A reliable 2-min noise acceptance test that predicts more than hearing aid acceptance

It measures *subjective* speech intelligibility

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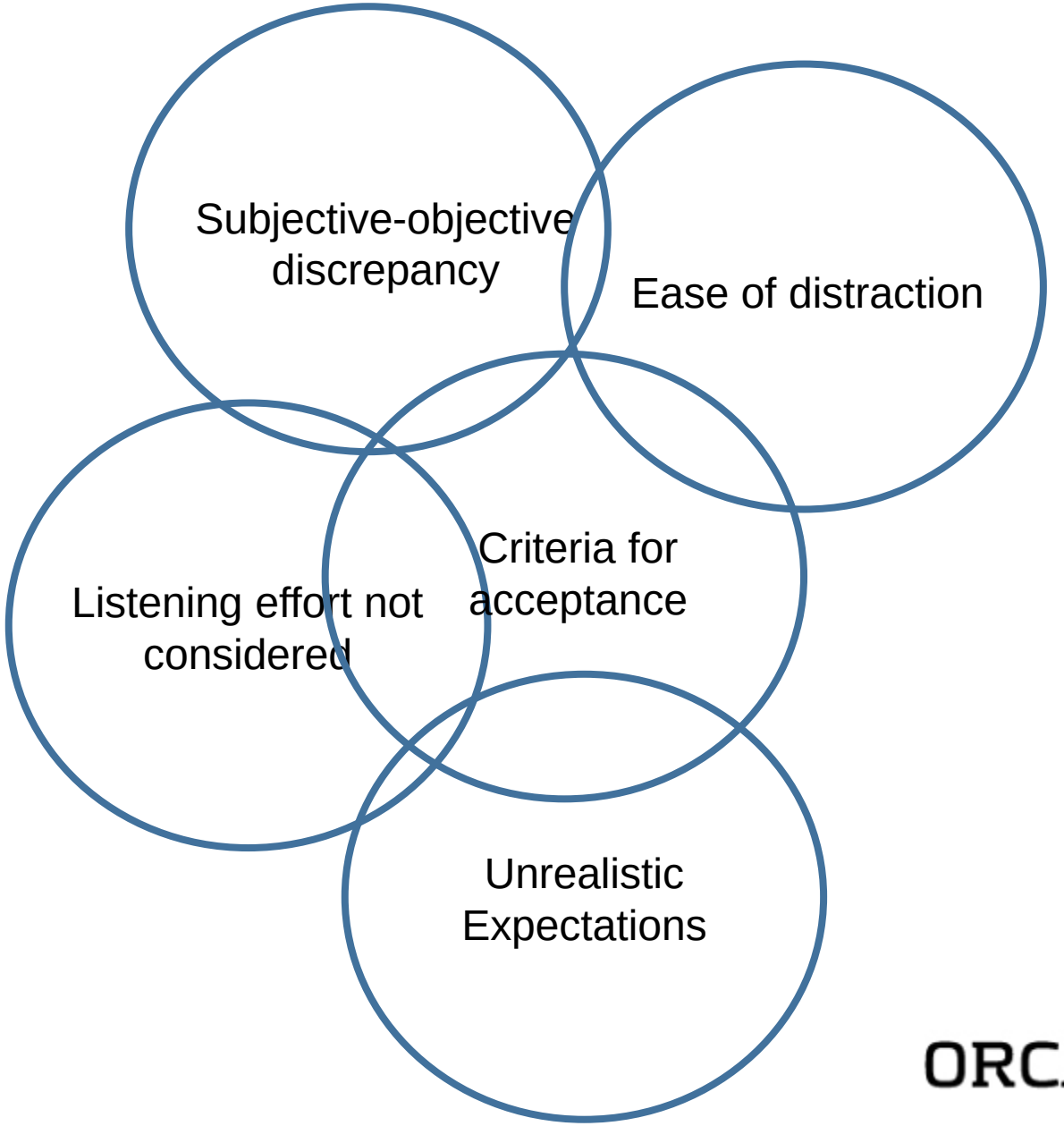
SPEAKER DISCLOSURE

Relevant Financial Relationships: Employee of WS Audiology

Relevant Nonfinancial Relationships: None

COMMUNICATION OR DEVICE SATISFACTION IN NOISE IS MORE THAN SPEEECH UNDERSTANDING SCORES



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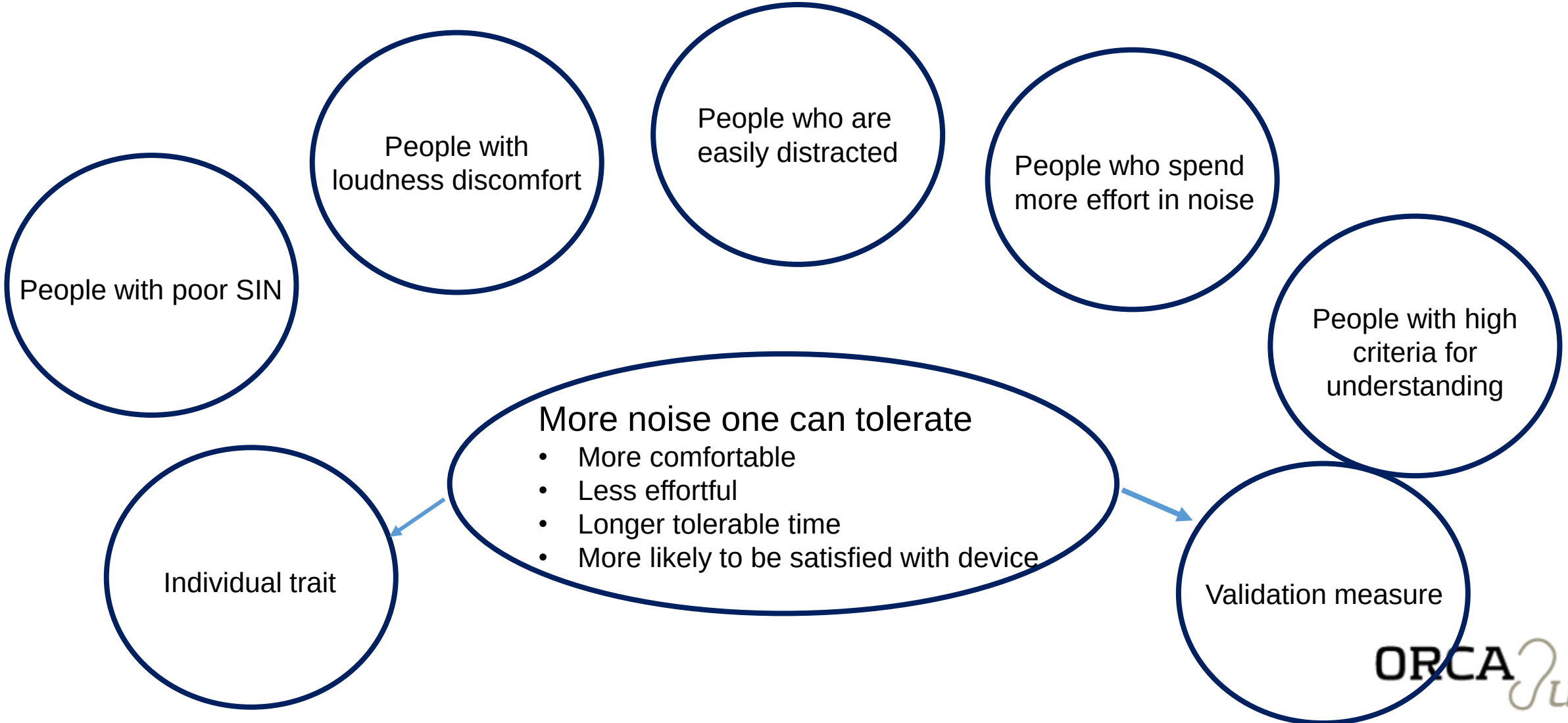
ARE WE **BARKING UP THE WRONG TREE**?

Speech in noise complaint/problem may not be just a problem with objective speech understanding, but a problem with how the person ***perceives*** his/her handling of noise

We need to consider the subjective factors involved in speech-in-noise problems; measuring noise acceptance is one way to get at this information

WHY MAY MEASURING NOISE TOLERANCE (WHILE MAINTAINING SPEECH UNDERSTANDING) BE BETTER AT ESTIMATING DEVICE SATISFACTION?



WHAT IS THE **ACCEPTABLE NOISE LEVEL** (ANL) TEST?

ANL = Most Comfortable Level (MCL) – Background Noise Level (BNL)

e.g., 5 = 75 – 70, thus *smaller number means better performance*

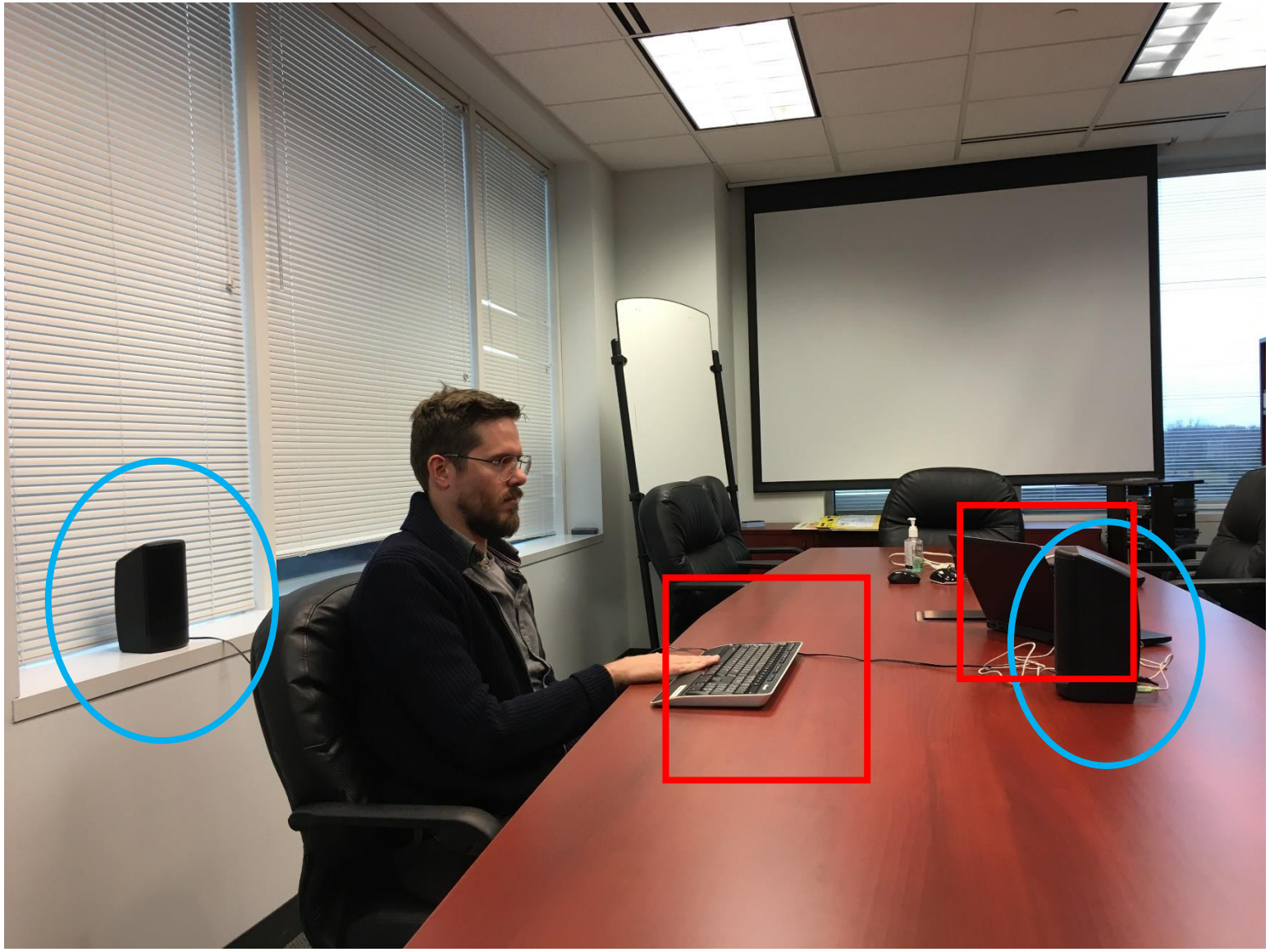
POTENTIAL ISSUES WITH ANL

- Test-retest reliability may not be sufficient to evaluate device efficacy
- Same travelogue passage – learning effect
- Non-specific instructions
  - ..*follow the story*…
- Appropriateness of speech at MCL for noise evaluation
- “Discrete point” sampling

HOW MAY NOISE ACCEPTANCE BE MEASURED?

- Improve reliability
  - Fixed speech input level
  - Tracking noise level for 2 min
  - Use multiple equivalent passages
- Speech filtered according to input level to approximate speech spectra of increased vocal effort
- Specify intelligibility criteria – > 90%
- Direct interpretation
  - **TNT** = TNL – speech
  - Higher TNT, greater noise tolerance

TRACKING OF NOISE TOLERANCE (TNT) - PHYSICAL **SETUP**



Headphone (unaided) also

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INSTRUCTIONS – TOLERABLE NOISE LEVEL

- *You will hear some noise in the background while you listen to the male talker. The noise will automatically get louder. I want you to monitor the noise level and maintain the loudest noise level you can put up with while still understanding 90% of the words in the story. If the noise becomes too loud, where you can no longer put up with it or understand less than 90% of the words in the story, you can turn the noise down by pressing and holding the space bar. If it appears softer than before, you should allow the volume to increase by letting go of the space bar. If it is louder than before, you should turn the volume down to keep at the same level by pressing the space bar again. Your ability to understand speech should never change to below 90%. The test will run for two minutes and then stop.*

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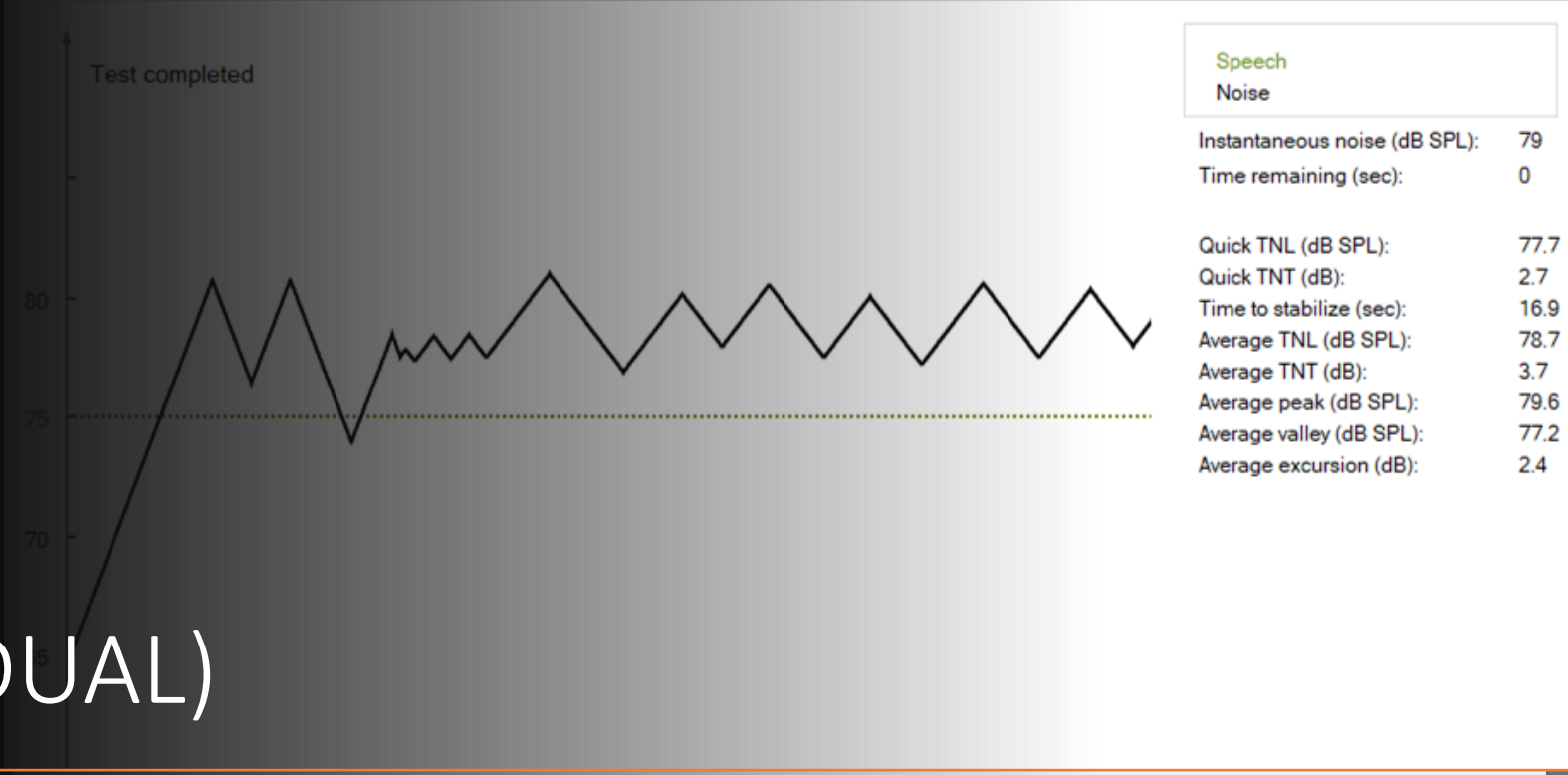
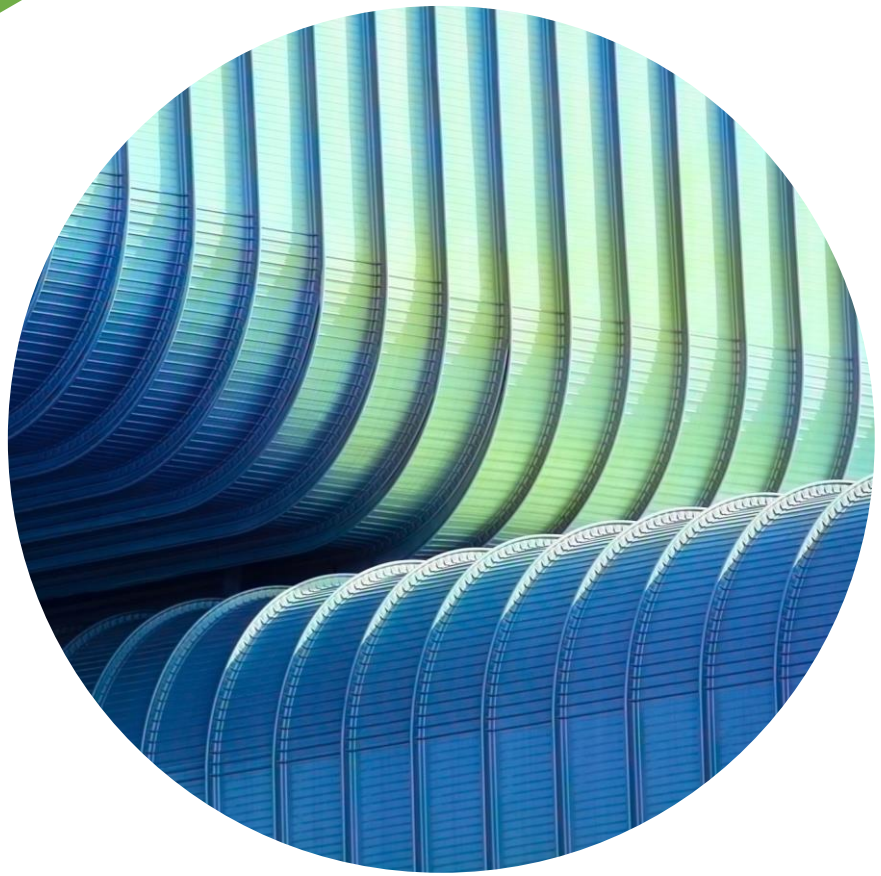
TNL TRACKING **RESULTS** (INDIVIDUAL)



