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Towards Measuring Tinnitus in a New Way: Listening Effort and Affective Processing

Nicholas Giuliani, Au.D., Ph.D., CCC-A

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Nicholas Giuliani, AuD, PhD

Dr. Giuliani's research focuses on how the body, particularly the autonomic nervous system, responds during challenging listening situations. His current research project explores whether these responses are altered in patients experiencing distressing tinnitus. His long-term goals are to develop tools that will allow future research to 1) objectively measure therapeutics designed to reduce tinnitus distress by targeting the different components of the Cognitive-Behavioral Model of Tinnitus Distress, and 2) examine how different comorbidities such as blast exposure, traumatic brain injury, and post-traumatic stress disorder affect components of the Cognitive-Behavioral Model of Tinnitus Distress.

Disclosures

- **Presenter Disclosure**: Financial: Nicholas Giuliani is employed by the Department of Veterans Affairs. Non-financial: Nicholas Giuliani has no relevant non-financial relationships to disclose. In lieu of an honorarium, a donation has been made to AVAA in the form of AudiologyOnline CEU memberships.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
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- **The information presented herein is my own and does not necessarily reflect the position of the Department of Veterans Affairs or the federal government.**

Learning Outcomes

After this course, participants will be able to:

- Describe how listening effort and affective processing fit within the Cognitive Behavioral Model of Tinnitus Distress.
- Summarize the findings and identify the knowledge gaps regarding listening effort and affective processing in patients experiencing tinnitus distress.
- Discuss how to apply new verification techniques to improve the fitting of noise generators on hearing aids.

Tinnitus is common

- In the United States, nearly 1 in 10 adults report tinnitus (Bhatt et al., 2016)
- US military Veterans: this increases to ~4 in 10 (Carlson et al., 2019).
- Most people are not bothered by their tinnitus, but estimates suggest that ~1.5 million people experience tinnitus distress (Bhatt et al., 2016).

Tinnitus is costly

<u>Refresher</u>

Incidence: # of new cases

Prevalence: proportion of cases/time

Stock photo

Totals – all recipients

Veterans receiving compensation benefits	5,417,012
Survivors receiving service-connected death benefits	477,573
Total:	5,894,585

Estimated annual payments– all recipients

Benefit program	Number of recipients	Estimated annual total payments	Estimated annual average individual payment
Compensation	5,417,012	$112.06 Billion	$20,686
Service-Connected Death	477,573	$8.69 Billion	$18,196
Total:	5,894,585	$120.75 Billion	$20,484

Most prevalent SC disabilities of all compensation recipients

Tinnitus	2,703,665
Limitation of flexion, knee	1,657,593
Hearing loss	1,426,183
Post-traumatic stress disorder	1,343,669
Lumbosacral or Cervical Strain	1,325,248
Paralysis of the sciatic nerve	1,308,812
Scars, general	964,644
Limitation of motion of the ankle	930,108
Limitation of motion of the arm	894,846
Migraine	837,211
Total number of most prevalent disabilities:	13,391,979
Total number of disabilities	33,794,007

Average number of SC disabilities per compensation recipient

All Veterans: 5,417,012	Total number of disabilities[3]: 33,794,007
Average SC disabilities per Veteran:	6.24

[3] Total does not reflect all claimed disabilities as some disabilities are determined not to be related to service.

VA | U.S. Department of Veterans Affairs | Veterans Benefits Administration

Tinnitus is costly

Compensation rates for Veterans with a 10% to 20% disability rating

Effective December 1, 2022

Note: If you have a 10% to 20% disability rating, you won't receive a higher rate even if you have a dependent spouse, child, or parent.

Disability rating	Monthly payment (in U.S. $)
10%	165.92 x 12m x 2.7 million=$5.38 billion
20%	327.99

Tinnitus is costly

- The epidemiological and financial data are staggering
  - Payors (e.g., the federal gvt., private insurance) may look at the numbers and deduce that they are overpaying
  - For example: “if tinnitus does not bother most people, why are we paying so much for it?”
  - Outside of the VA, patients may not have insurance coverage

When tinnitus treatment is covered

Psychological coping therapy including cognitive-behavioral therapy, self-help cognitive-behavioral therapy, tinnitus coping therapy, acceptance and commitment therapy, and psychophysiological treatment, may be considered **medically necessary** for persistent and bothersome tinnitus.

When tinnitus treatment is not covered

Treatment of tinnitus with any of the following therapies is considered **investigational**:

- biofeedback
- tinnitus maskers, customized sound therapy
- combined psychological and sound therapy (eg, tinnitus retraining therapy)
- transcranial magnetic stimulation,
- transcranial direct current stimulation
- electrical transcutaneous electrical stimulation of the ear, electromagnetic energy
- transmeatal laser irradiation.

Tinnitus is costly

- Easy SC to cut to reduce expenditures?
- This is problematic because we rely on subjective reports
- So that we do not deny Veterans' timely compensation, it is important that we find a way to objectively measure some aspect of tinnitus

Tinnitus is difficult to isolate

- There is evidence for tinnitus generator sites at all levels of the ascending auditory pathways.
- "…anywhere between the cochlea and auditory cortex" (Henry et al., 2014)
- Many approaches to measuring tinnitus, each with strengths and weaknesses

Tinnitus is difficult to isolate

Approaches and advantages

- Auditory Brainstem Response (ABR)
  - Milloy et al., 2017: lower amplitude and longer latency Wave I (tinnitus vs. NH)
  - Routine equipment in many clinics
  - Little to no additional training
- Functional Magnetic Resonance Imaging (fMRI)
  - Kim et al., 2012: decreased resting state activity between auditory cortices (n=4);
  - good spatial resolution
- Electroencephalography (EEG)
  - Sedley et al., 2019: tinnitus group had greater MMN to loud deviants
  - good temporal resolution
  - compatible with hearing prostheses

Tinnitus is difficult to isolate

Weaknesses

- ABR
  - inconsistent methodologies; Wave I can be difficult to record; may need additional equipment (e.g., “tiptrodes”)
- fMRI
  - poor temporal resolution; high noise (>130 dB SPL)—especially problematic for tinnitus patients with hyperacusis (sensitivity to loud sounds; often comorbid w/tinnitus); not compatible with hearing prostheses; most expensive; requires a team.
  - Davies et al., 2014: no differences in resting state activity between auditory cortices (n=12)
- EEG
  - poor spatial resolution; requires special training/equipment; time?
  - Jackson et al., (2019): low sensitivity and low clinical utility

Tinnitus can be distressing

- In the clinic, some patients report that their tinnitus impacts cognition and mental health (i.e., anxiety, depression, etc.)
  - Aligns with mechanisms proposed by others (e.g., Sedley et al., 2019)

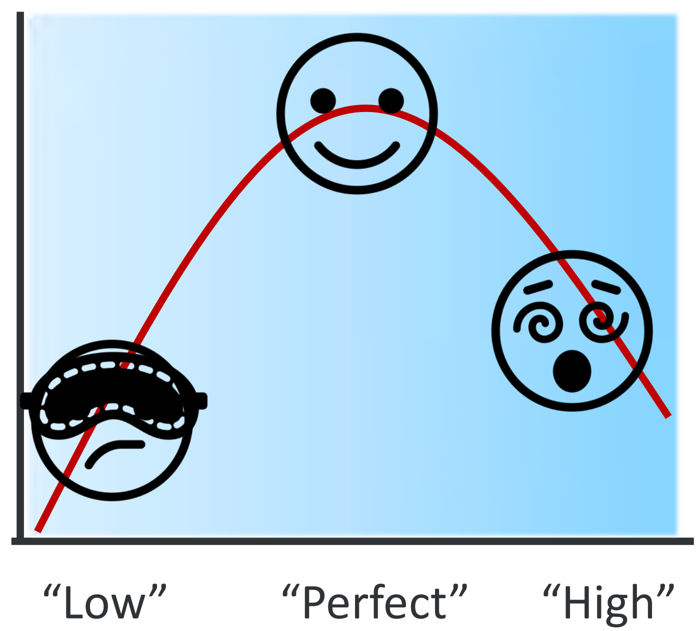
Tinnitus can be distressing

- In the clinic, some patients report that their tinnitus impacts cognition and mental health (i.e., anxiety, depression, etc.)
  - Aligns with mechanisms proposed by others (e.g., Sedley et al., 2019)
- *Presence* of tinnitus versus *distressing (effects of)* tinnitus?
- If this is to be explored further, what options are available and what is being measured?

