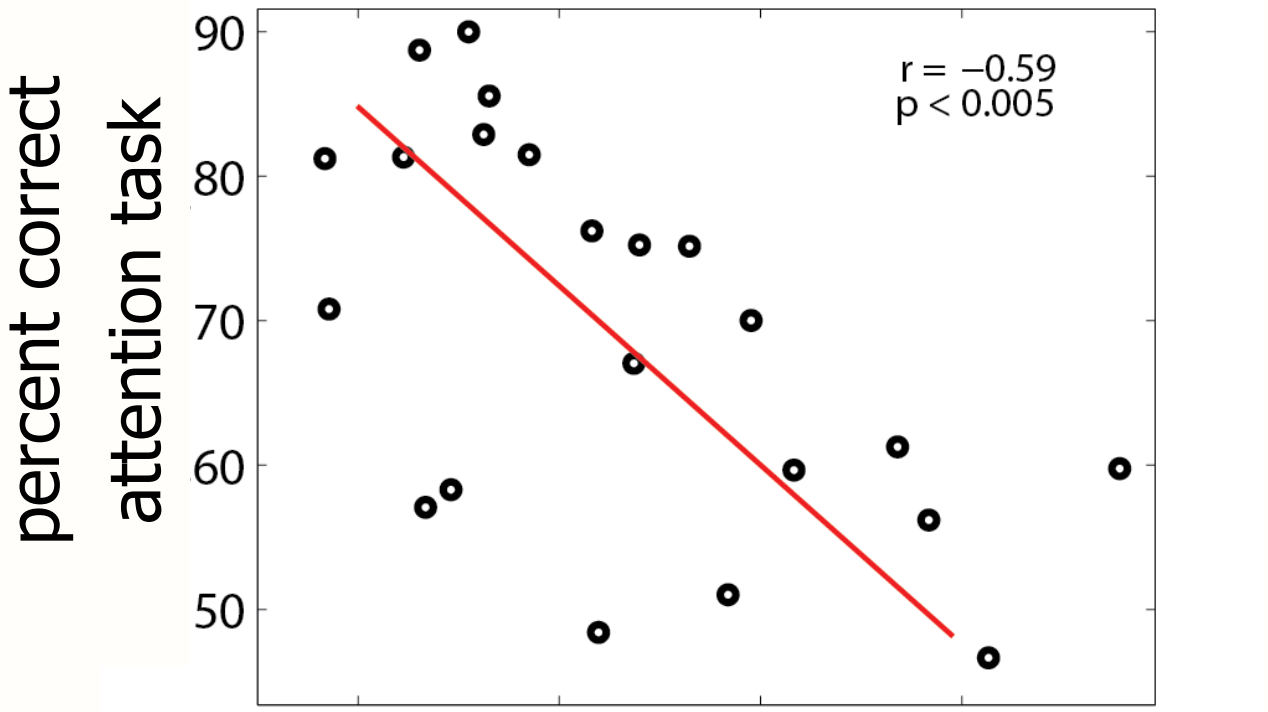




Bharadwaj et al., 2015

Attention performance correlates with brainstem coding



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