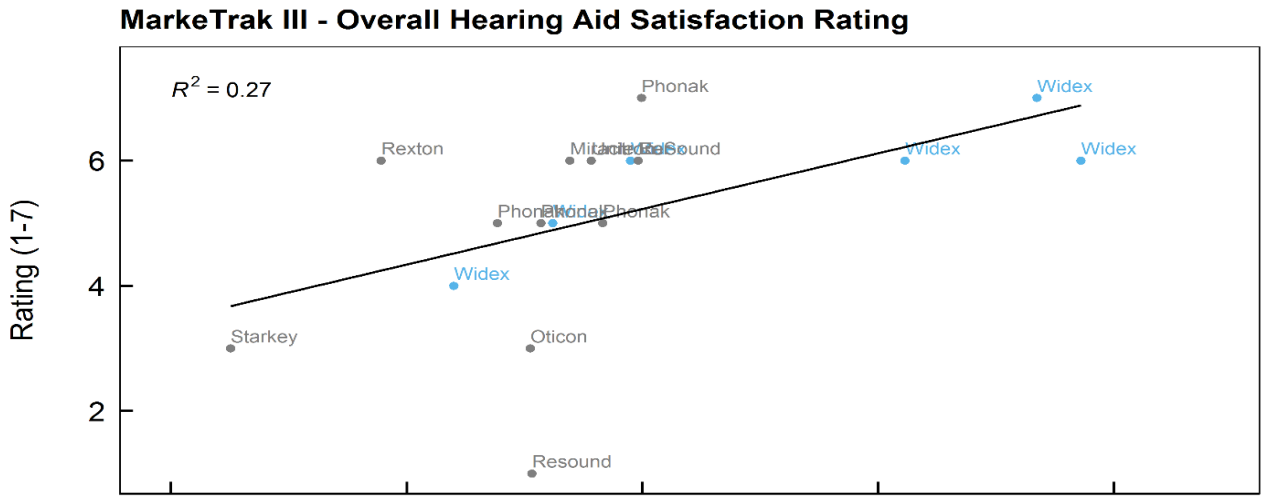
THE TNT HAS GOOD **TEST-RETEST** RELIABILITY

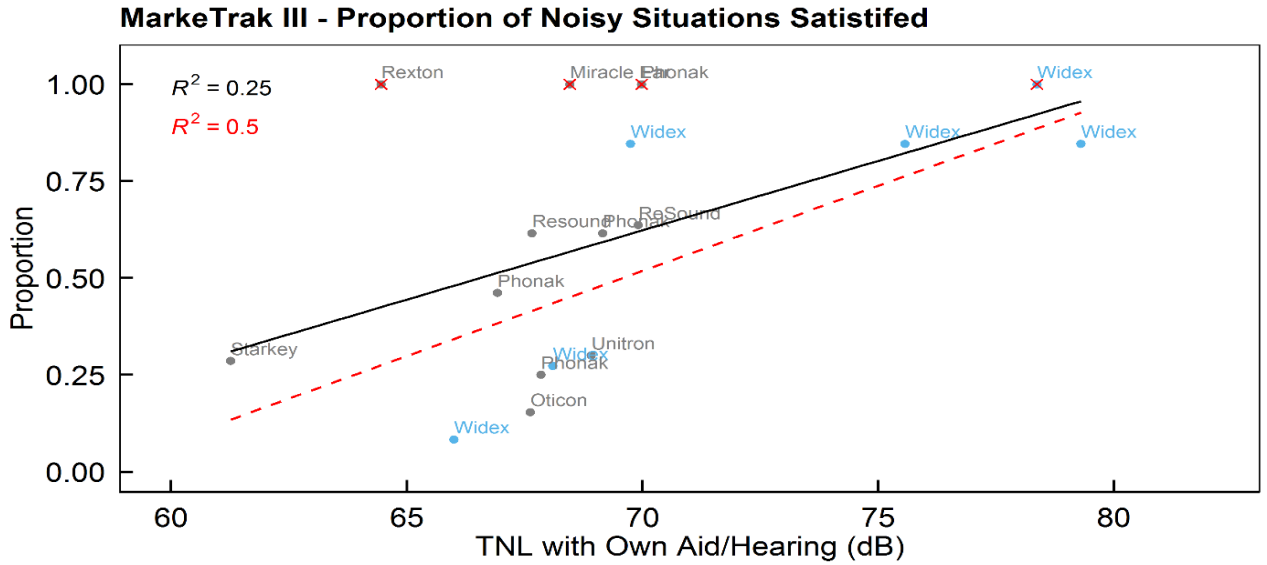
Within session test-retest difference (95% confidence interval) of 2 dB

Between sessions test-retest difference (95% confidence interval) of 4 dB



OBSERVATION: WEARERS WHO ARE MORE SATISFIED WITH THEIR HEARING AIDS HAVE HIGHER TNTS



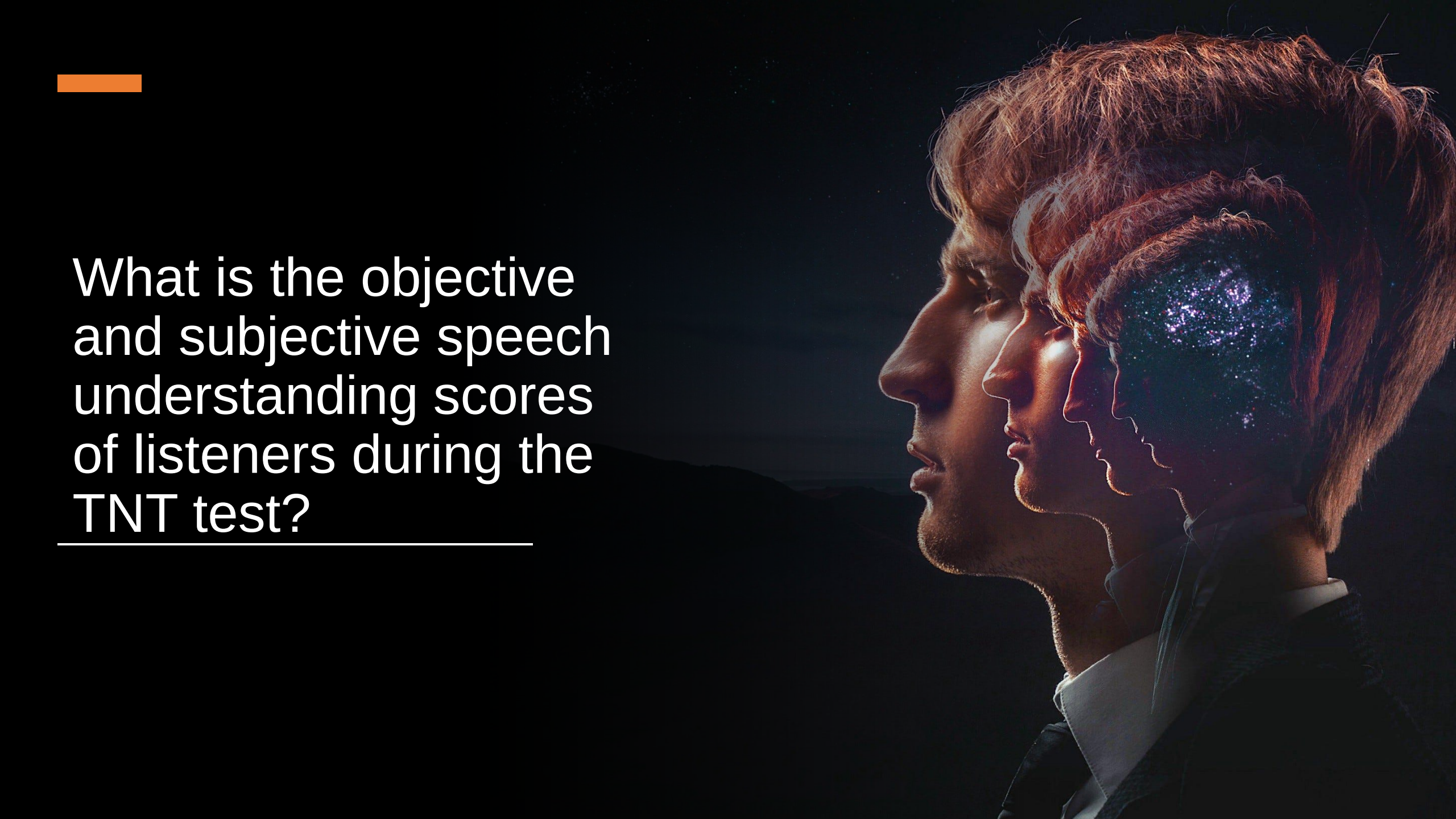


Hypothesis: Higher noise acceptability, less likely to object to the loud sounds that HAs may result

AN **ALTERNATIVE** HYPOTHESIS: DIFFERENCE IN INTERNAL CRITERION

- Speech Intelligibility Index (SII) predicts higher noise level means lower speech intelligibility (from noise masking)
- 2 listeners with identical hearing loss and instructed the same way on the TNT to respond to >90% of speech should yield the same TNT – iff 100% compliance and used same criterion to judge 90%
- If they showed different TNTs, SII would predict that their objective speech scores are different even though both may perceive that they understand >90% of words (i.e., subjective speech scores)
- Thus, those with a higher TNT have a *lower criterion for speech intelligibility* (i.e., their 90% may be 50% for someone with lower TNT)

What is the objective and subjective speech understanding scores of listeners during the TNT test?



If so, the TNT is a test of *speech intelligibility*

Specifically, it tells us the noise level that a listener can accept and still understands over 90% of what is said

LET'S TAKE A CLOSER LOOK AT OUR **INSTRUCTIONS** FOR TNT

- *You will hear some noise in the background while you listen to the male talker. The noise will automatically get louder. I want you to monitor the noise level and maintain the loudest noise level you can put up with while still understanding 90% of the words in the story. If the noise becomes too loud, where you can no longer put up with it or understand less than 90% of the words in the story, you can turn the noise down by pressing and holding the space bar. If it appears softer than before, you should allow the volume to increase by letting go of the space bar. If it is louder than before, you should turn the volume down to keep at the same level by pressing the space bar again. Your ability to understand speech should never change to below 90%. The test will run for two minutes and then stop.*

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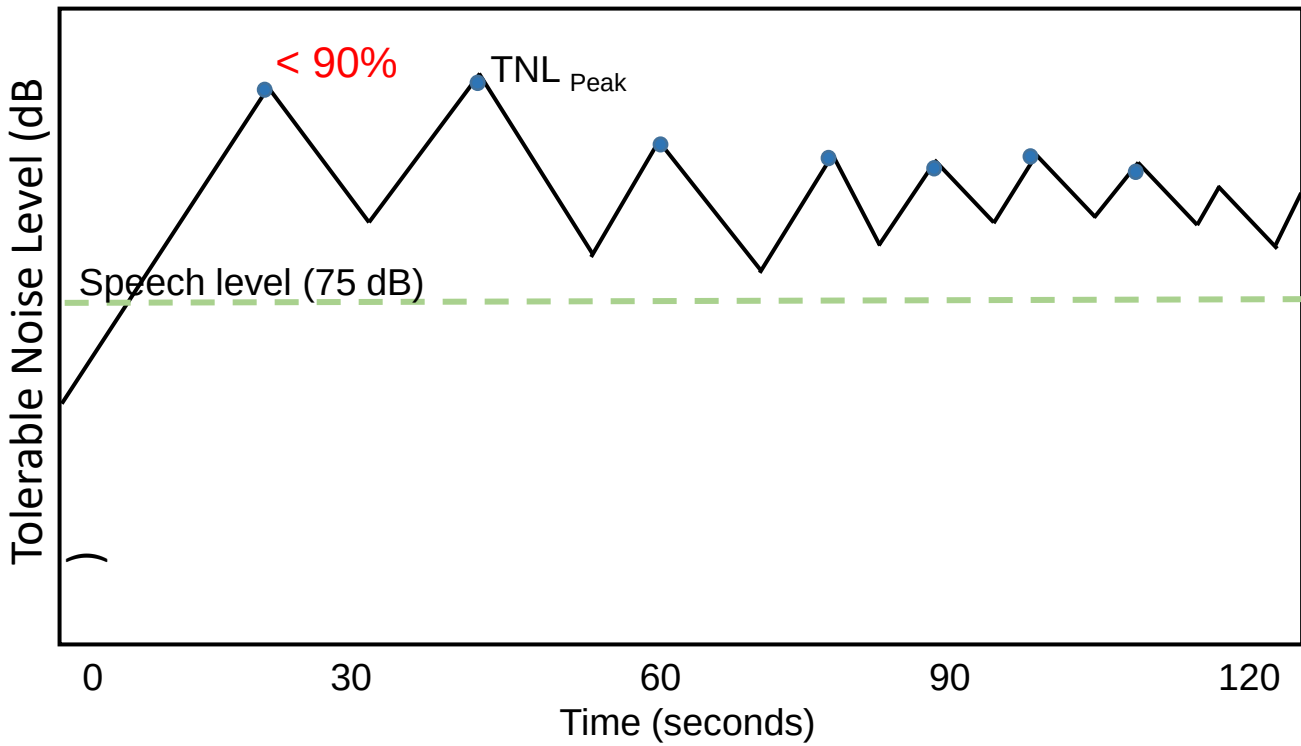
TNL Peak

- The noise level (or signal-to-noise level) where listeners perceive their understanding of the passage is < *90% or too loud* per instruction.
- They *press the spacebar* to lower the noise level so speech understanding goes back to ≥90% and acceptable.
- If listeners follow instructions, this should represent the *maximum noise level* that listeners *can put up with* and *still understand speech* 90% of the time.