"Arousal"

Many forms

- Arousal falls on a continuum.
- Frequently characterized as an inverted "U" shape, which is also known as the Yerkes-Dodson Continuum
- "Fight or flight" response (sympathetic nervous system; SNS)
- Subdivision of the autonomic nervous system (also includes the parasympathetic and enteric)
- Norepinephrine (aka Noradrenaline) is a neuromodulator (and hormone)
- Produced in the locus coeruleus.
- Disengaged→participatory→hypervigilant /"on-edge"



Arousal

Wuyts et al., 2012: “pre-sleep cognitive arousal”

- Digit span, Stroop, recognition, symbol substitution
- Sleep onset was significantly increased in the cognitive group
  - Eight minutes—not a lot, but the tasks were “rather mild…lasting ‘only’ half an hour.”

- Kaltenbach et al., 2019: “Heighted cognitive arousal at night is linked to objective sleep disturbance and indicators of physiological hyperarousal at night and during the day.”
- Therefore, one way to possibly quantify tinnitus distress is by examining arousal

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The influence of pre-sleep cognitive arousal on sleep onset processes

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ABSTRACT

Cognitive hyperarousal, resulting in enhanced cognitive activation, has been cited as an important contributor to the development and preservation of insomnia. To further understand this process, our study examined the effects of acutely-induced pre-sleep cognitive hyperarousal on sleep onset processes in healthy volunteers. Following an adaptation night, 15 subjects slept two nights in our sleep laboratory: one reference night and another one with cognitive arousal induction, in a counterbalanced order. In the cognitive arousal condition, subjects worked through half an hour of cognitive tasks without interference of an emotional component prior to retiring to bed. Objective sleep onset latency was significantly prolonged in the cognitive arousal condition compared to the reference condition. Significantly more high frequency activity was recorded during the first and second deep-sleep period. Moreover, differences in heart rate and proximal temperature during and after sleep onset were observed in the nights after the cognitive induction. Pre-sleep cognitive activation successfully induced a significant cognitive load and activation in our subjects to influence subsequent sleep (onset) processes.

Cognition and tinnitus

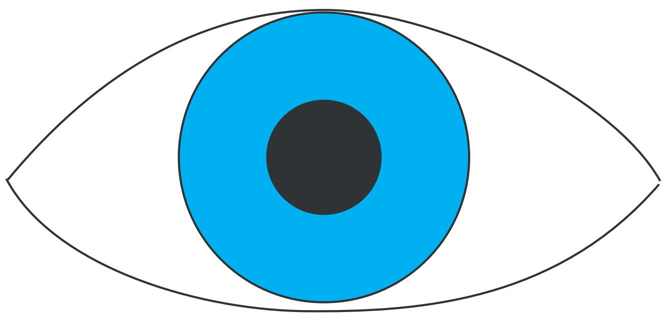
- NE has an inhibitory effect on the auditory cortex, which improves auditory attention (Foote et a., 1975; Glennon et al., 2019)
- [Rats + optical stim of LC]
  - Rats with LC stimulation learned auditory task faster and were more accurate than those who did not (Glennon et al., 2019).
- The LC receives projections from--and sends projections to--the dorsal cochlear nucleus (DCN; Kaltenbach, 2006)
  - “First stop” nucleus of the ascending auditory pathways
  - Evidence for hyperactivity of CN with tinnitus (e.g., Kaltenbach, 2006; Wang et al., 2009)
- LC is likely responsible for modulating and/or maintaining tinnitus (Theodoroff & Kaltenbach, 2019)

Cognition and tinnitus

- One problem: most auditory tasks **<u>are not impacted by tinnitus</u>** (Zeng et al., 2020)
  - 32 out of 36 measures
  - Important suggestion: top-down processes influence tinnitus
- So, if there are no differences (that hold) for people with tinnitus, what do we do? How can we measure distressing tinnitus?
- Zeng and colleagues suggest “top-down” governance of tinnitus, not “bottom-up.”
- Listening effort may provide additional insight

Cognition and tinnitus-measuring?

- Both arousal and cognitive effort (promoted by NE) have been linked to changes in pupil diameter
- Fluctuations in NE covary with pupil size (e.g., Rajkowski et al., 1994)
- The pupil dilates more in response to a cognitively demanding arithmetical task (Kahneman & Beatty, 1966) and when trying to understand speech in noise (Ohlenforst et al., 2017).
- The pupil also dilates in response to arousing images and sounds (Bradley et al., 2008)
- Mostly governed by the SNS
- Sensitive and reliable
  (Alhanbali et al., 2019; Giuliani et al., 2021)



Arousal and tinnitus

Szibor et al. (2018) measured pupil dilations to positive, negative, and neutral sounds in 10 adults with chronic tinnitus and found that they exhibited large pupil dilations to negative sounds, but smaller and statistically similar dilations to positive and neutral sounds.

- Dampened” pupil responses to positive sounds
- These results were interpreted as evidence for altered affective processing of positive sounds in patients with chronic tinnitus.
- “Like results obtained in depressed patients

Listening effort and tinnitus

- LE is a subcategory of cognitive effort
- Many components and many ways to measure (See Pichora-Fuller et al., 2016 and McGarrigle et al., 2014 for review)
- Pupillometry and dual tasks are common
- Why use a physiological/behavioral tool when we can just ask?
  - Lack of understanding (Moore & Picou, 2018)
    - Others are hesitant to use the extremes of scales
  - Not sensitive to differences between NH and HI (Ohlenforst et al., 2017)

Listening effort and tinnitus

Promising, but not well-studied in tinnitus patients

- Degeest et al., (2017; 2021): Adults with chronic tinnitus exhibit greater listening effort than controls with NH
- Juul Jensen et al., 2018 found no significant differences in LE (i.e., pupil diameter) between tinnitus and non-tinnitus groups
  - Attributed to greater fatigue
- Many potential confounders in these studies (hearing not assessed, HAs?, low subjective tinnitus ratings)

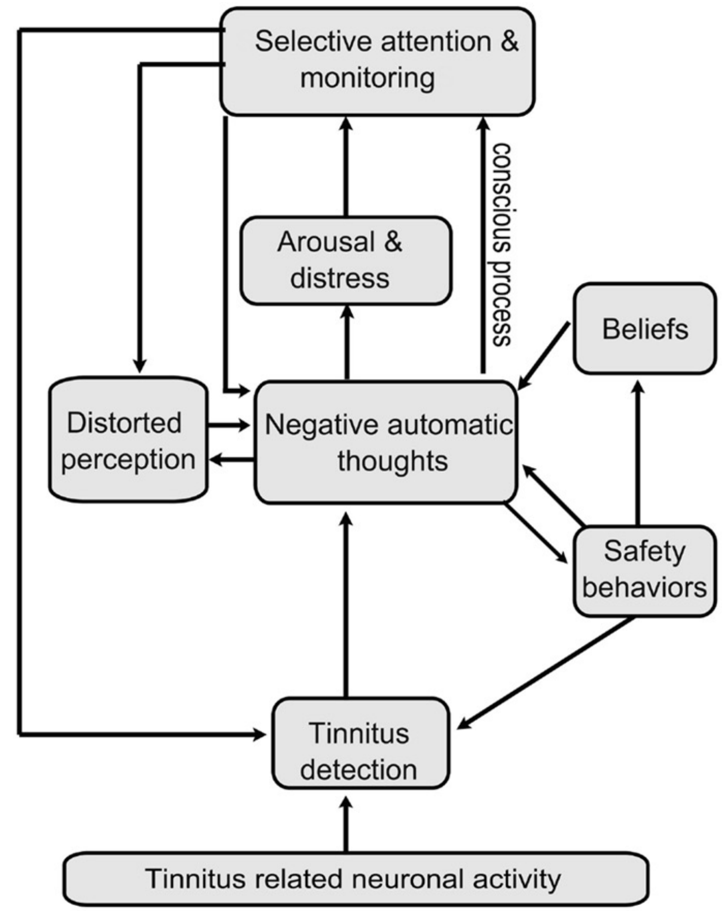
Listening effort and tinnitus

- Pupillometry shows how listening effort changes, even in the absence of decrements to word understanding
  - Winn et al., 2015: vocoded speech
  - McLaughlin & Van Engen, 2018: stand American English versus Chinese Mandarin
  - Fiedler et al., 2021: noise reduction on hearing aids
- May explain why Zeng et al., (2020) did not observe differences amongst groups, yet subjective/clinical reports from tinnitus patients suggest differently.
- Investigating listening effort and arousal in tinnitus patients is supported by the Cognitive Behavioral Model of Tinnitus Distress (McKenna et al., 2014)