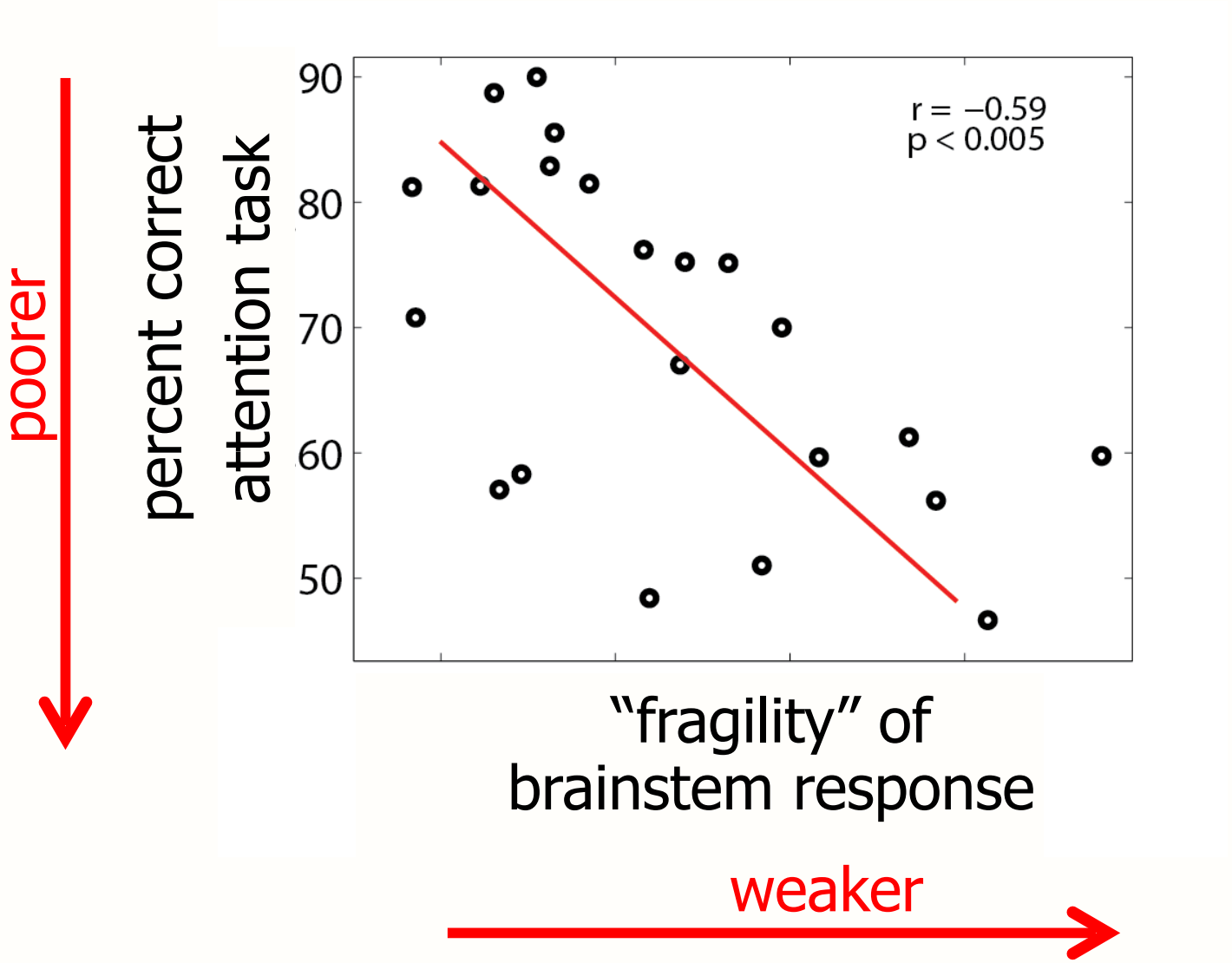


Bharadwaj et al., 2015

Many supra-threshold metrics are correlated

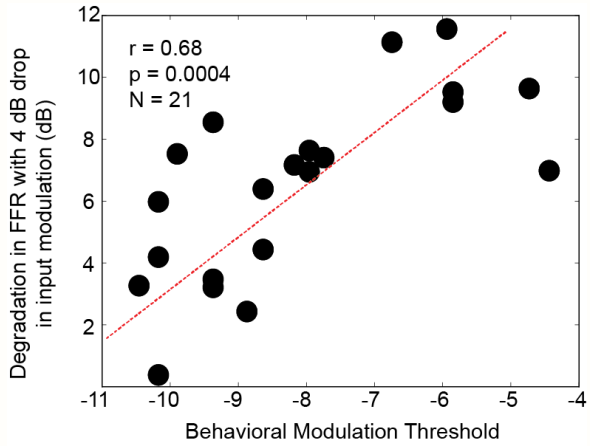
Envelope Following Response (EFR)