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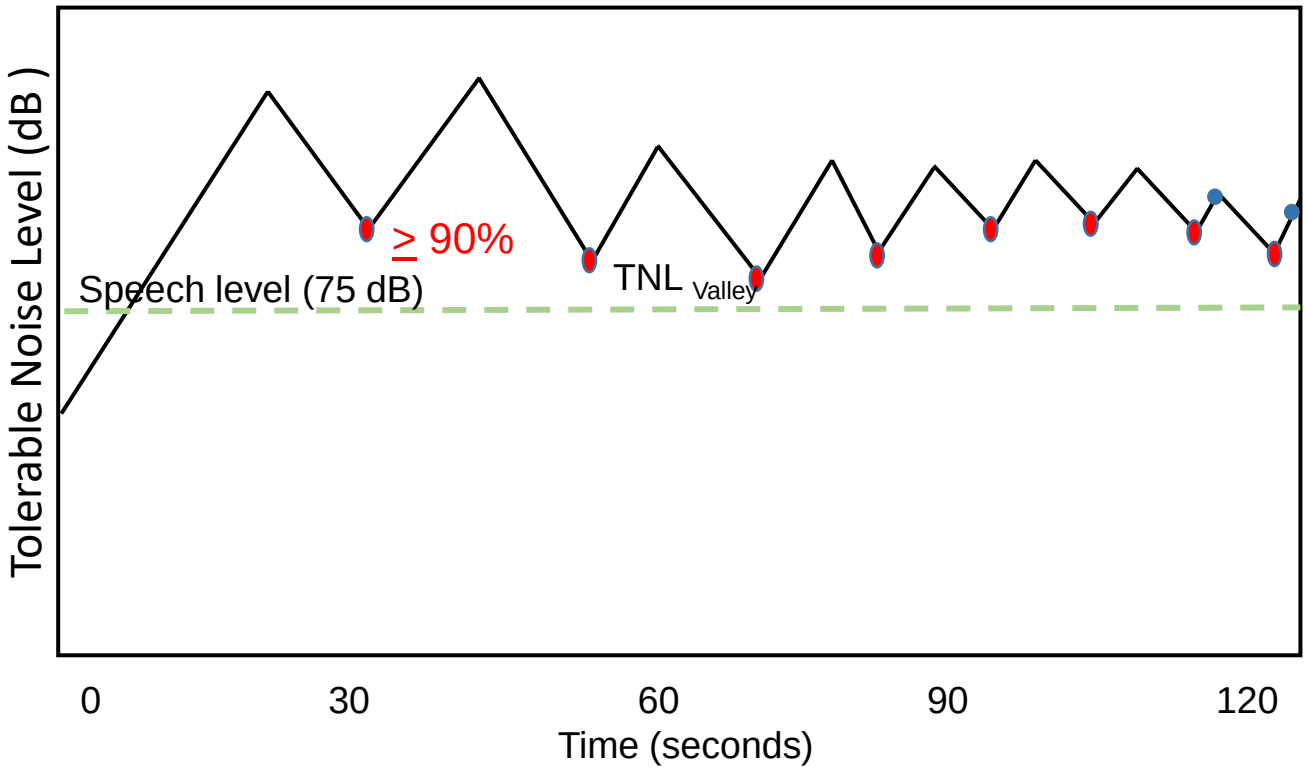
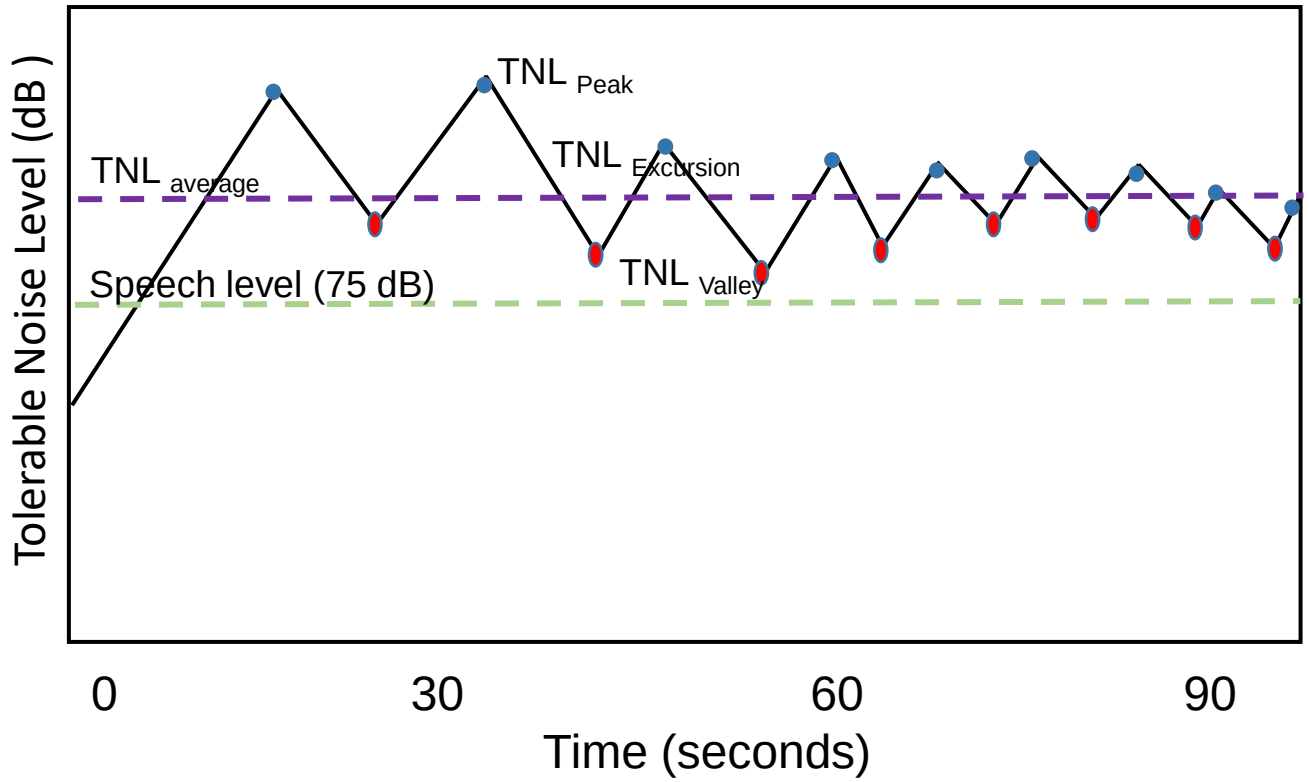
TNL_{Valley}

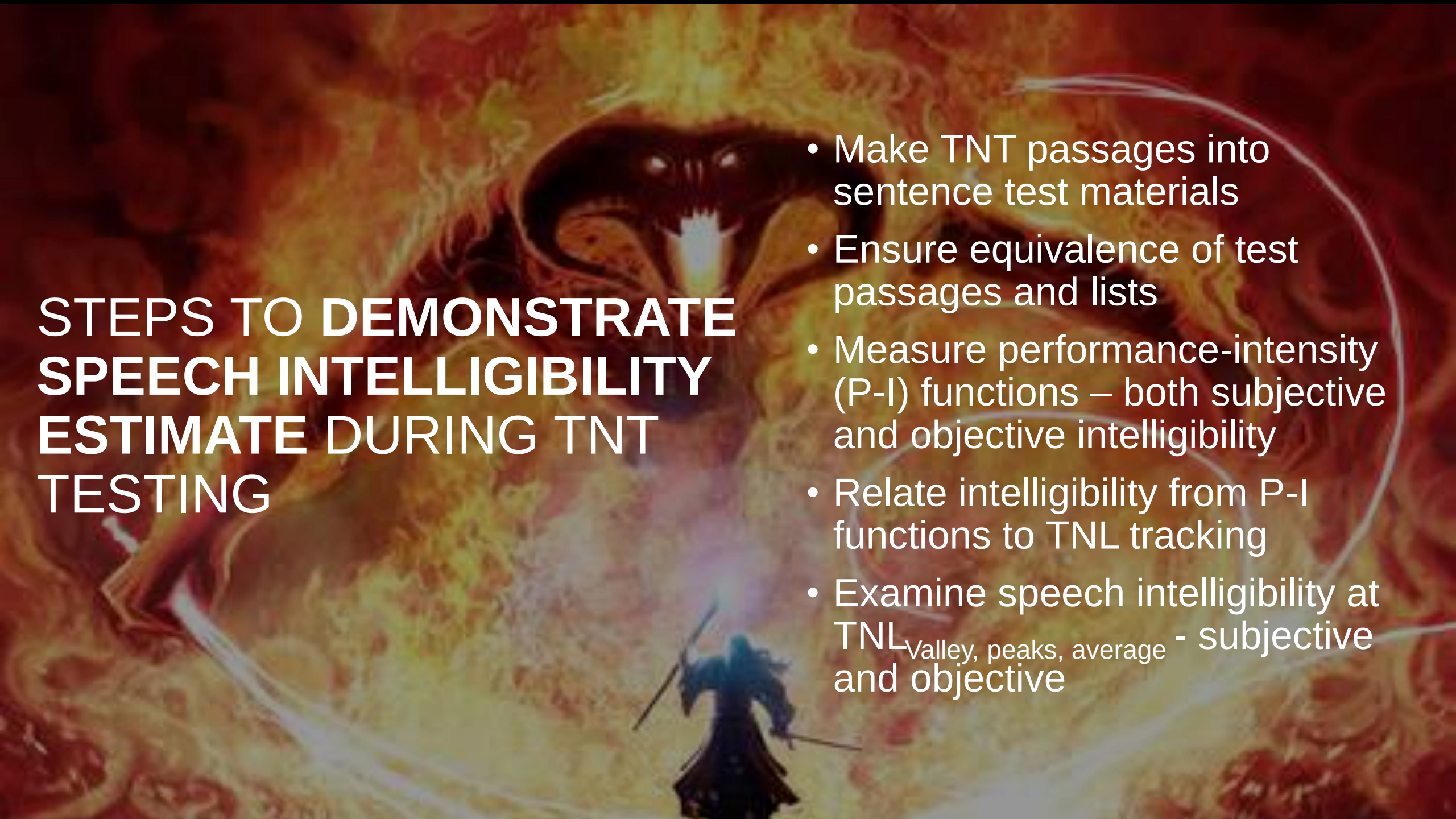
- The noise level (or signal-to-noise level) where listeners perceive their understanding of the passage is ≥ 90% per instruction.
- They *let go of the spacebar* to let noise get louder (and speech understanding to fall below 90%).
- If listeners follow instructions, this should represent the *SNR* that listeners need to understand speech ≥90% of the time.
- This likely represents the lowest noise level that patient needs to *be certain of ≥90%* understanding of the passage
- If we measure intelligibility at TNL_{valley}, it should be close to 90%



$TNL_{Excursion}$

- The difference between TNL_{Peak} and TNL_{Valley}.
- In principle, excursion should be small



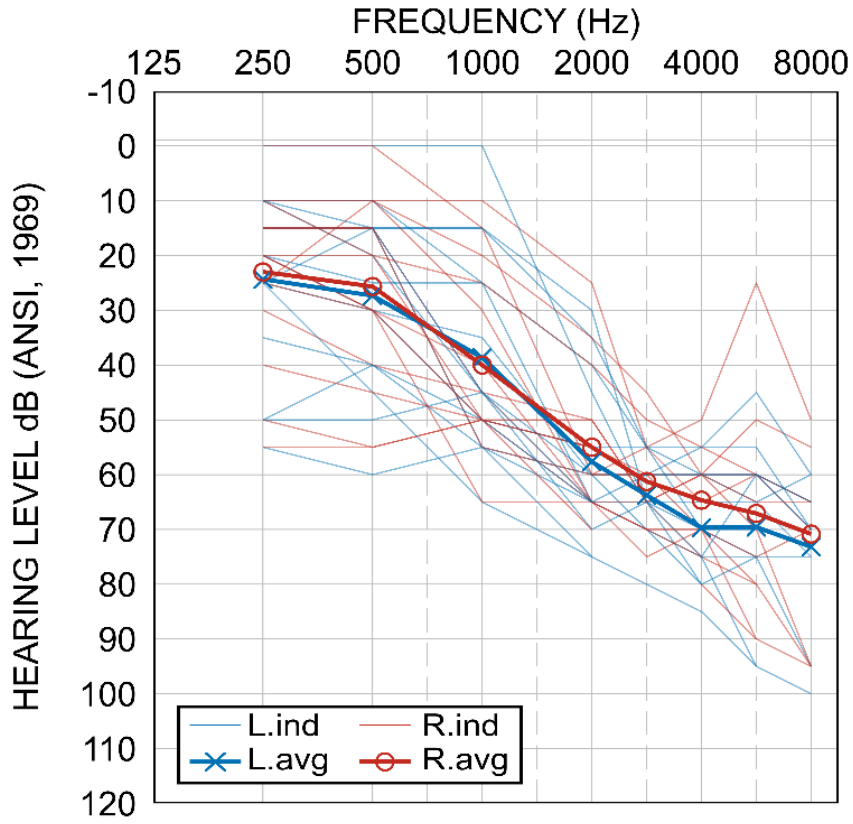


STEPS TO **DEMONSTRATE SPEECH INTELLIGIBILITY ESTIMATE** DURING TNT TESTING

- Make TNT passages into sentence test materials
- Ensure equivalence of test passages and lists
- Measure performance-intensity (P-I) functions – both subjective and objective intelligibility
- Relate intelligibility from P-I functions to TNL tracking
- Examine speech intelligibility at $TNL_{Valley,\ peaks,\ average}$ - subjective and objective

TEST SUBJECTS – 24 NORMAL-HEARING AND 17 HEARING-IMPAIRED

Participant ID	Age (years)	Sex	MoCA (score)	Left 4PTA (dB HL)	Right 4PTA (dB HL)	Binaural 4PTA (dB HL)
NH01	70	F	29	15.0	16.3	15.6
NH02	82	M	26	10.0	7.5	8.8
NH03	59	F	30	2.5	7.5	5.0
NH04	78	M	25	16.3	20.0	18.1
NH05	57	M	25	6.3	7.5	6.9
NH06	57	F	29	5.0	10.0	7.5
NH07	58	F	28	6.3	7.5	6.9
NH08	53	F	28	10.0	13.8	11.9
NH09	68	F	25	12.5	15.0	13.8
NH10	60	F	30	6.3	5.0	5.6
NH11	62	M	29	13.8	15.0	14.4
NH12	70	F	28	11.3	12.5	11.9
NH13	53	F	26	7.5	6.3	6.9
NH14	51	M	27	2.5	7.5	5.0
NH15	68	F	28	18.8	13.8	16.3
NH16	74	F	26	7.5	12.5	10.0
NH17	73	F	29	15.0	18.8	16.9
NH18	72	M	24	16.3	11.3	13.8
NH19	61	M	28	5.0	3.8	4.4
NH20	64	F	28	10.0	13.8	11.9
NH21	73	F	27	8.8	7.5	8.1
NH22	64	M	27	17.5	21.3	19.4
NH23	58	F	27	11.3	10.0	10.6
NH24	57	F	30	5.0	6.3	5.6
NH MEAN	64.3	F = 16	27.5	10.0	11.3	10.6
HI01	81	F	26	33.8	31.3	32.5
HI02	67	M	27	35.0	27.5	31.3
HI03	81	F	27	55.0	56.3	55.6
HI04	85	F	29	47.5	48.8	48.1
HI05	85	M	25	58.8	51.3	55.0
HI06	69	M	27	57.5	48.8	53.1
HI07	86	M	28	51.3	55.0	53.1
HI08	80	M	27	58.8	61.3	60.0
HI09	67	F	26	41.3	41.3	41.3
HI10	85	M	29	37.5	35.0	36.3
HI11	62	F	30	58.8	53.8	56.3
HI12	73	M	27	30.0	36.3	33.1
HI13	86	M	27	51.3	52.5	51.9
HI14	71	M	25	47.5	45.0	46.3
HI15	84	M	25	65.0	56.3	60.6
HI16	65	F	29	45.0	45.0	45.0
HI17	80	M	30	57.5	61.3	59.4
HI MEAN	76.9	F = 6	27.3	48.9	47.4	48.2



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EXAMPLE OF **TNT PASSAGE** (MONEY2)

Money is easier to divide than many trade goods. It is harder to divide goods than it is to divide money. Certain tradable goods can die or spoil. Money lasts longer than most trade goods. If someone sells an item for money, he can save that money until he needs it. He can always leave it to his children when he dies. It can last a very long time, and he can use it at any time. Not every item is the same as another item. If animals are traded some animals are younger and more desirable than older animals. Some food is fresh and other food is stale. This can lead to problems in the true value of the item. Money is standard. That means one dollar is worth the same as another dollar. It is easier to add up and count money compared to other goods. Coins were used for hundreds of years. Paper money was first used as a promise to pay later in coins. The first true paper money was used in China in the 10th century. Paper money was also printed in Sweden during the 17th century. Early paper money did not work well. Paper money had to be stopped because the banks kept running out of coins to pay back the paper money. Massachusetts Bay Colony printed paper money in the late 17th century. This time, the use became more common. Today, people might think of money in a larger scale. Money is something you can hold. Money can also be something that somebody else holds for you. A bank is a place where money is held for you. The bank will tell you how much money you have in the bank. Banks will pay you interest for allowing them to hold your money. Computers allow people to pay electronically. This means that paper money or coins are not used. Money is removed from the bank and paid to the other party. Many people still feel more comfortable using coins and paper, and do not totally trust using electronic money. Commodity money can be used for other purposes besides purchasing items. Commodities are useful or valuable by itself. Some examples of commodity money are cattle, silk, gold and silver. Convertible paper money is money that is convertible into gold and silver.