Cognitive Behavioral Model of Tinnitus Distress(CBMTD)

McKenna et al., 2014

- Testable
- Path analyses suggest a good relationship amongst many components (Handscomb et al., 2020).



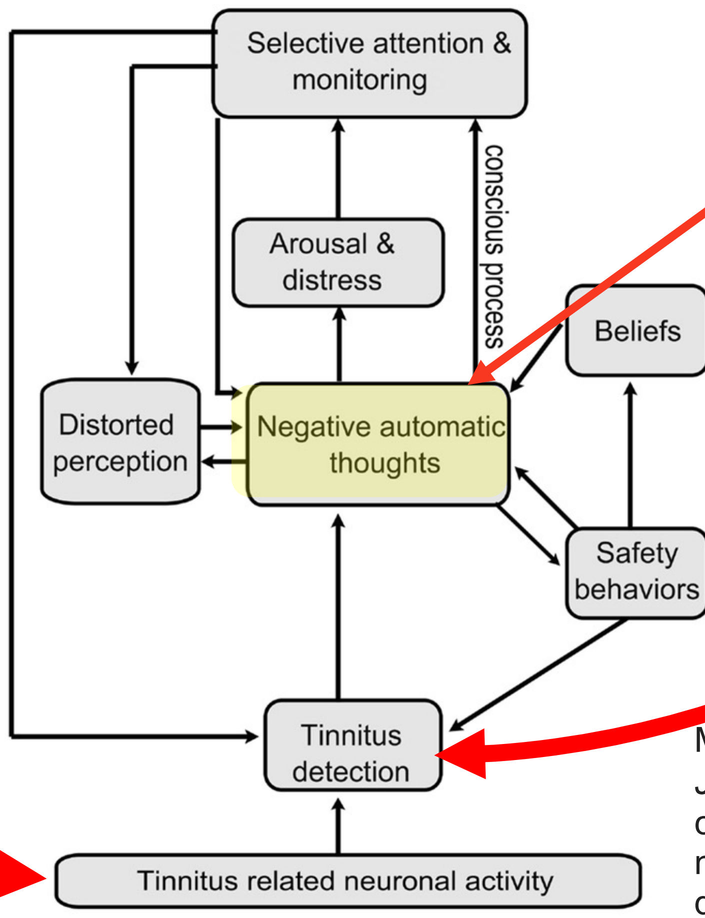
McKenna, L., Handscomb, L., Hoare, D. J., & Hall, D. A. (2014). A scientific cognitive-behavioral model of tinnitus: novel conceptualizations of tinnitus distress. *Frontiers in neurology*, *5*, 196.**Open-access**

Cognitive Behavioral Model of Tinnitus Distress

Key sustaining component

“I hear this noise”

Event (e.g., HL, noise exp.)



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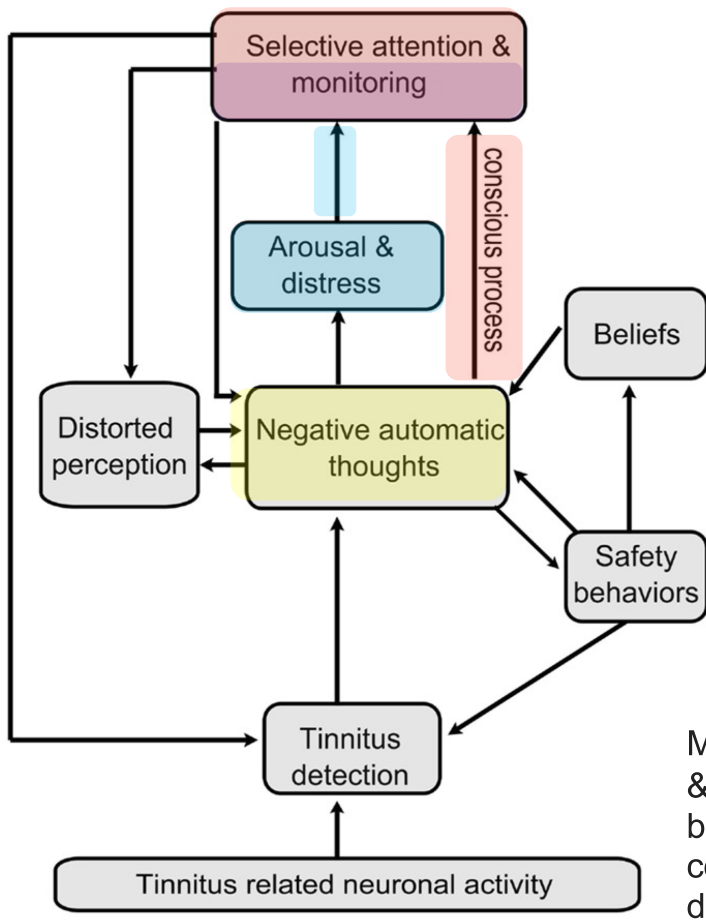
Cognitive Behavioral Model of Tinnitus Distress



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Measuring the effects of tinnitus?