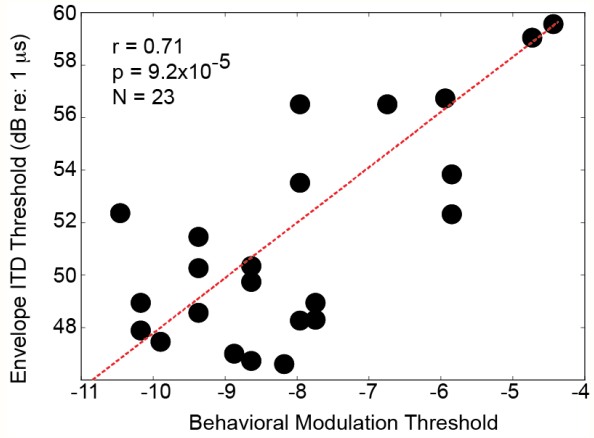
Selective attention ability

Amplitude modulation detection

Frequency modulation discrimination

Interaural time difference discrimination





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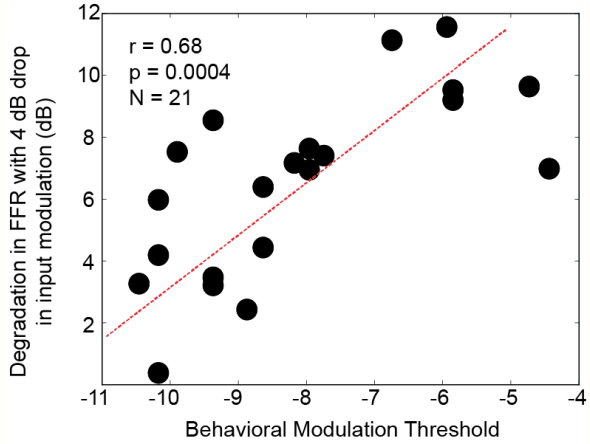
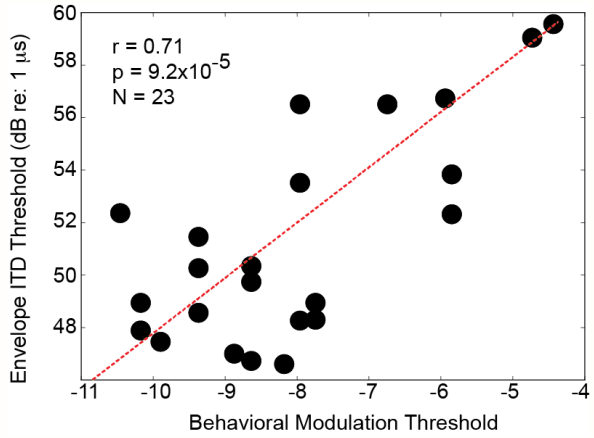
These are all related to coding of fine spectrotemporal features in clearly audible (supra-threshold) sound





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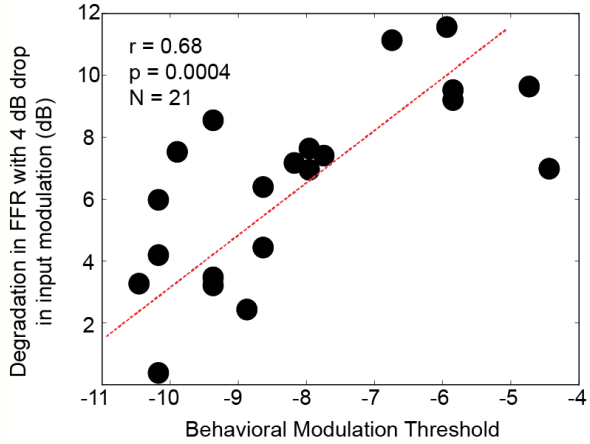

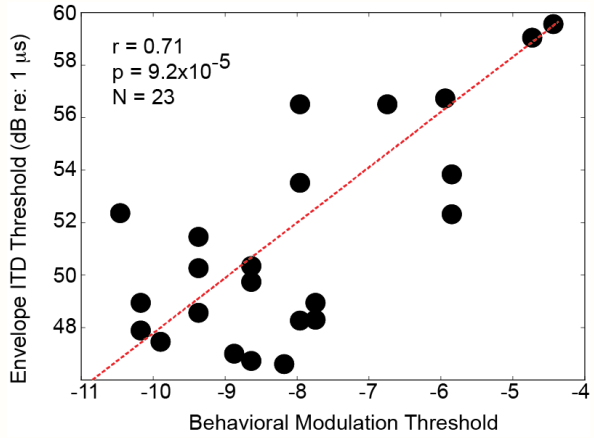

These are all related to coding of fine spectrotemporal features in clearly audible (supra-threshold) sound

Noise exposure history predicts supra-threshold coding fidelity

Bharadwaj et al., 2015

Summary Part I

Auditory attention allows us to understand speech in noise (at the expense of missing other information)

Attention changes in what information is represented in auditory cortex (for those who can control it)

Even listeners with "normal hearing" may have trouble directing selective attention, likely due to cochlear synaptopathy

Part I mysteries

Where in the brain can one see “objects” emerge?

How much of the “knowledge” we have to parse ambiguous scenes is learned, vs. hardwired?

OTICON FONDEN

NIH National Institute on Deafness and Other Communication Disorders (NIDCD)

CELEST

National Science Foundation

Science of Learning Center