CONVERT TNT PASSAGES INTO **SUBJECTIVE – OBJECTIVE SPEECH (SOS) TEST** – MONEY2

Topic 1

Topic 2

Topic 3

Topic 4

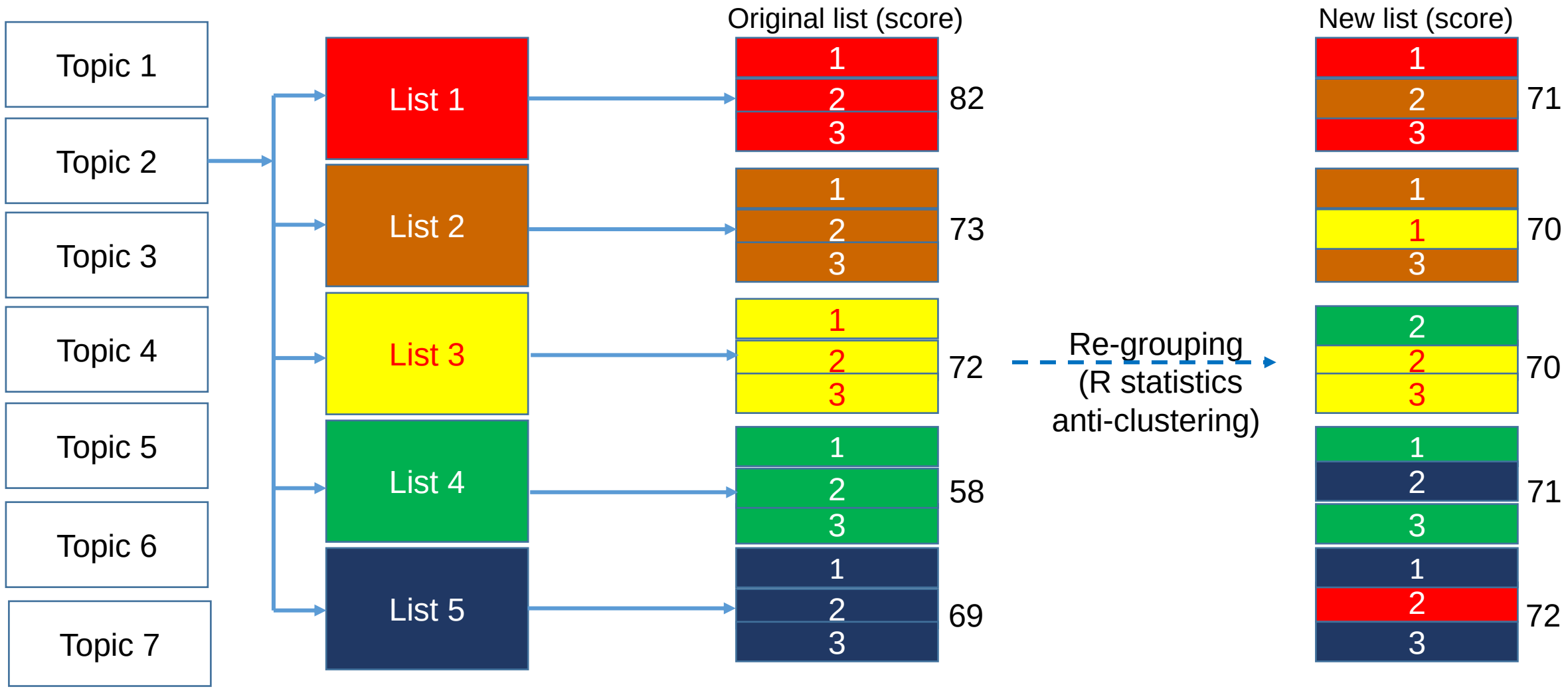
Topic 5

Topic 6

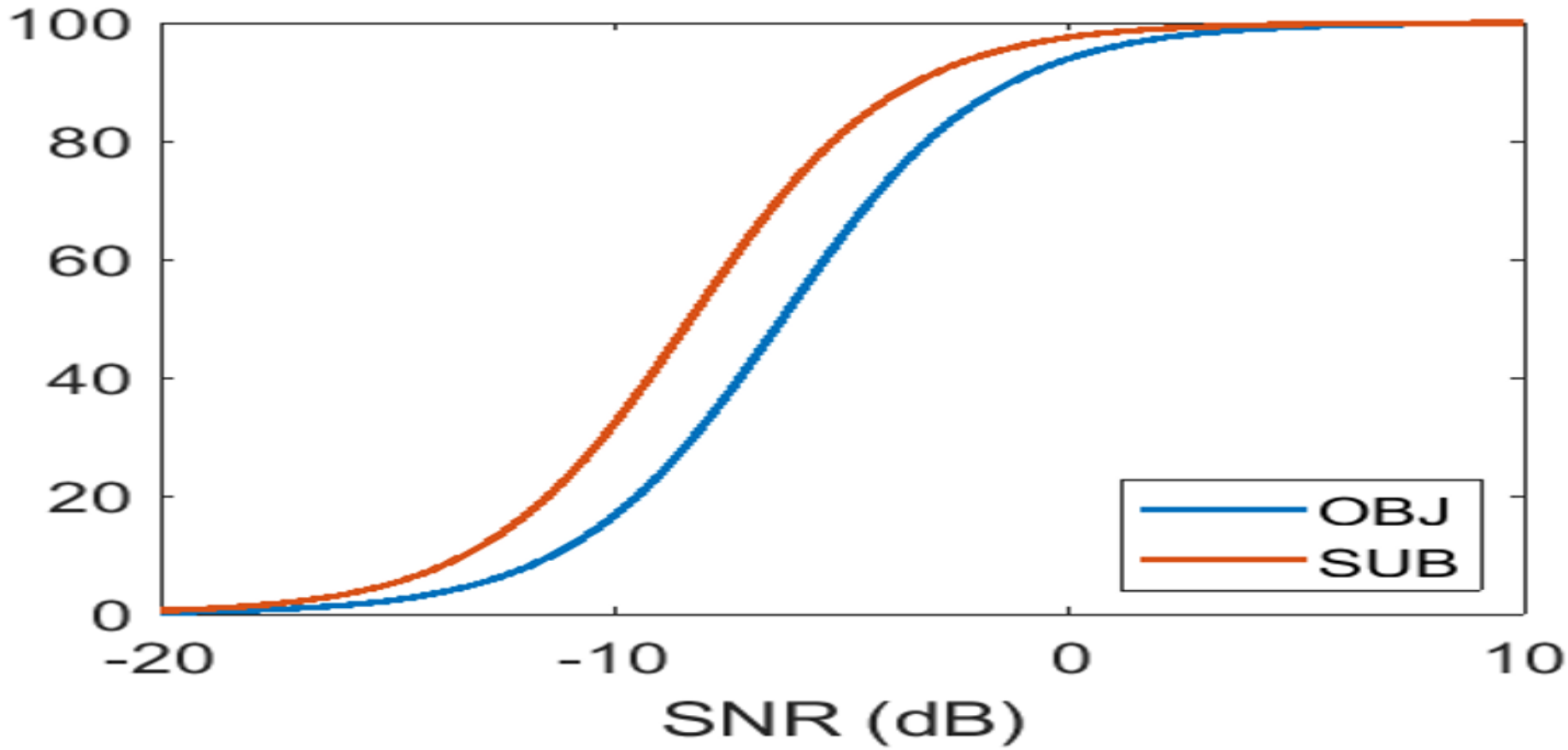
Topic 7

		Sentence	Target words			
LIST 1	1	**Commodity money can be used for other purposes besides purchasing items**	purposes	besides	purchasing	items
	2	**Gold and Silver certificates are convertible paper money**	gold	silver	convertible	
	3	**Money lasts longer than most trade goods**	lasts	longer	trade	
LIST 2	4	**Commodities are useful or valuable by itself**	commodities	useful	valuable	
	5	**Computers allow people to pay electronically**	computers	allow	electronically	
	6	**He can always leave it to his children when he dies**	always	leave	children	dies
LIST 3	7	**It can last a very long time, and he can use it at any time**	last	long	use	
	8	**Massachusetts Bay Colony printed paper money in the late 17th century**	massachusetts	colony	printed	century
	9	**Today, people might think of money in a larger scale**	think	larger	scale	
LIST 4	10	**Banks will pay you interest for allowing them to hold your money**	banks	interest	allowing	
	11	**It is easier to add up and count money compared to other goods**	easier	count	compared	
	12	**Many people still feel more comfortable using coins and paper**	people	feel	comfortable	using
	13	**Money is removed from the bank and paid to the other party**	removed	paid	party	
LIST 5	14	**Paper money had to be stopped because the banks kept running out of coins**	stopped	running	coins	
	15	**This can lead to problems in the true value of the item**	lead	problems	true	value

ESTABLISHING **LIST EQUIVALENCE**



MEASURING SUBJECTIVE AND OBJECTIVE SPEECH (SOS) INTELLIGIBILITY - **PERFORMANCE-INTENSITY** FUNCTION



NH SNR fixed at -9, -6, -3, 0, and 3 db. HI SNR varied between -5 and 10 dB SNR random; Objective before subjective

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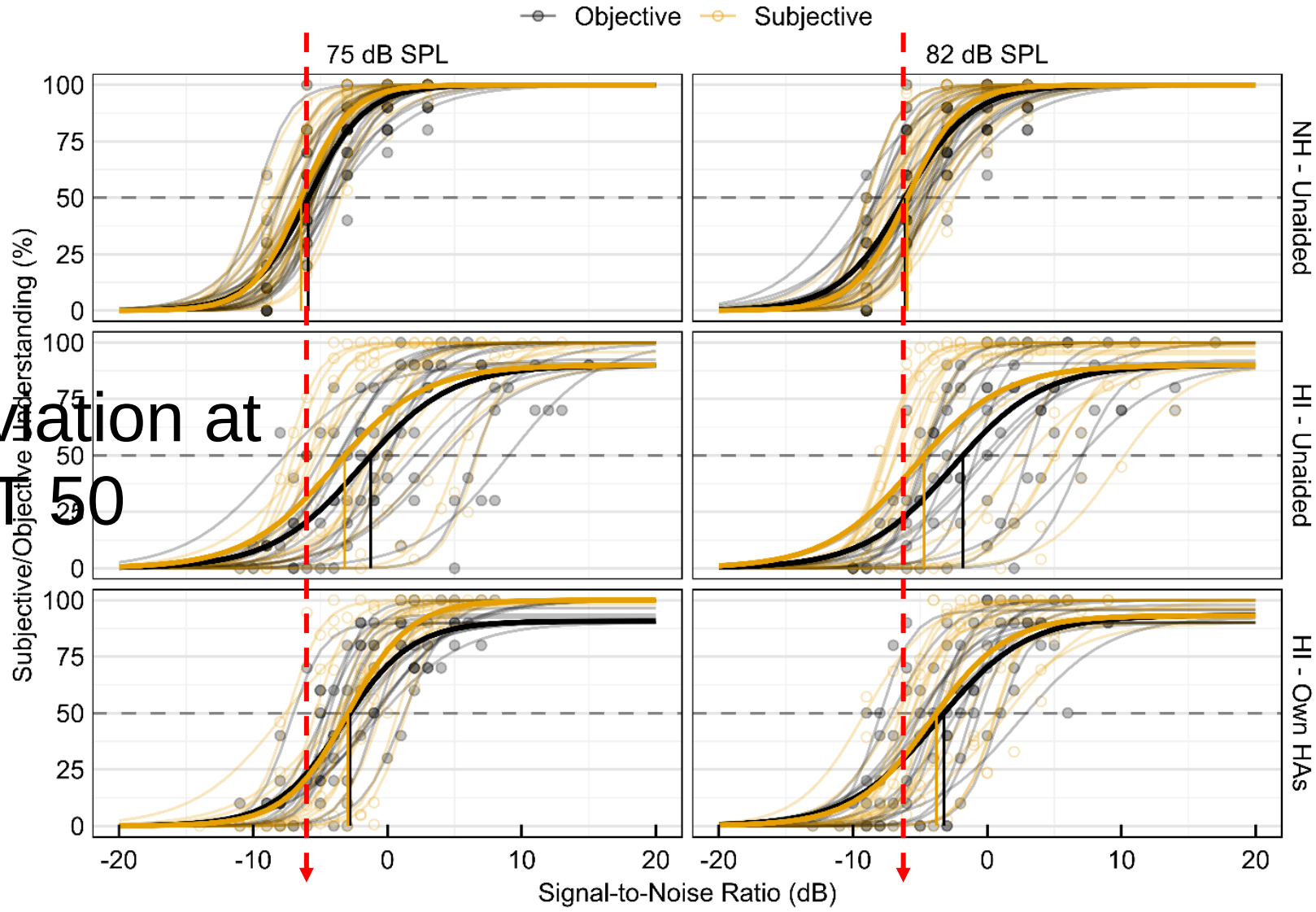
PERFORMANCE-INTENSITY FUNCTIONS FOR **NORMAL-HEARING AND HEARING-IMPAIRED LISTENERS**

Max deviation at SRT 50



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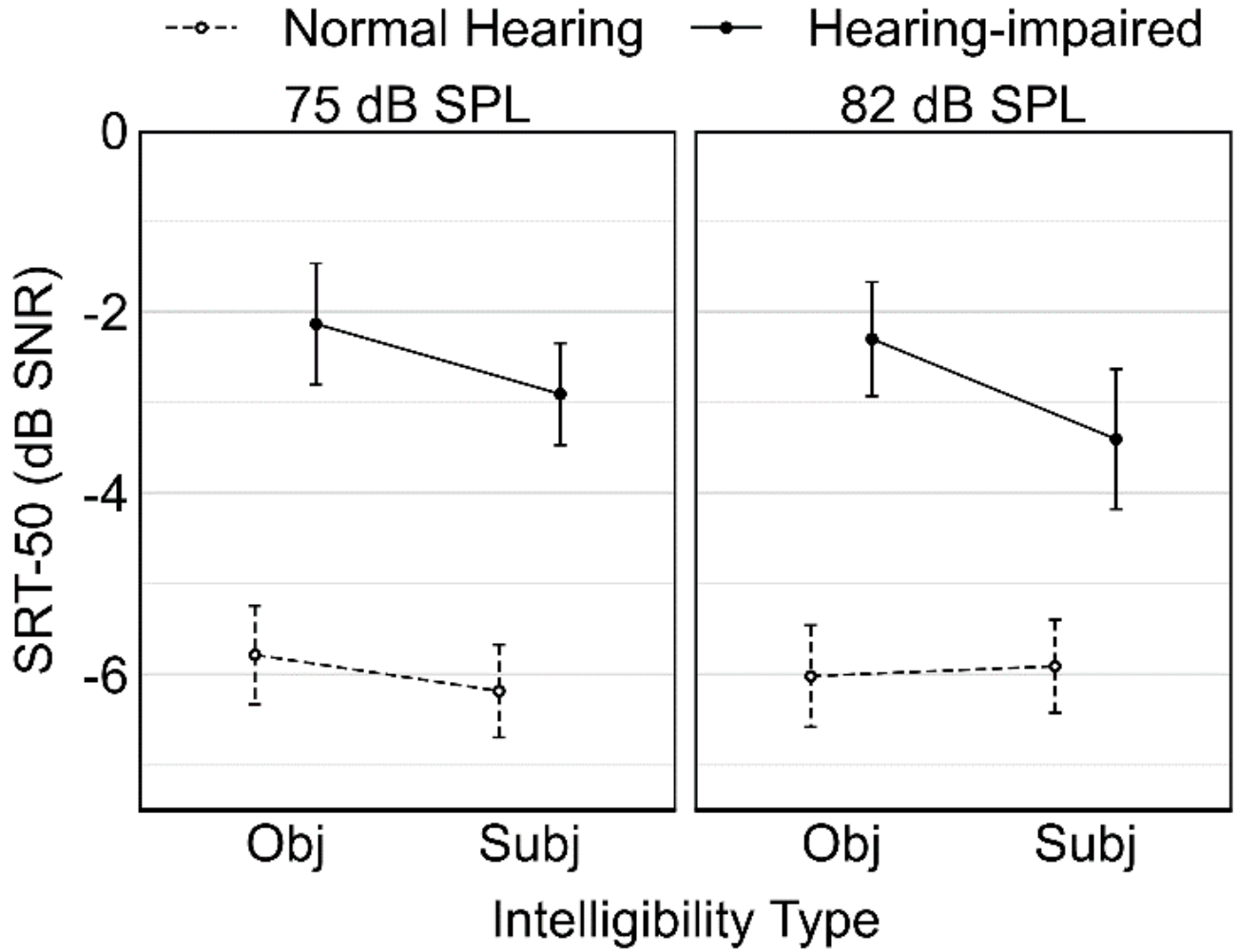
SUBJECTIVE-OBJECTIVE INTELLIGIBILITY DIFFERENCE (SRT50) BETWEEN NORMAL-HEARING AND HEARING-IMPAIRED (**UNAIDED MODE**)