Pupillometry

Listening Effort

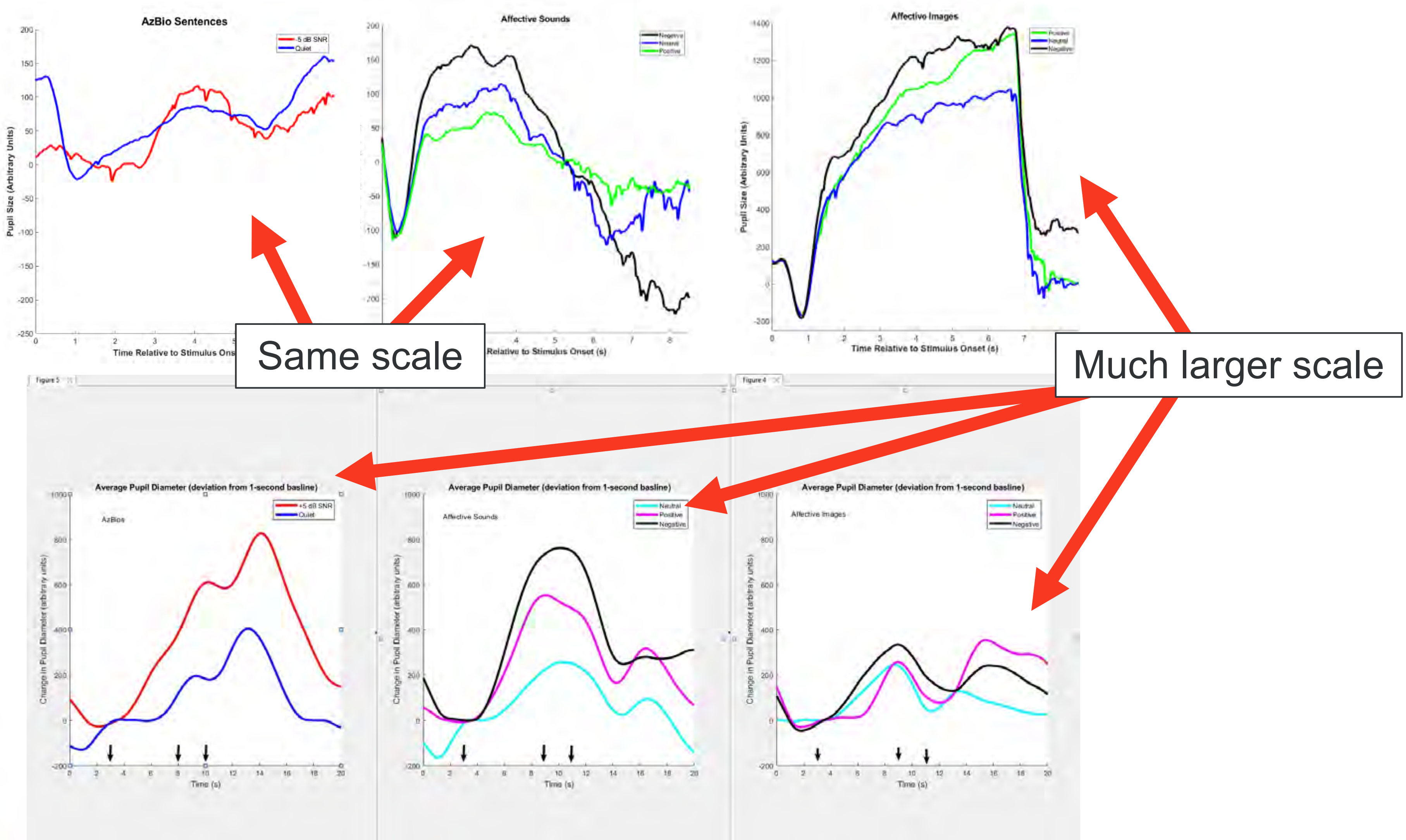
- AzBios (Spahr et al., 2012)
    - Commonly used in VA clinics
    - Quiet and +5 dB SNR

Arousal/Affective Processing

- International Affective Digital Sounds system (IADS; Bradley & Lang, 2007)
- International Affective Pictures System (IAPS; Bradley & Lang, 2008)

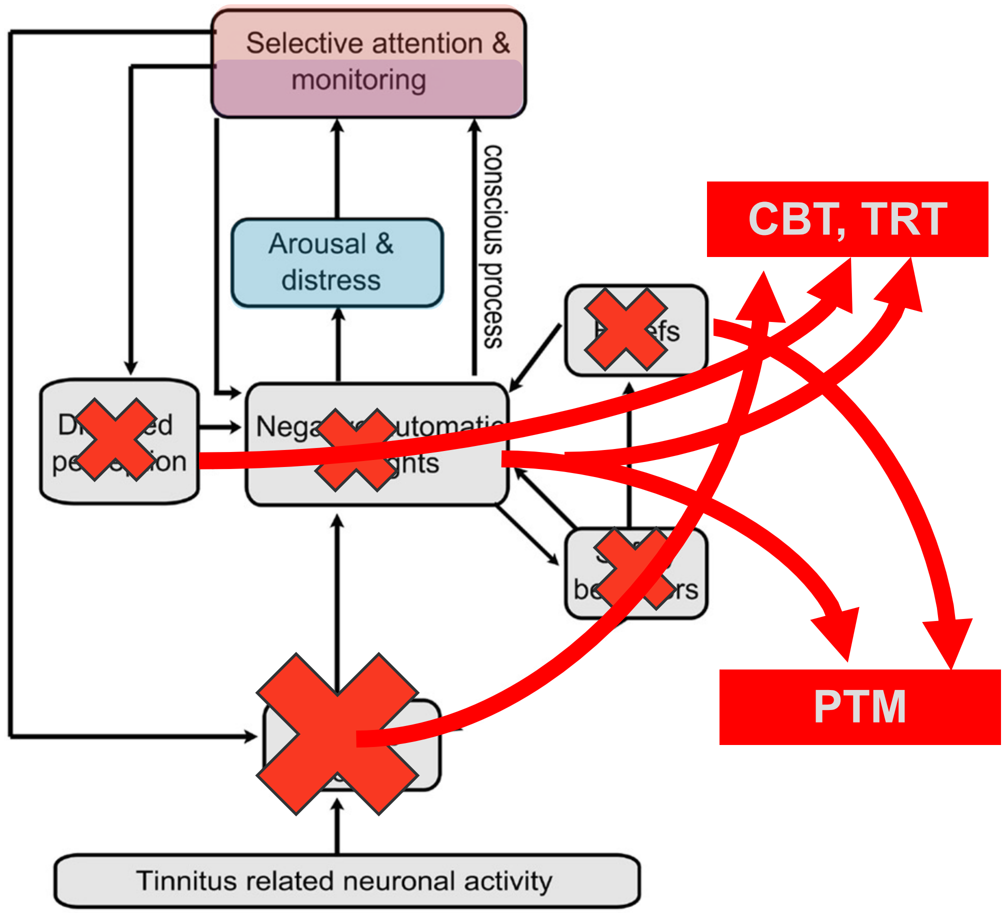
The end goal is to have several measurements that can be used as a potential way to quantify the benefit of various interventions

Measuring the effects of tinnitus?



Current therapies

- The paths are many



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Hearing Aids and Tinnitus

- Yakunina et al., 2019—wearing hearing aids for three months significantly decreased tinnitus annoyance
- Parazzini et al., 2011—Sound generators or HA + Tinnitus Retraining Therapy
- Waechter & Jönsson, 2022—**verified** aids reduce tinnitus loudness; seems to remain effective longitudinally (compared to non-verified aids)
- Tyler et al., 2020—tinnitus patients benefit from sound therapy

BUT

Hearing Aids and Tinnitus

- Systematic reviews find fault in many studies suggesting problems with bias, small sample sizes, etc.
- Henry et al., (2022) suggest that **these reviews apply overly strict criteria**, thus obfuscating the potential benefit of SGs
    - Clinician evidence for positive benefit from SGs

For individuals who have tinnitus who receive sound therapy, the evidence includes RCTs and a systematic review of RCTs. Relevant outcomes are symptoms, functional outcomes, quality of life, and treatment-related morbidity. The evidence on tinnitus masking includes RCTs and a systematic review of RCTs. The RCTs had medium- to high-risk of bias and did not show the efficacy of masking therapy. Research on customized sound therapy appears to be at an early stage. For example, the studies described the use of very different approaches for sound therapy, and it is not yet clear whether therapy is more effective when the training frequency is the same or adjacent to the tinnitus pitch. A 2016 trial, double-blind and adequately powered, found no benefit of notched music on the primary outcome measures of tinnitus perception and tinnitus distress, although the subcomponent score of tinnitus loudness was reported to be reduced. Two more recent RCTs evaluating notched music therapy for tinnitus found no significant differences in efficacy between this approach and ordinary music therapy or counseling. A benefit on tinnitus loudness, but not tinnitus perception or tinnitus distress is of uncertain clinical significance, may be spurious, and would need corroboration in additional studies. The evidence is insufficient to determine that the technology results in an improvement in the health outcome.