For Normal-Hearing listeners, average subjective SRT_{50} is same as objective SRT_{50} around -6 dB

For Hearing-Impaired listeners, average subjective SRT_{50} is better (or lower) than objective SRT_{50} by 1 – 1.5 dB (average around -2.5 to -3.0 dB)

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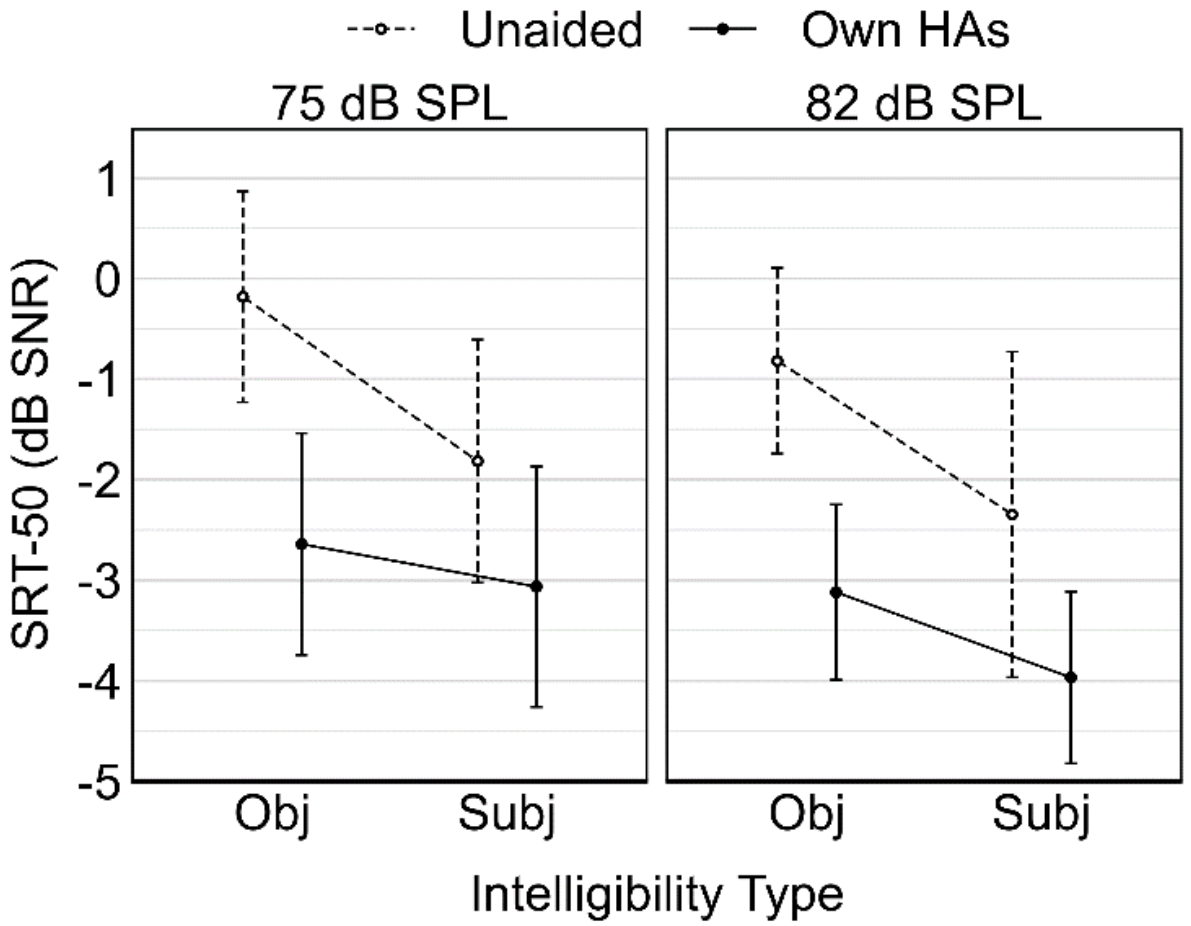
SUBJECTIVE-OBJECTIVE INTELLIGIBILITY DIFFERENCE (SRT50) BETWEEN **UNAIDED AND AIDED** MODES IN HEARING- IMPAIRED



For the Hearing-Impaired listeners,

- Unaided – subjective SRT > objective SRT about 1.5 dB
- Aided – subjective SRT = objective SRT (+/-0.5-1, not significant); SRT about -3 to -4 dB

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IMPLICATIONS AND CHALLENGES

- Implications
  - Unaided - HI perceives less difficulty than reality (S>O)
  - Aided – HI's subjective intelligibility closer to NH
    - HAs restore some level of "normal" perception of intelligibility
    - HI perceive less benefit than reality (benefit = aided – unaided performance)
- Challenges
  - Convincing HI listeners to try amplification when they perceive less difficulty than they really have and to show them more benefit than they perceive - ***demonstration***
  - Appropriateness of using subjective evaluation – ***as a supplement to objective measure***

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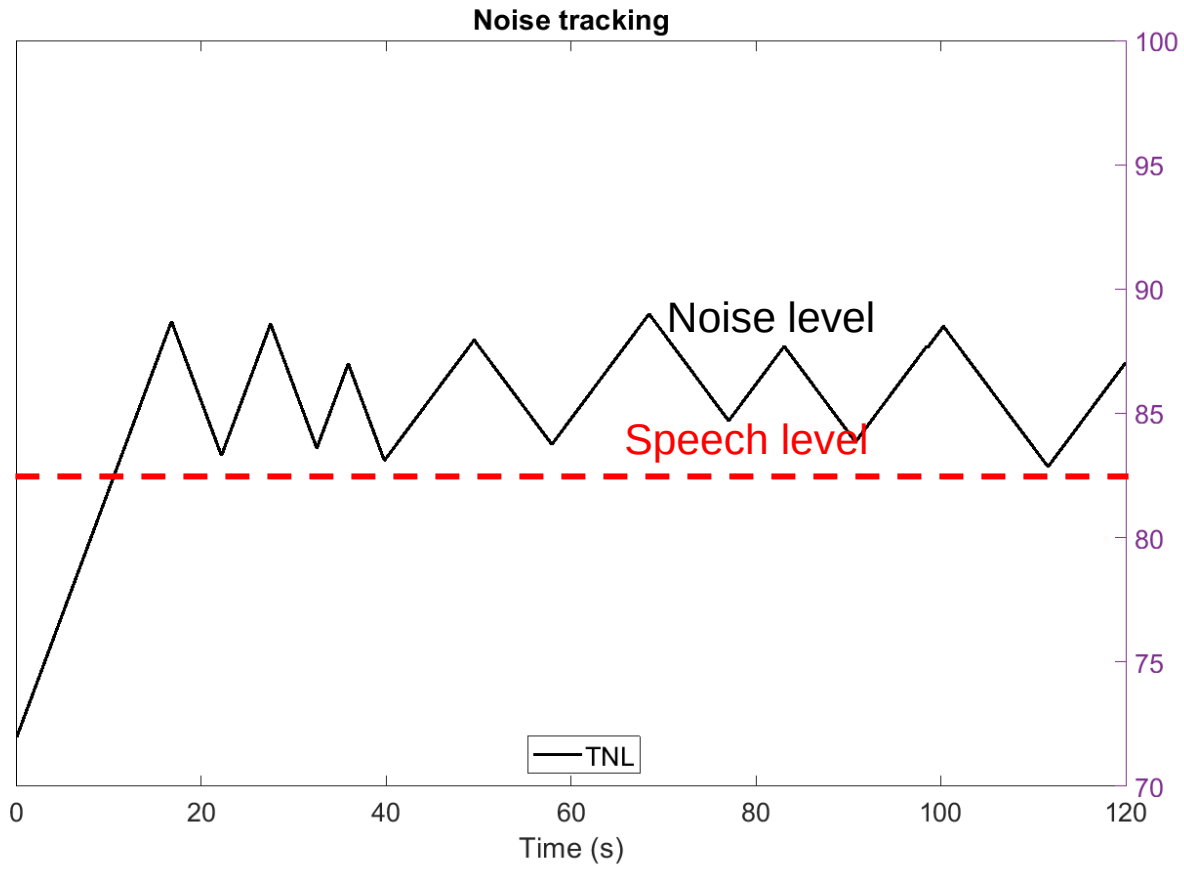
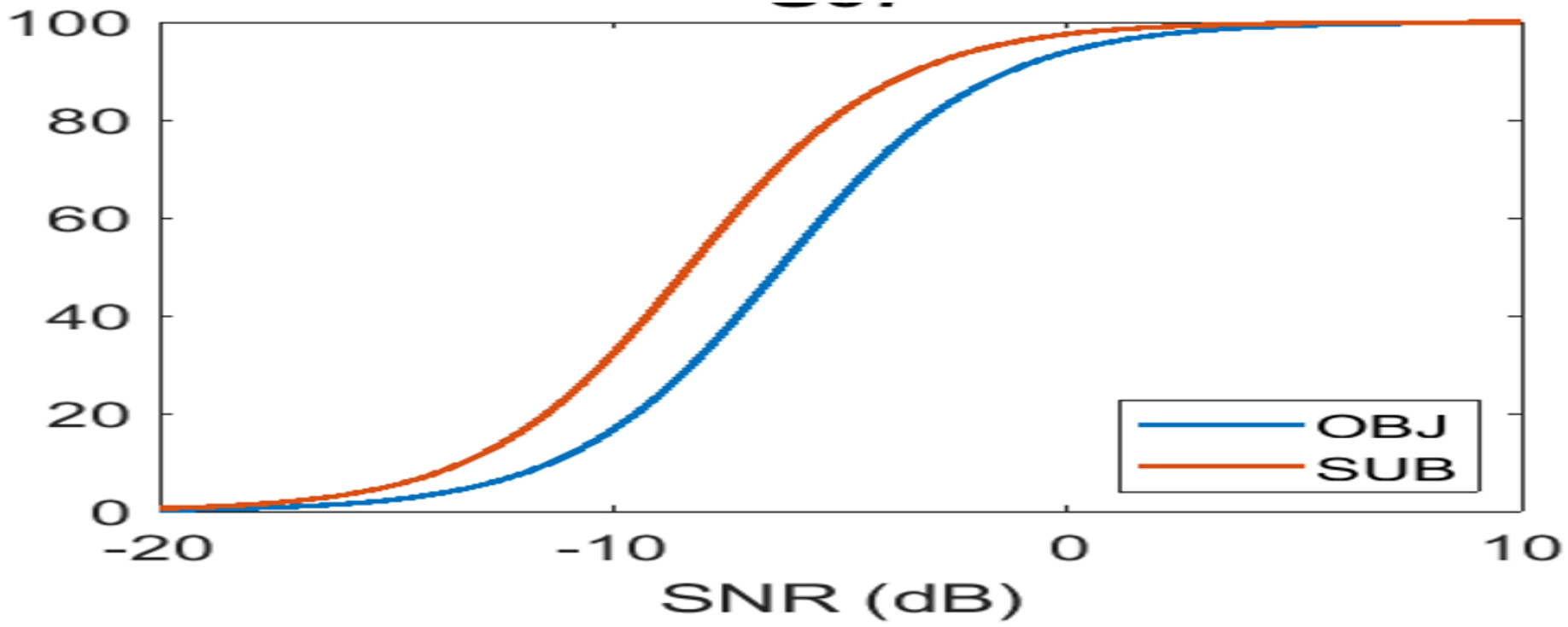
RELATING INTELLIGIBILITY FROM PI TO TNL TRACKING I:**TNL**



RELATING INTELLIGIBILITY FROM PI TO TNL TRACKING II:**PERFORMANCE-INTENSITY FUNCTION**



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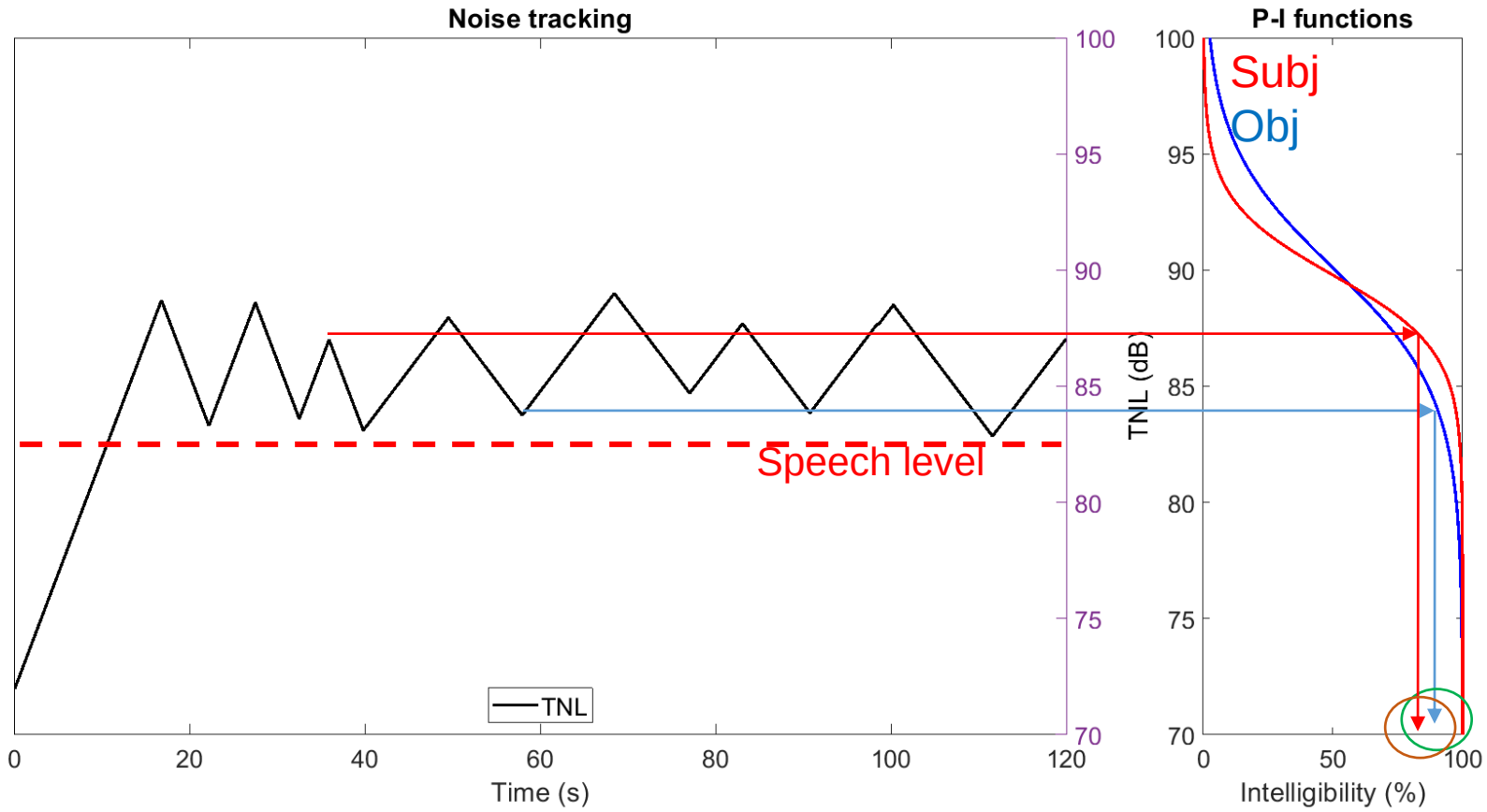
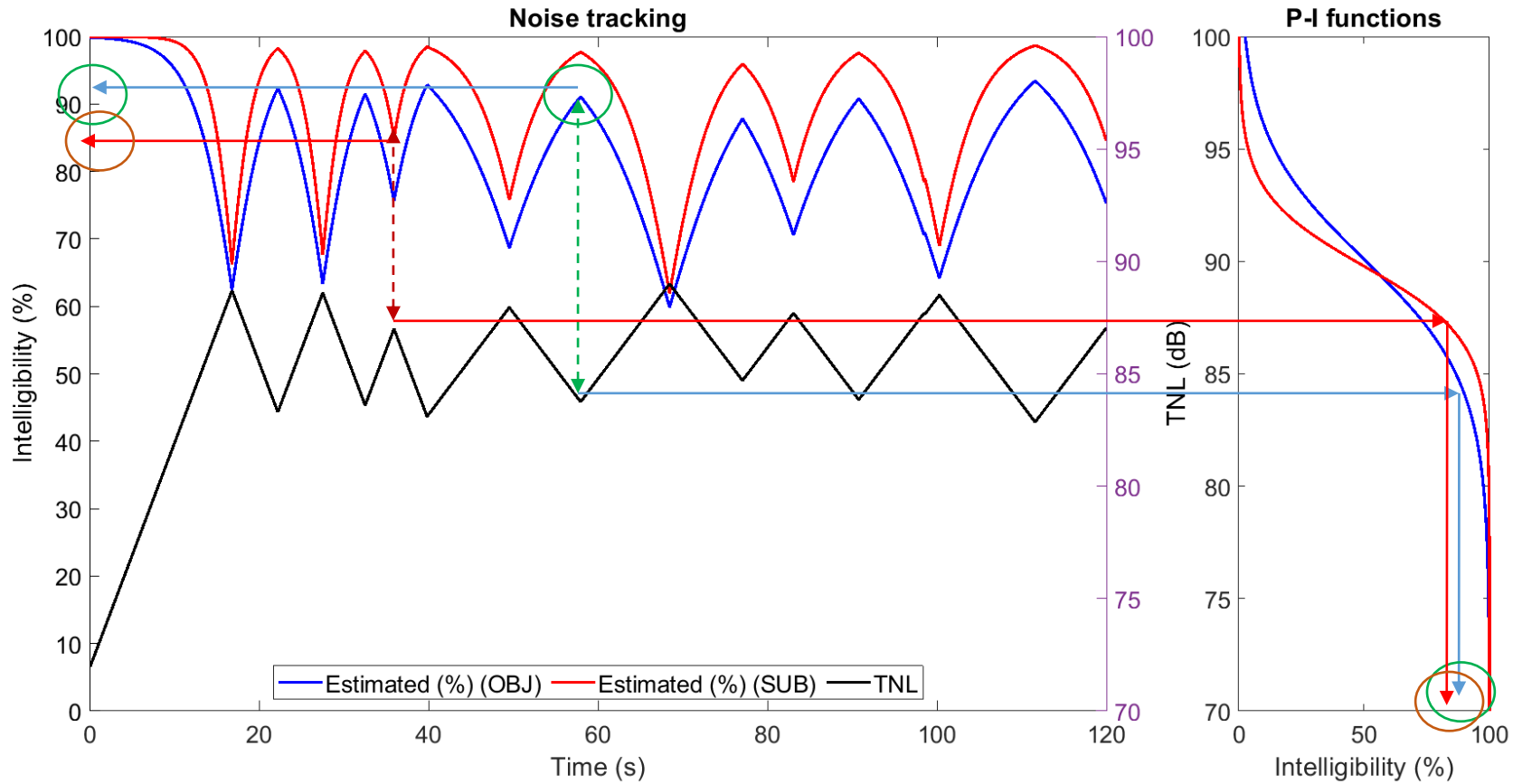
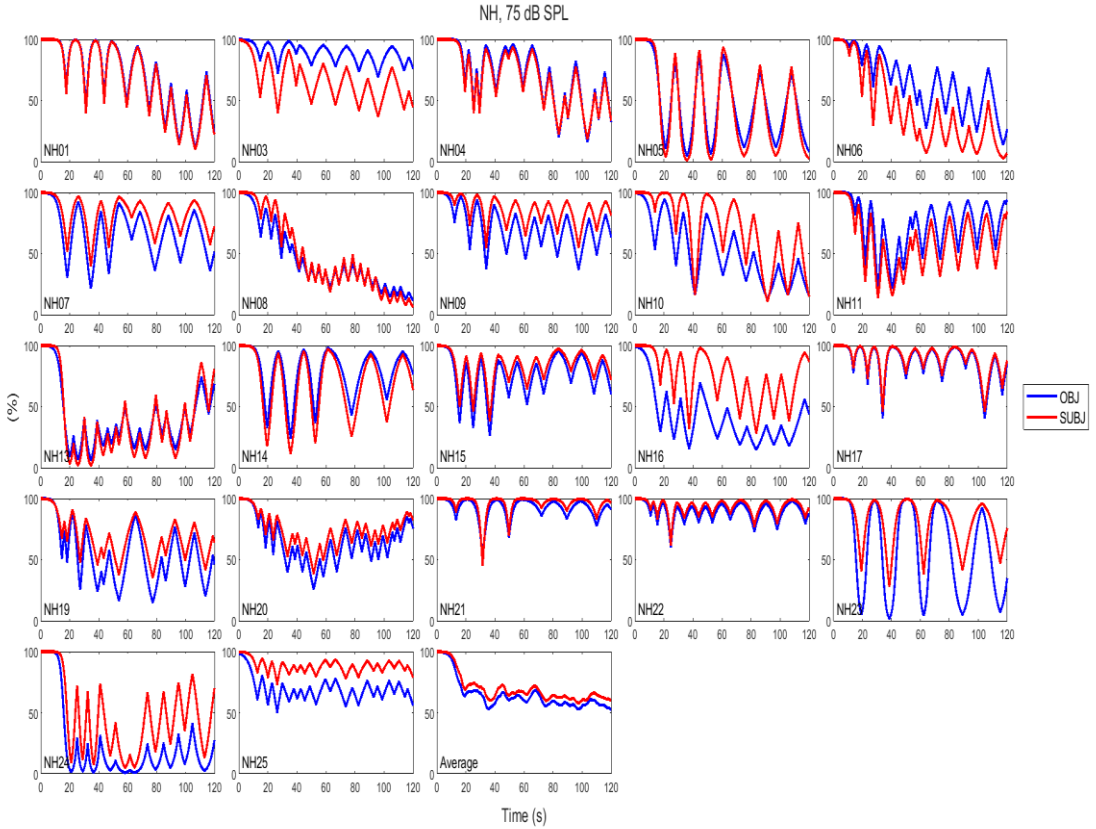
RELATING INTELLIGIBILITY FROM PI TO TNL TRACKING III:**TNL & PI**

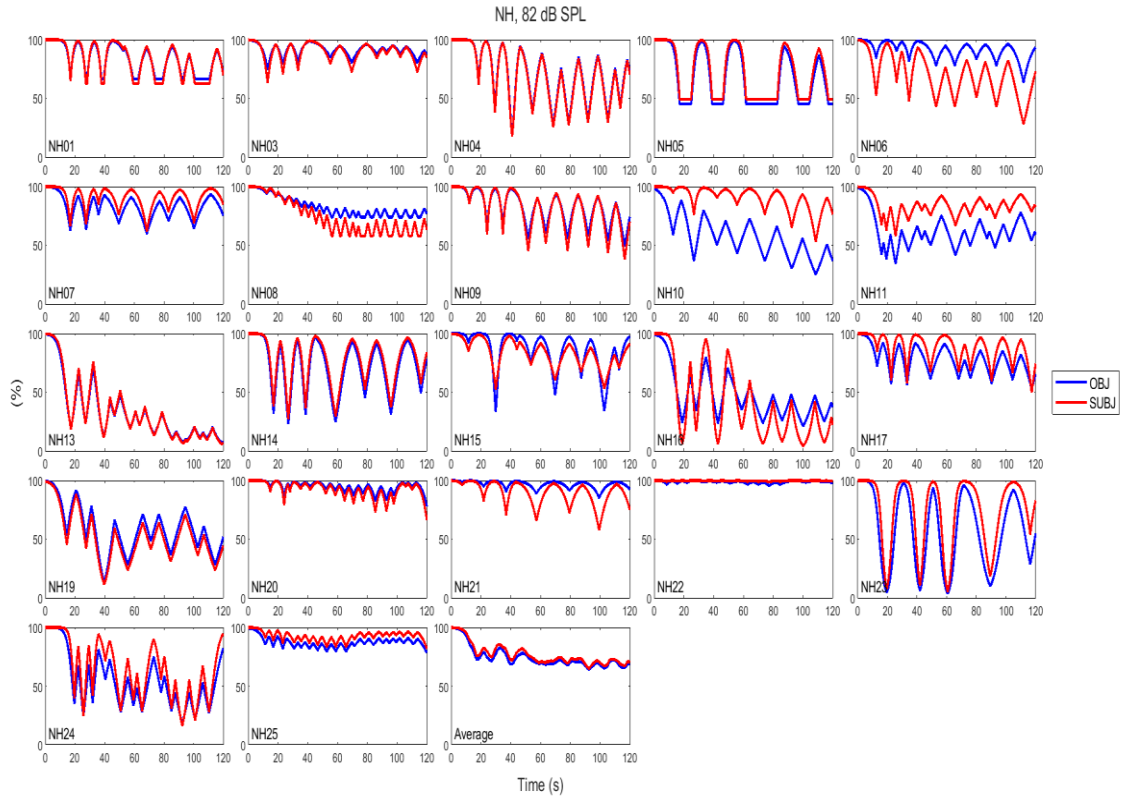


RELATING INTELLIGIBILITY FROM PI TO TNL TRACKING IV:**TNL, PI & INTELLIGIBILITY**



INTELLIGIBILITY DURING NOISE TRACKING - **NORMAL-HEARING**





- For the most part, subjective intelligibility similar as objective (red on top of blue)
- Intelligibility changes varied among subjects

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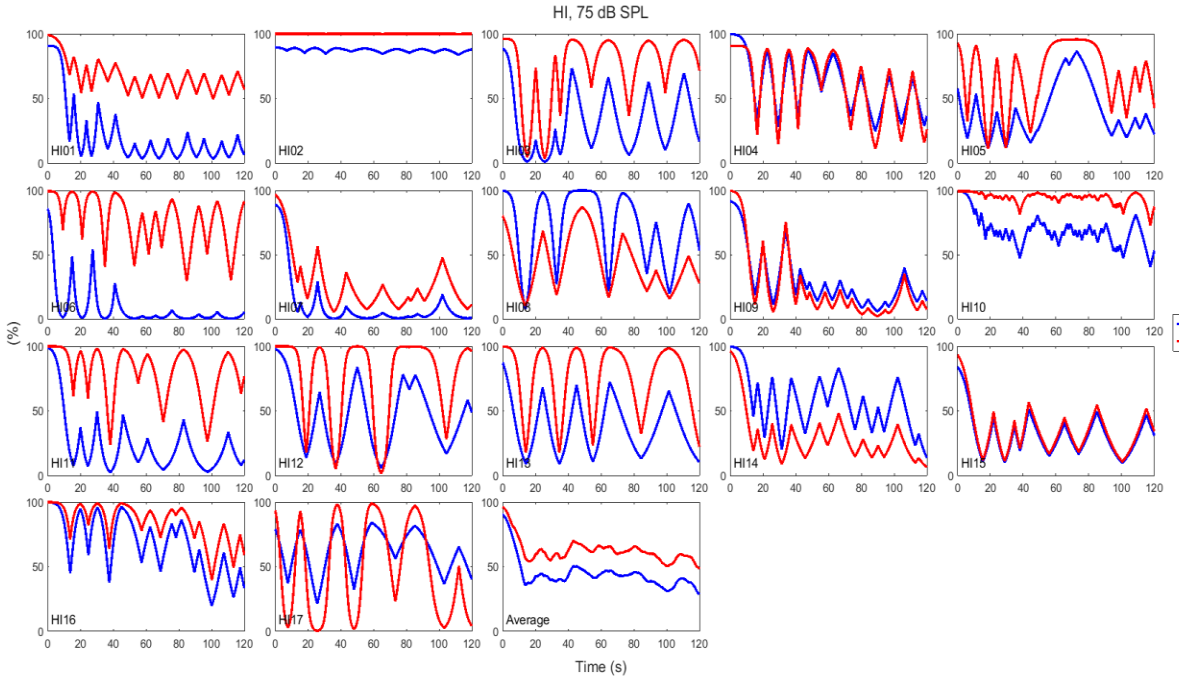
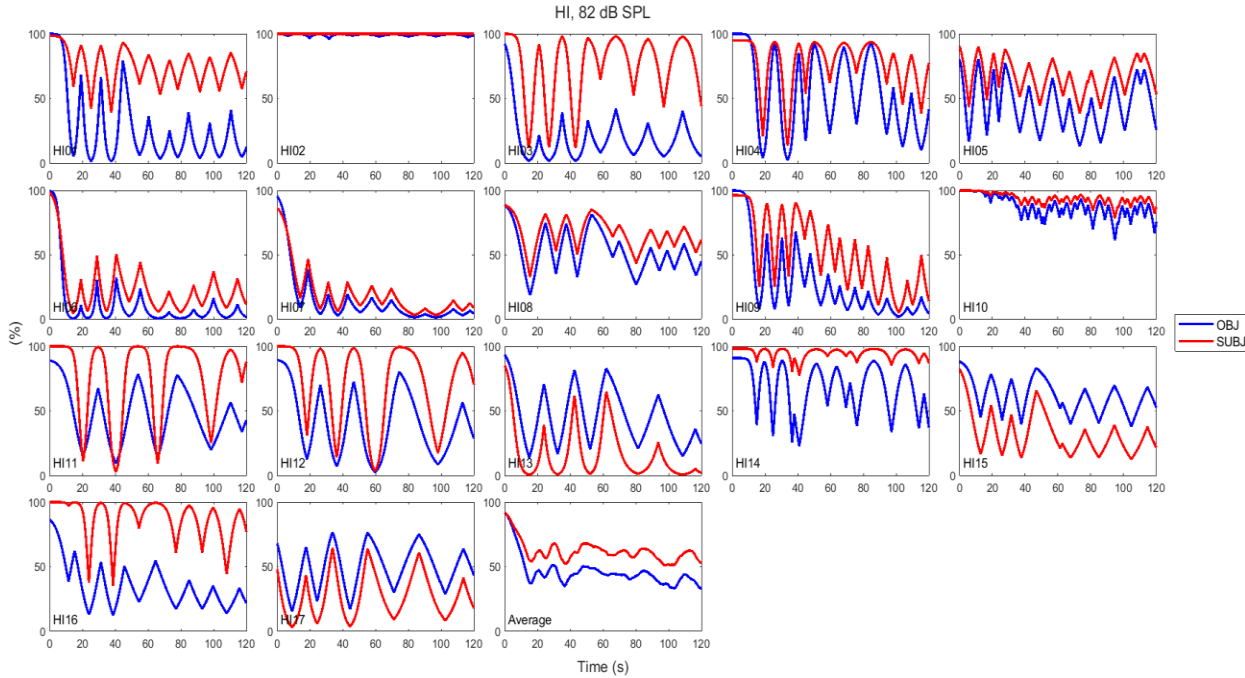
INTELLIGIBILITY DURING NOISE TRACKING - **HEARING-IMPAIRED (UNAIDED)**





- For the most part, more instances of separation between subjective and objective (red separate from blue)
- Intelligibility changes varied among subjects; wider excursions than NH