Hearing Aids and Tinnitus

- Suggestion: develop standard procedures for fitting SGs and quantify them
- At what level do you set the SG? Threshold? Of what? A certain number of dB SL?
  - Currently not addressed in the literature
- Suggestions from ASHA

Future Directions

Tinnitus presents several challenges for clinicians because there is generally no cure, and there is a lack of consensus and standardization regarding definition, objective measurement, assessment, and management. Future responses to these difficulties may include

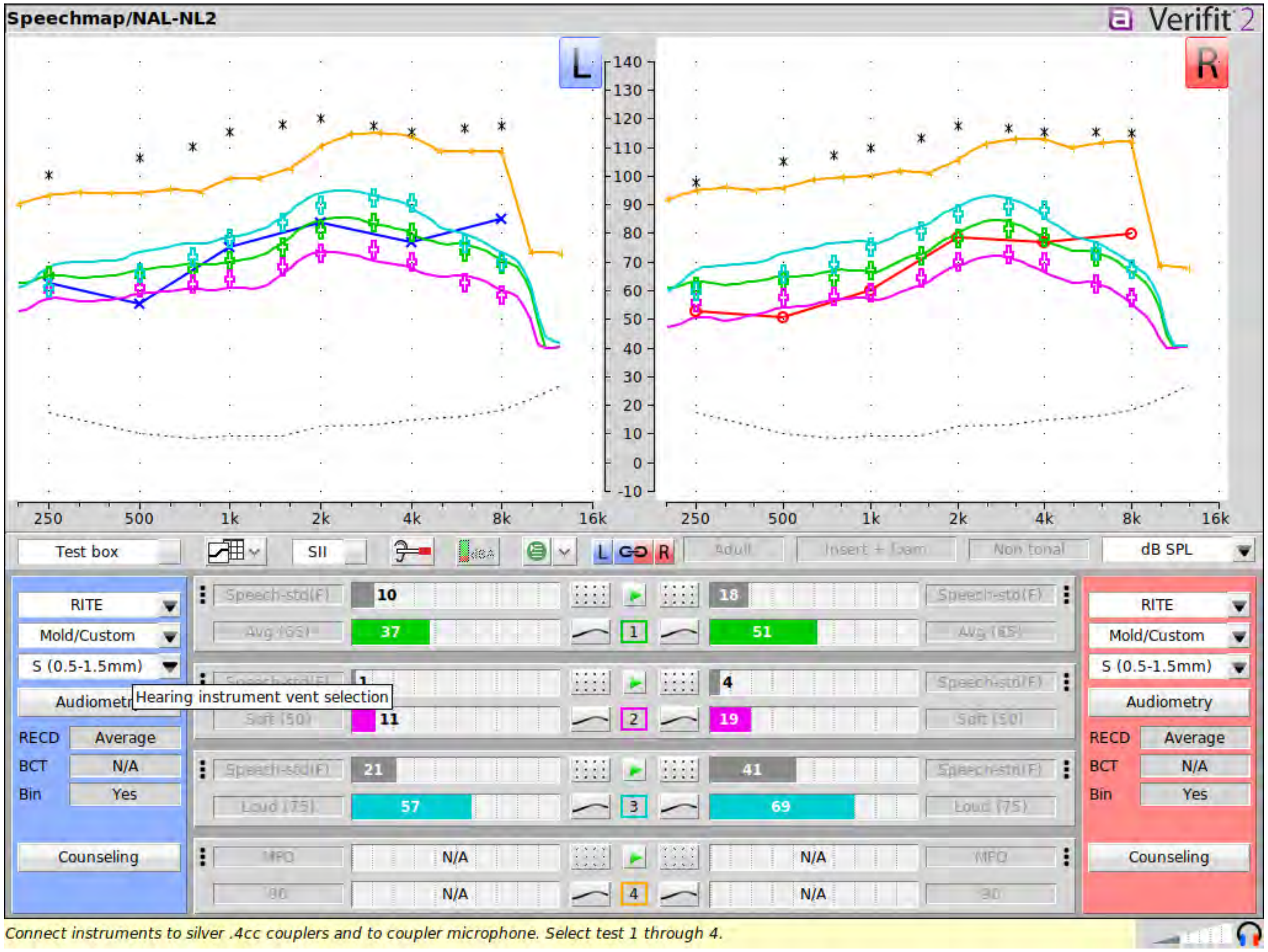
- standardized training for students, audiologists, and other practitioners;
- collaboration among tinnitus experts to define important outcomes of focus for clinical trials; and
- standardized procedures for the diagnosis, assessment, and management of tinnitus.

https://www.asha.org/practice-portal/clinical-topics/tinnitus-and-hyperacusis/#collapse_6

SG verification

- Not challenging, can be done with clinic equipment, AND validates your settings.
- We do not use “first fit” algorithms, nor do we rely entirely on patient’s subjective reports or what the software says
- Verifying SGs will ensure they are providing benefit AND that they are doing what we think they are doing

Step I

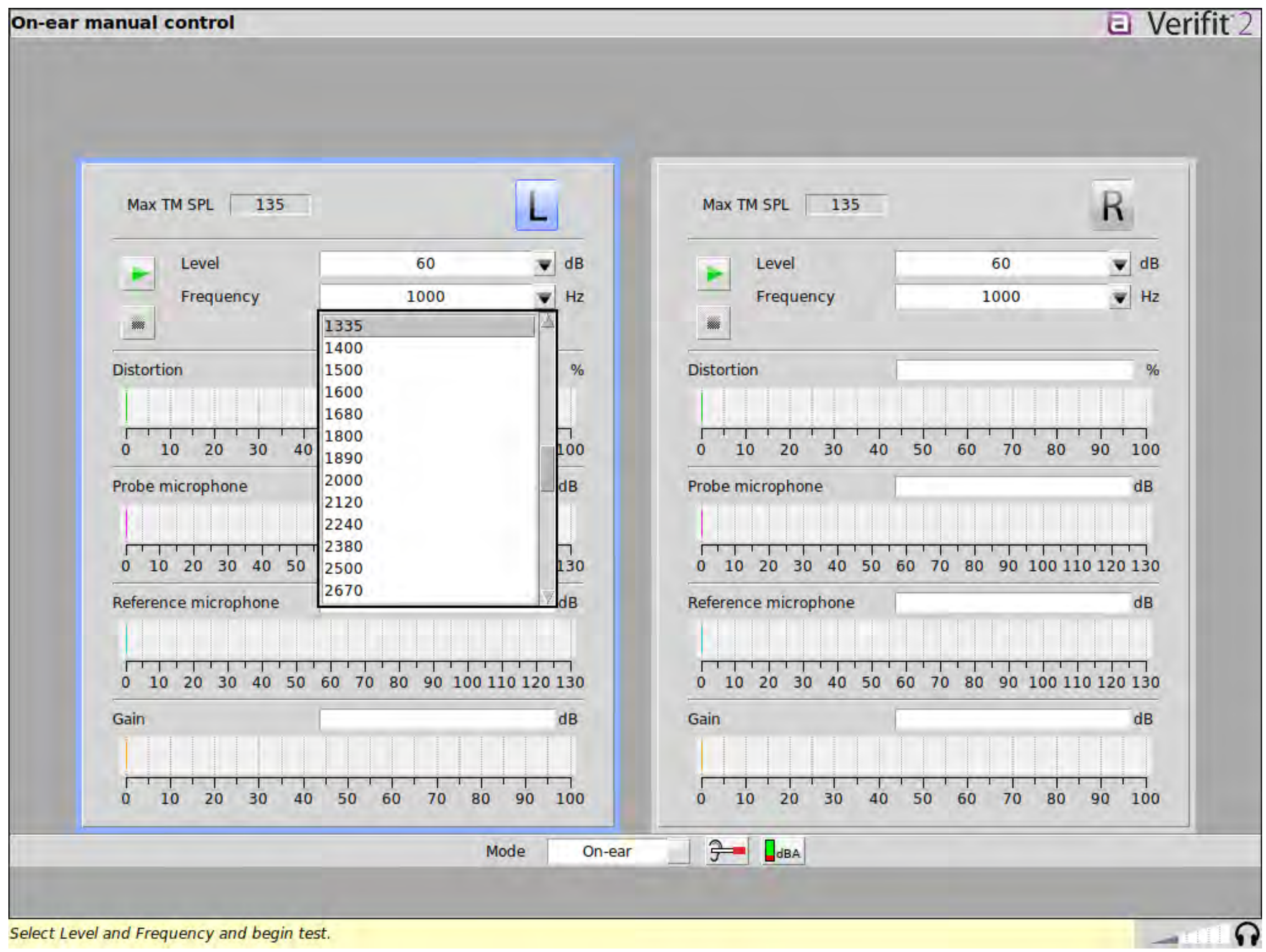


Speechmap/NAL-NL2
Verifit 2
L
R
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
250
500
1k
2k
4k
8k
16k
Test box
SII
dB SPL
RITE
Mold/Custom
S (0.5-1.5mm)
Audiometry
Hearing instrument vent selection
RECD
Average
BCT
N/A
Bin
Yes
Counseling
Speech-std(F)
Avg (65)
Soft (50)
Loud (75)
MPO
90
10
37
18
51
11
4
19
21
57
41
69
N/A
1
2
3
4
Connect instruments to silver .4cc couplers and to coupler microphone. Select test 1 through 4.

Step II

“Manual Control”

Intent was to use as SLM



Clinical Value

Why would I want to add time to my fitting?

- May be able to use additional CPT codes, which =additional RVUs

Clinical Value

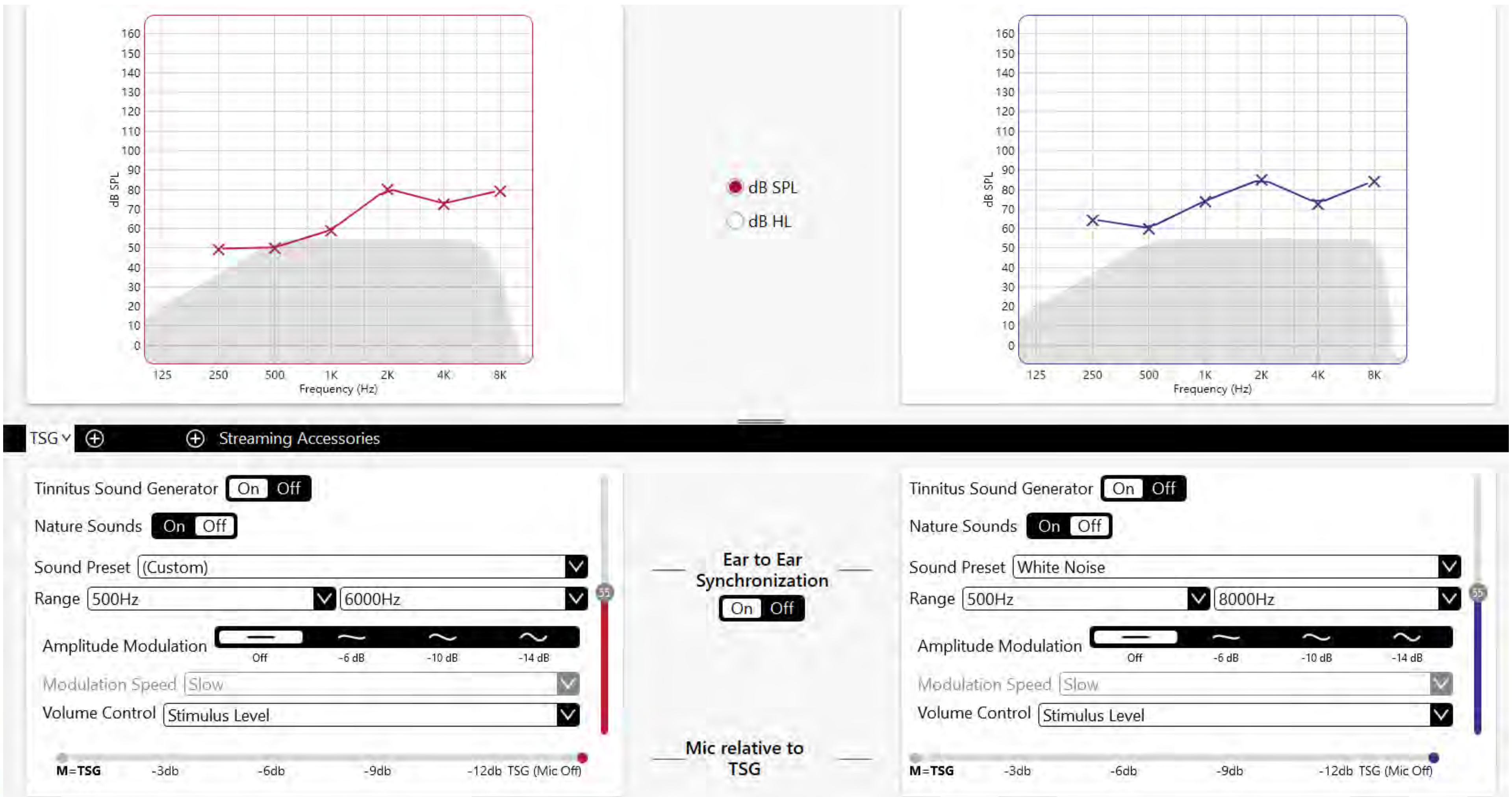
Why would I want to add time to my fitting?

- May be able to use additional CPT codes, which =additional RVUs

<u>I am not a coding specialist</u>

- ASHA lists: 92625 Tinnitus assessment
  - Pitch/loudness matching, masking
  - Technically, not ear specific but could plug/mask contralateral ear
  - V5020—but cannot use twice (e.g., NAL-NL2 then SG)
  - V5299—might be able to use for fitting SG