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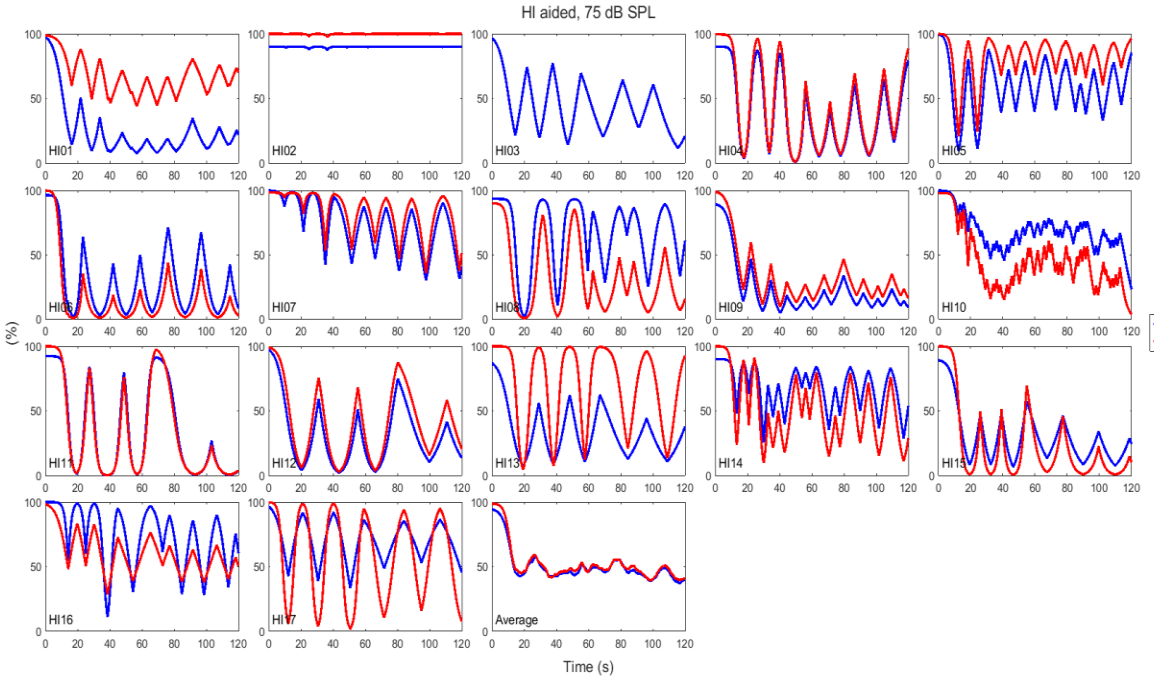
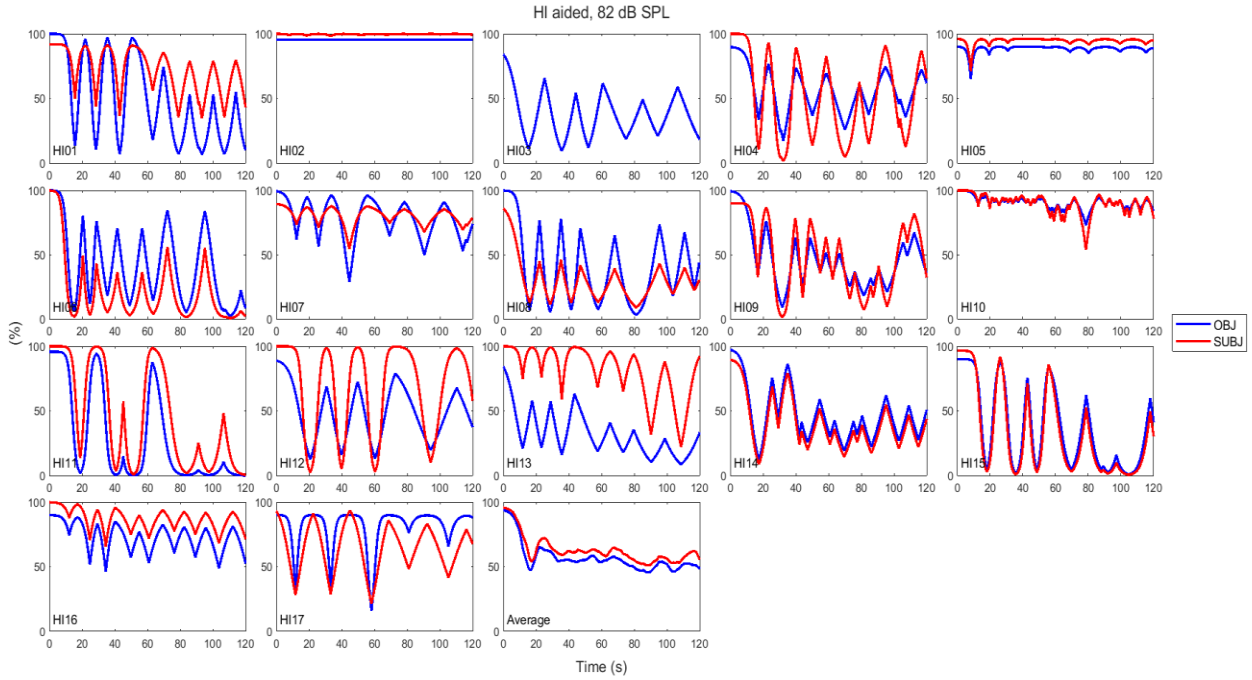
INTELLIGIBILITY DURING NOISE TRACKING - **HEARING-IMPAIRED (AIDED-OWN)**





- For the most part, less instances of separation between subjective and objective (red separate from blue) than unaided
- Intelligibility changes varied among subjects; wider excursions than NH

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SO HOW ARE THE VARIOUS **TNT INDICES RELATED TO INTELLIGIBILITY**?

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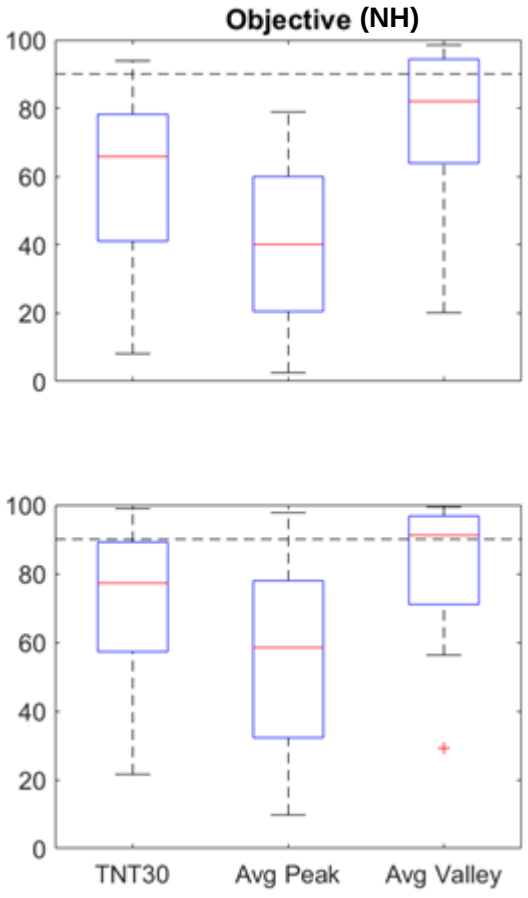
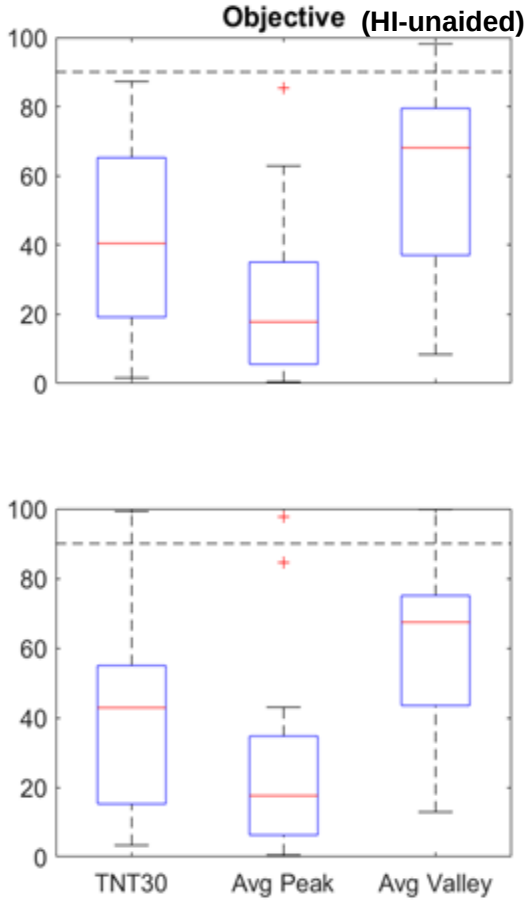
COMPARING SPEECH INTELLIGIBILITY MEASURED AT THE PEAKS & VALLEYS OF THE TNL FUNCTION AMONG GROUPS - **OBJECTIVE**



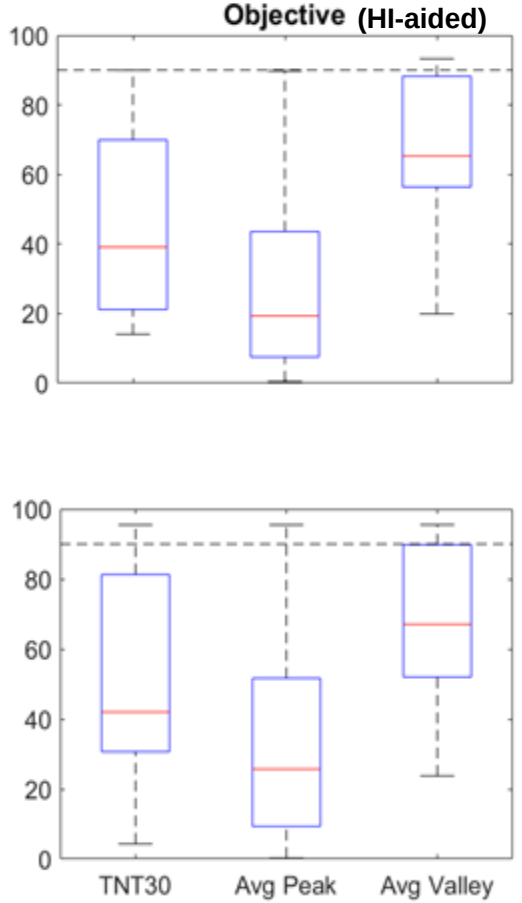
Valley at 90%
Peak at 40-60%
Average at 70-75%
Excursion 30-40%

HI < NH
Effect of HL



Valley at 75%
Peak at 20%
Average at 40-45%
Excursion 40-50%

aided = unaided



Valley at 70%
Peak at 20-30%
Average at 40-45%
Excursion 40-50%

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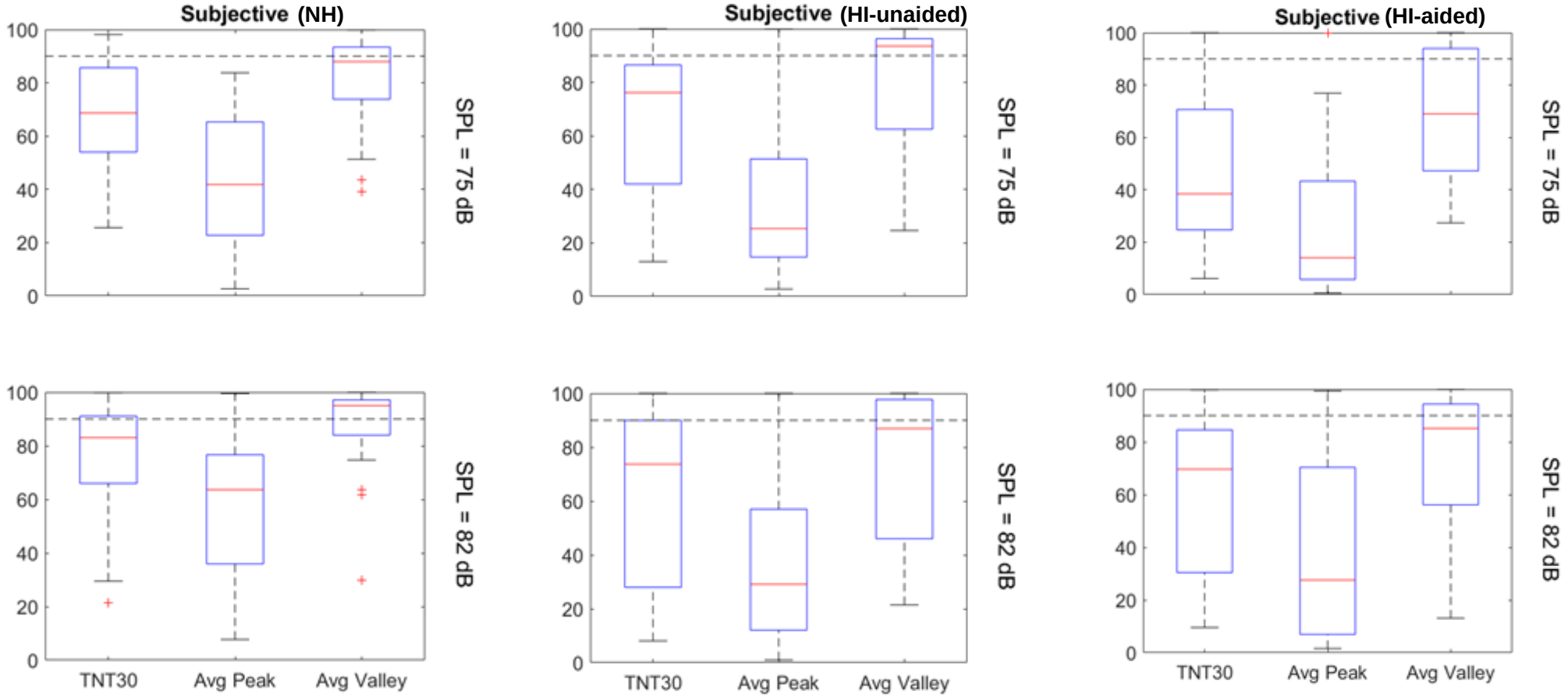
COMPARING SPEECH INTELLIGIBILITY MEASURED AT THE PEAKS & VALLEYS OF THE TNL FUNCTION AMONG GROUPS - **SUBJECTIVE**



Valley at 90%
Peak at 40-60%
Average at 70-80%
Excursion 30-40%

Valley at 90%
Peak at 20-30%
Average at 75-80%
Excursion 30-40%

Valley at 70 & 90%
Peak at 15-30%
Average at 40-70%
Excursion 40-50%

Difference in peak
?certainty in judgment?

Difference at 75 vs 82
?nonlinearity of HA?

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The *valleys* on the TNL tracking function represents, on average, *subjective speech intelligibility of >90%* in both normal-hearing and hearing-impaired listeners

In other words, it represents how much noise the listener can accept over the speech level and s/he *still thinks* s/he understands over 90% of conversational content

- For example, if TNL_{valley} is 78 dB and speech level is 75 dB
- The 3 dB (78-75=3) is a noise-to-signal ratio (NSR), which means a signal-to-noise ratio (SNR) of -3 dB (NSR=-SNR)
- In other words, the SNR requirements for the listener to think s/he understands the majority of ongoing TNT passage is -3 dB

DEFINITION OF “SUBJECTIVE”

- Webster dictionary definitions
  - “…peculiar to a particular individual…”
  - “…modified or affected by personal views, experience, or background…”
- Objective speech intelligibility score of 70% *may* mean subjective intelligibility of 50%, 70% or 90%
- As a group,
  - Normal hearing; subj = obj
  - Hearing-Impaired; subj > obj

A NEW **INTERPRETATION**

- The 90% subjective intelligibility score as reflected on the TNL $_{Valley}$ reflects the ***individual listener's criterion (which is subjective) of what 90% means*** to him/her
- So if someone's objective speech score is only 40% when we instructed him/her to understand >90% (subjective), this individual may think that s/he understands >90% of speech when s/he only understands 40% of speech

This confirms our *Ho* that people with high TNT (or low ANL, both of which are associated with lower objective speech intelligibility) are more likely to be satisfied with HAs or use HA longer – because of a lower criterion, leading to a lower expectation which may be met easier (assuming everything else the same)

BUT IT IS **JUST** SUBJECTIVE SPEECH INTELLIGIBILITY

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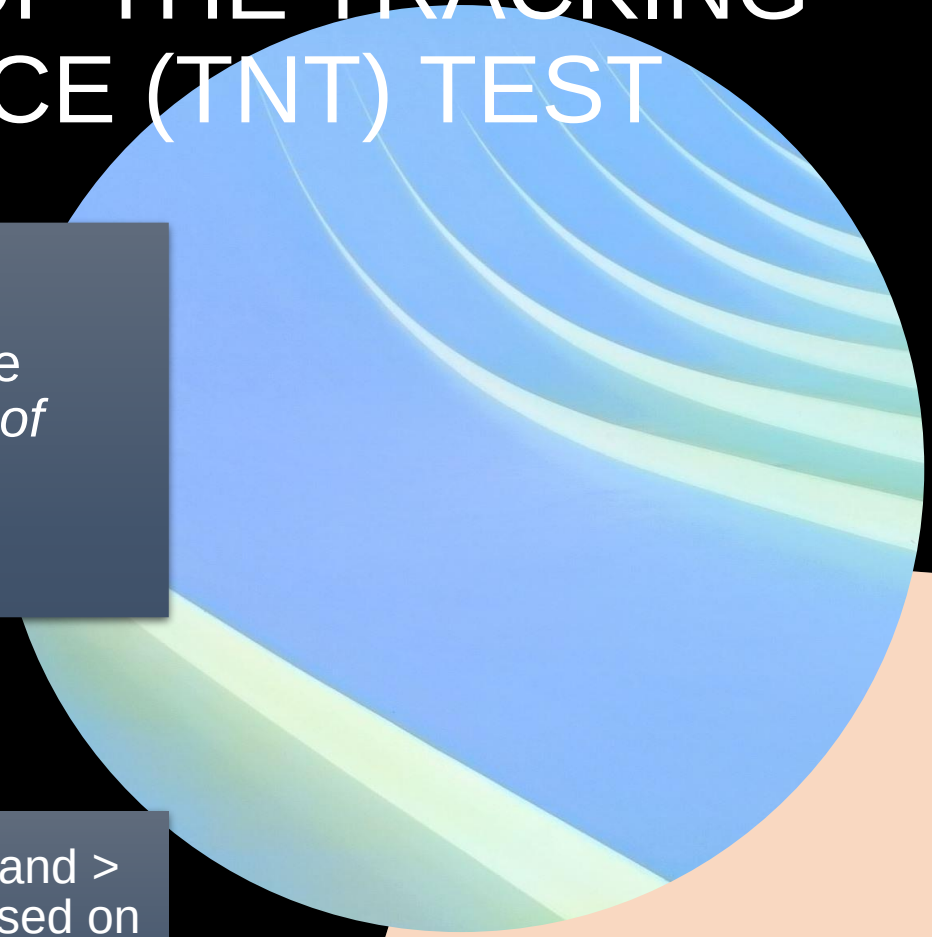
THE **USEFULNESS** OF THE TRACKING OF NOISE TOLERANCE (TNT) TEST