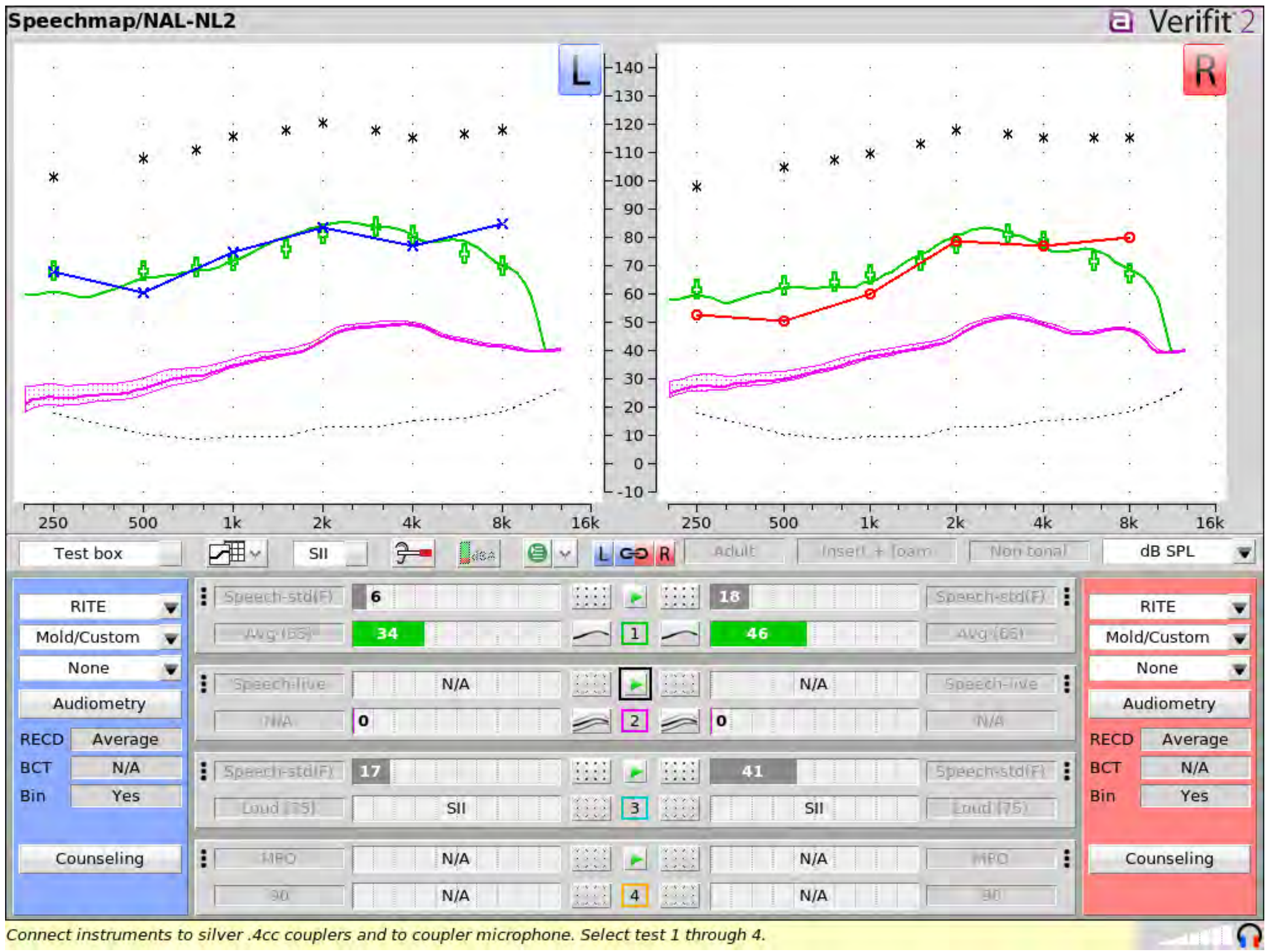
Part III



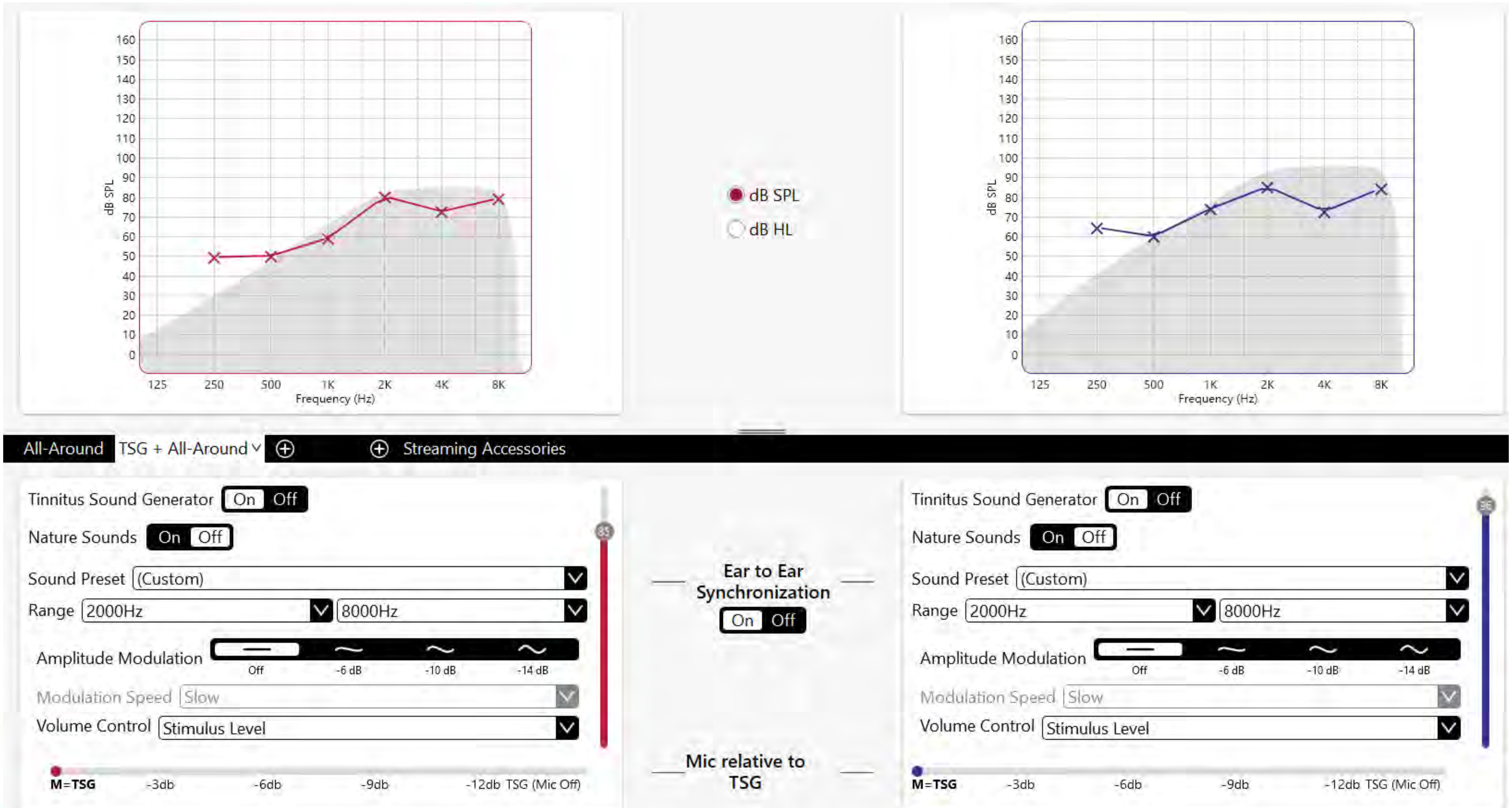
dB SPL
Frequency (Hz)
125
250
500
1K
2K
4K
8K
dB SPL
dB HL
TSG
Streaming Accessories
Tinnitus Sound Generator On Off
Nature Sounds On Off
Sound Preset (Custom)
Range 500Hz 6000Hz
Amplitude Modulation
Off
-6 dB
-10 dB
-14 dB
Modulation Speed Slow
Volume Control Stimulus Level
M=TSG -3db -6db -9db -12db TSG (Mic Off)
Ear to Ear Synchronization
On Off
Mic relative to TSG
Tinnitus Sound Generator On Off
Nature Sounds On Off
Sound Preset White Noise
Range 500Hz 8000Hz
Amplitude Modulation
Off
-6 dB
-10 dB
-14 dB
Modulation Speed Slow
Volume Control Stimulus Level
M=TSG -3db -6db -9db -12db TSG (Mic Off)

Part III

Output is much lower than software suggests.

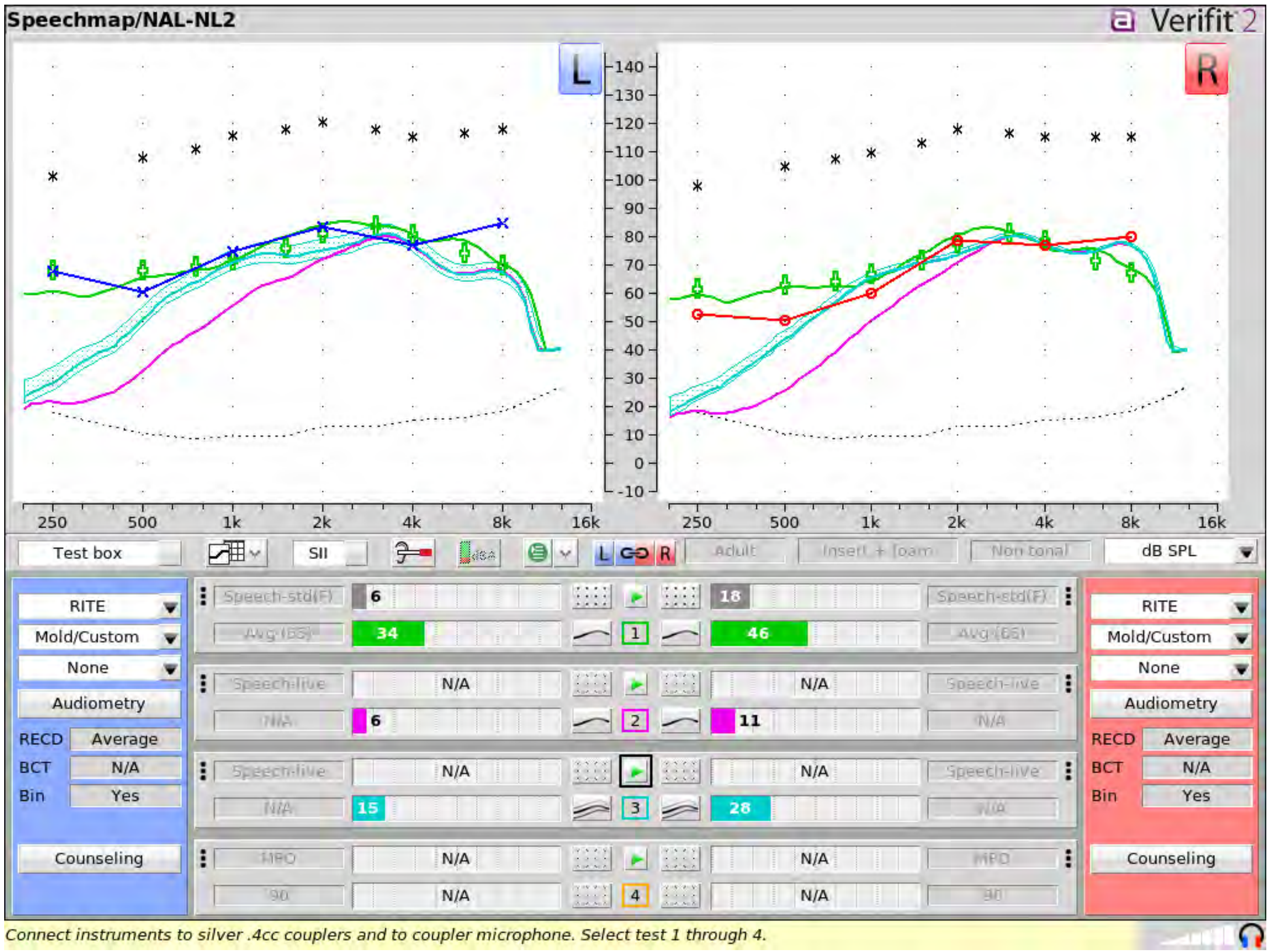


Part III


dB SPL
dB HL
Frequency (Hz)
dB SPL
125 250 500 1K 2K 4K 8K
All-Around
TSG + All-Around
Streaming Accessories
Tinnitus Sound Generator On Off
Nature Sounds On Off
Sound Preset (Custom)
Range 2000Hz 8000Hz
Amplitude Modulation
Off -6 dB -10 dB -14 dB
Modulation Speed Slow
Volume Control Stimulus Level
M=TSG -3db -6db -9db -12db TSG (Mic Off)
Ear to Ear Synchronization
On Off
Mic relative to TSG
Tinnitus Sound Generator On Off
Nature Sounds On Off
Sound Preset (Custom)
Range 2000Hz 8000Hz
Amplitude Modulation
Off -6 dB -10 dB -14 dB
Modulation Speed Slow
Volume Control Stimulus Level
M=TSG -3db -6db -9db -12db TSG (Mic Off)

Part III

- Software end: 96 dB for the left and 85 dB for the right
- SG is detectable (i.e., at threshold) ~2-4 kHz, AD; 3-4 kHz, AS
- Cyan line is broadest bandwidth
- Magenta line is bandpass filtered
- Confirm with patient



However,

<u>What we do not know</u>

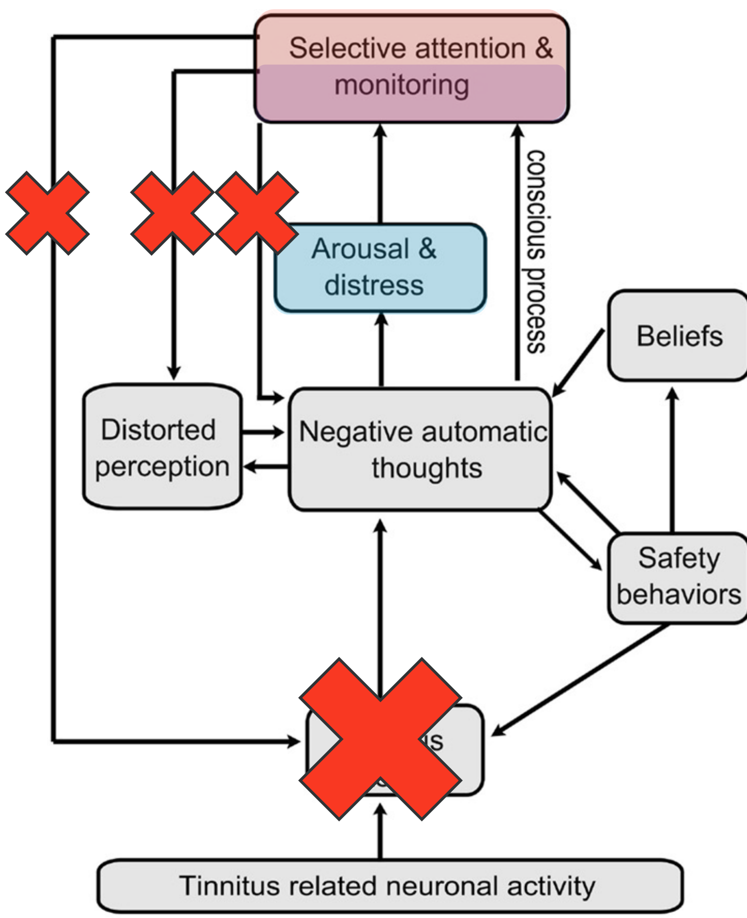
- Level of the masker?
  - One company suggests setting it to threshold
  - Ultimately, no data-driven suggestions
- How much control should the patient have?
- Should the noise be filtered or broadband?
- Monaural versus binaural?
- Prescription?
- Many others

Next steps?

- I am hoping to develop/evaluate the measures discussed here and then use them to evaluate the efficacy of different interventions (e.g., HAs, SGs, etc.)
- Perhaps the measures could address concerns raised in systematic reviews (especially SGs)

Next steps?

- Objective measures may satisfy concerns raised previously



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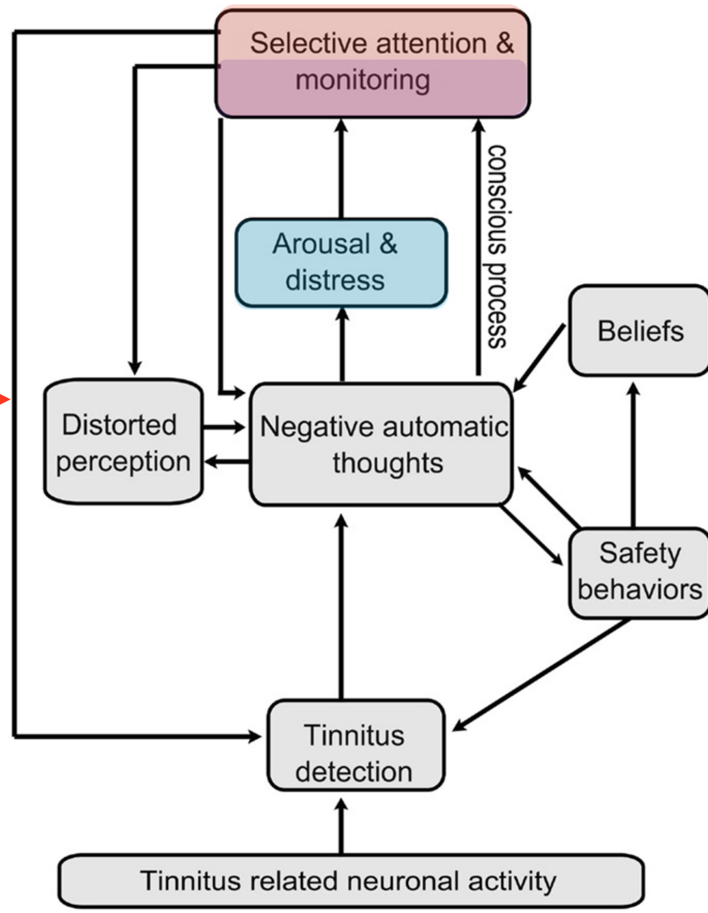
Next steps?

Blast exposure PTSD TBI



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Thank you!

- **AAA:** *New Investigator Research Grant*
- **AVAA**
- **AO**

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