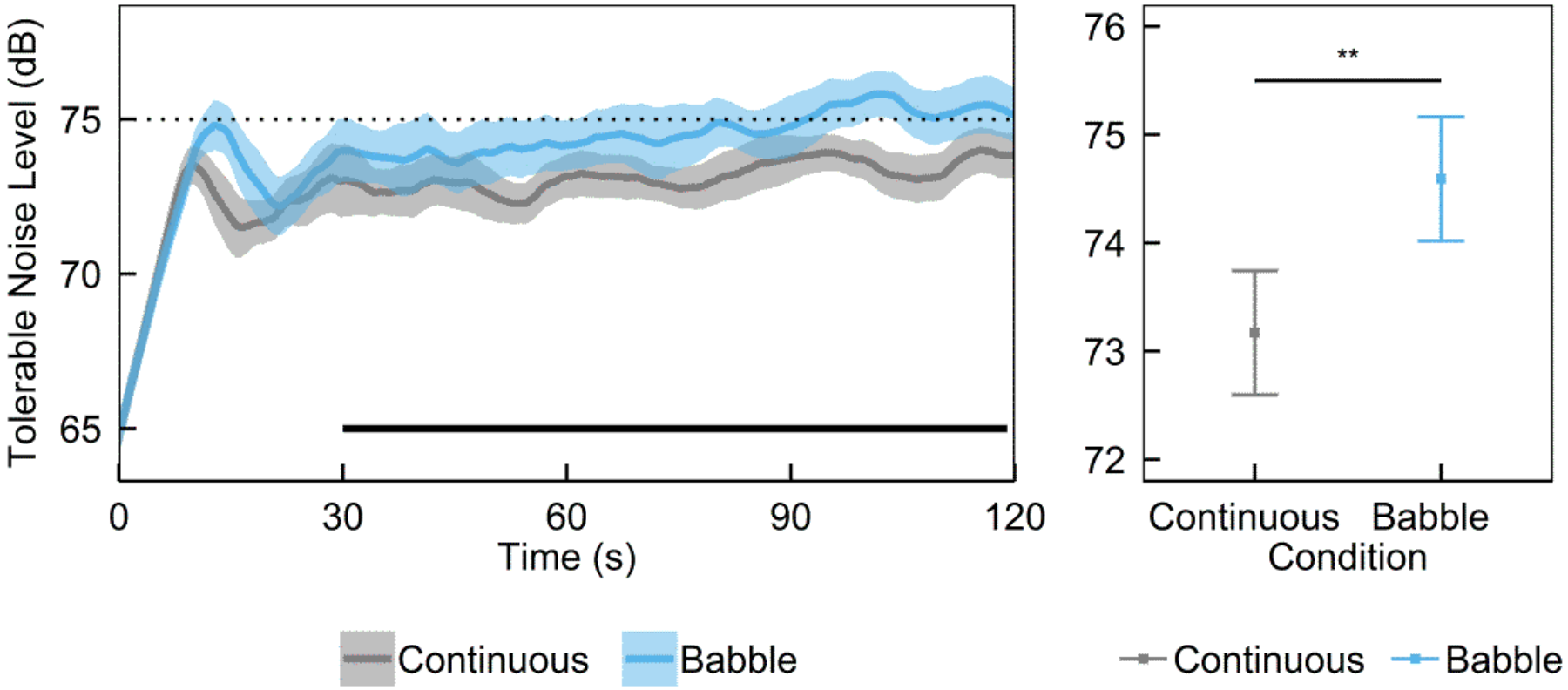


It offers a ***new dimension*** of outcome measurement (i.e., *individual criterion of subjective intelligibility*)

SNR that listener thinks s/he needs to understand > 90% of passage materials of simple content based on his/her own criterion of 90%

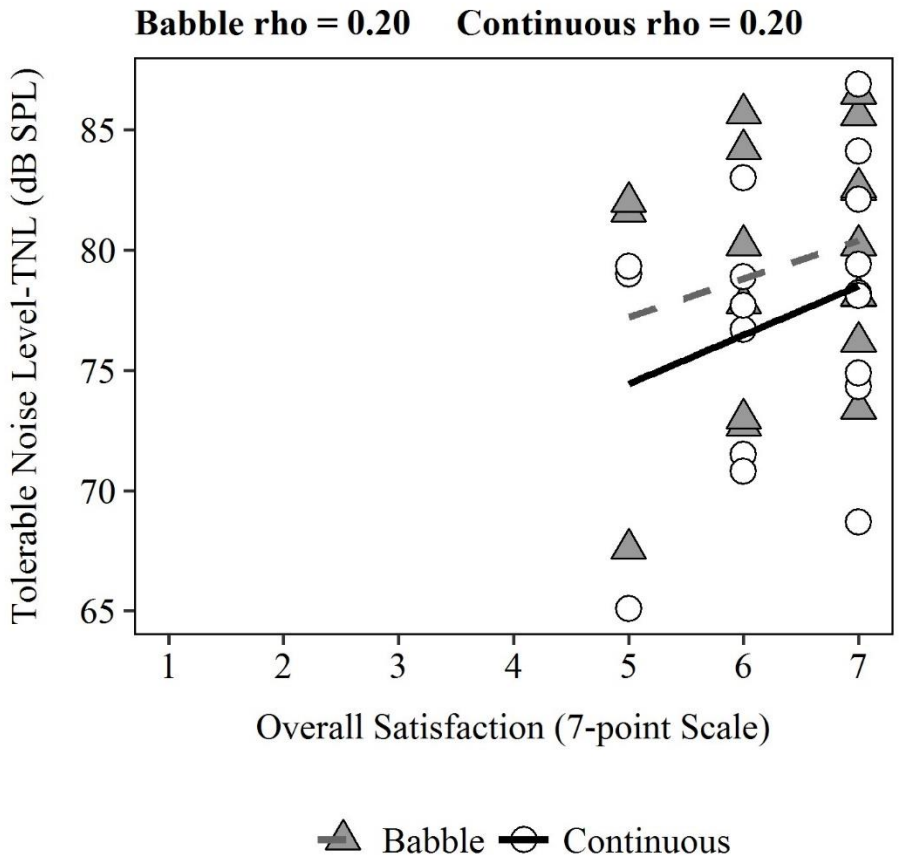
Profiling	Fine-tuning and comparison of HAs/features	Measurement/prediction of HA satisfaction/ success

PROFILING - COMPARISON TO NORMAL/NORMS

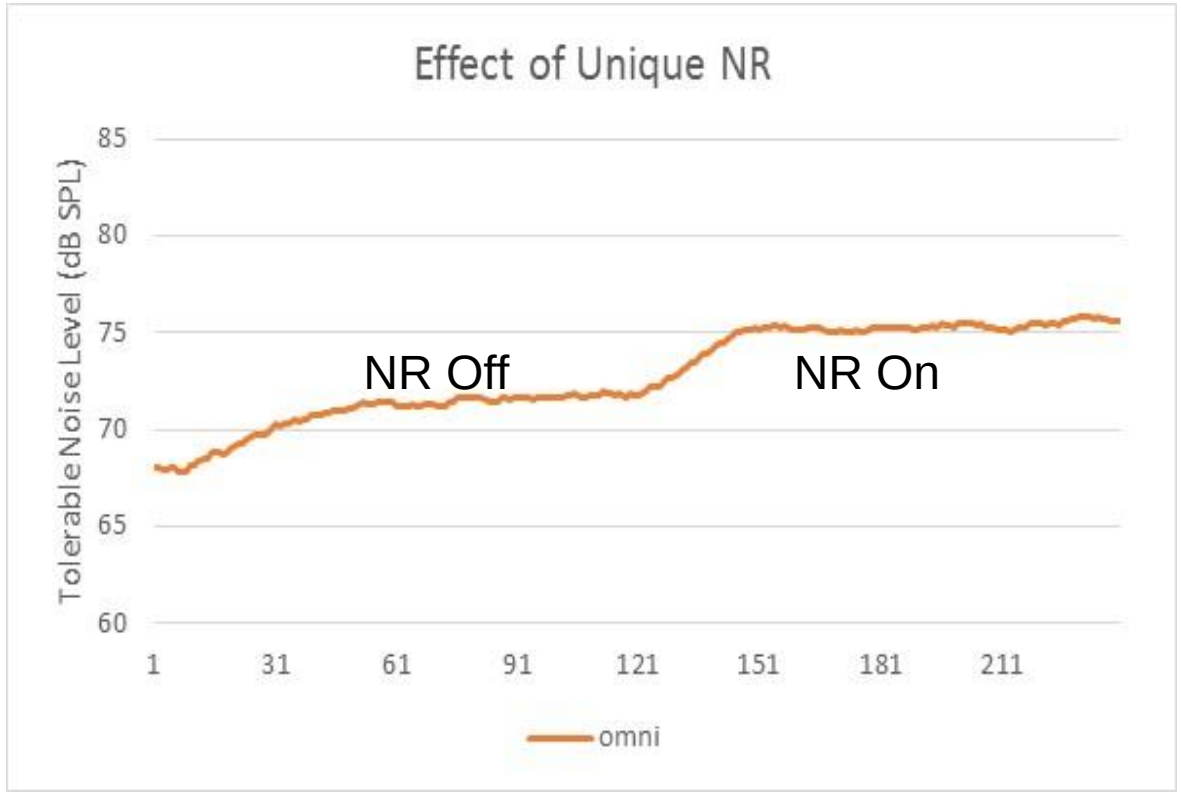


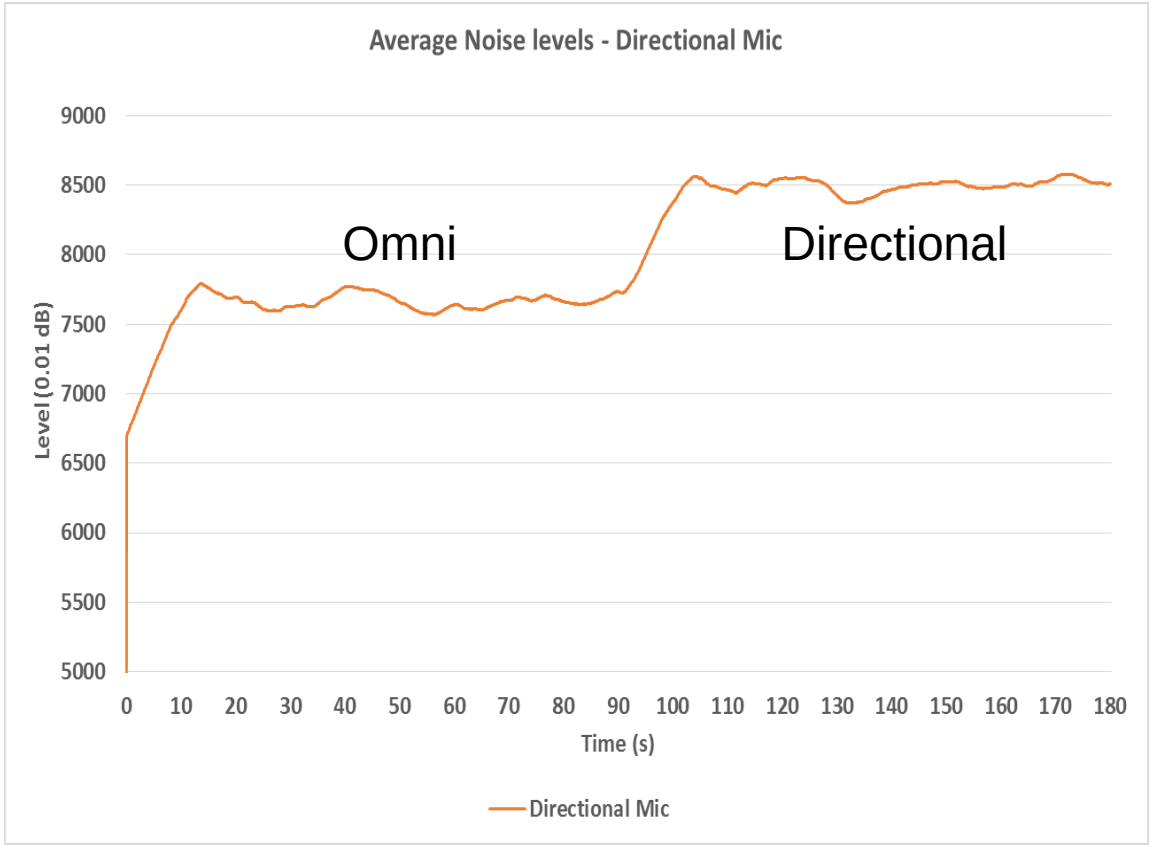
TARGET TNT – CLOSE TO NORMAL TNT

- Seper et al (2018) found in 17 satisfied wearers of hearing aids that their TNL were:
  - Babble noise = 79.2 dB (vs normal 79.5)
  - Continuous noise = 77 dB (vs normal 76.5)
  - ALL but one subject had TNL much below 70 dB SPL



EVALUATION OF **HEARING AID FEATURE EFFICACY/FINE-TUNING**





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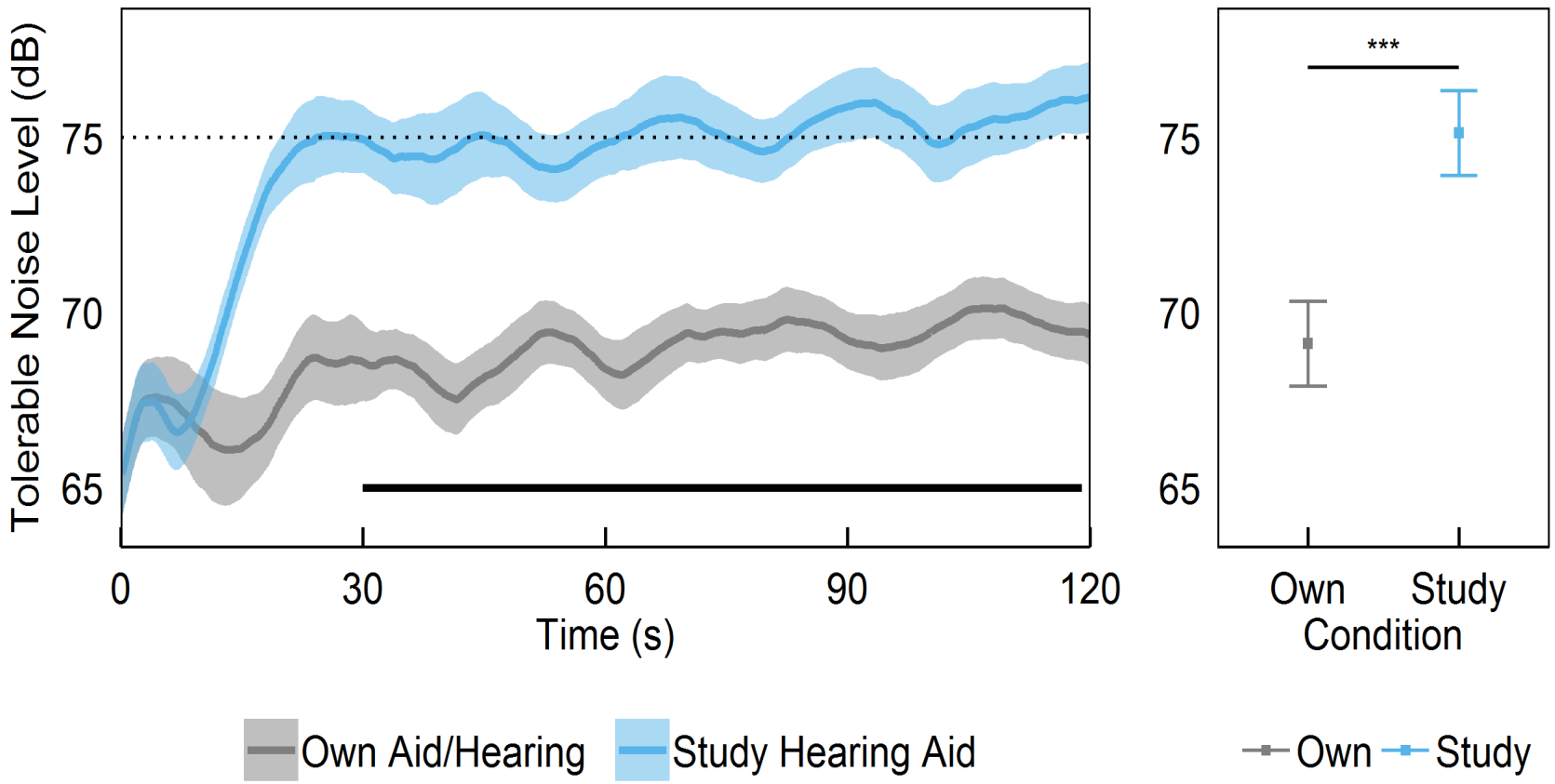
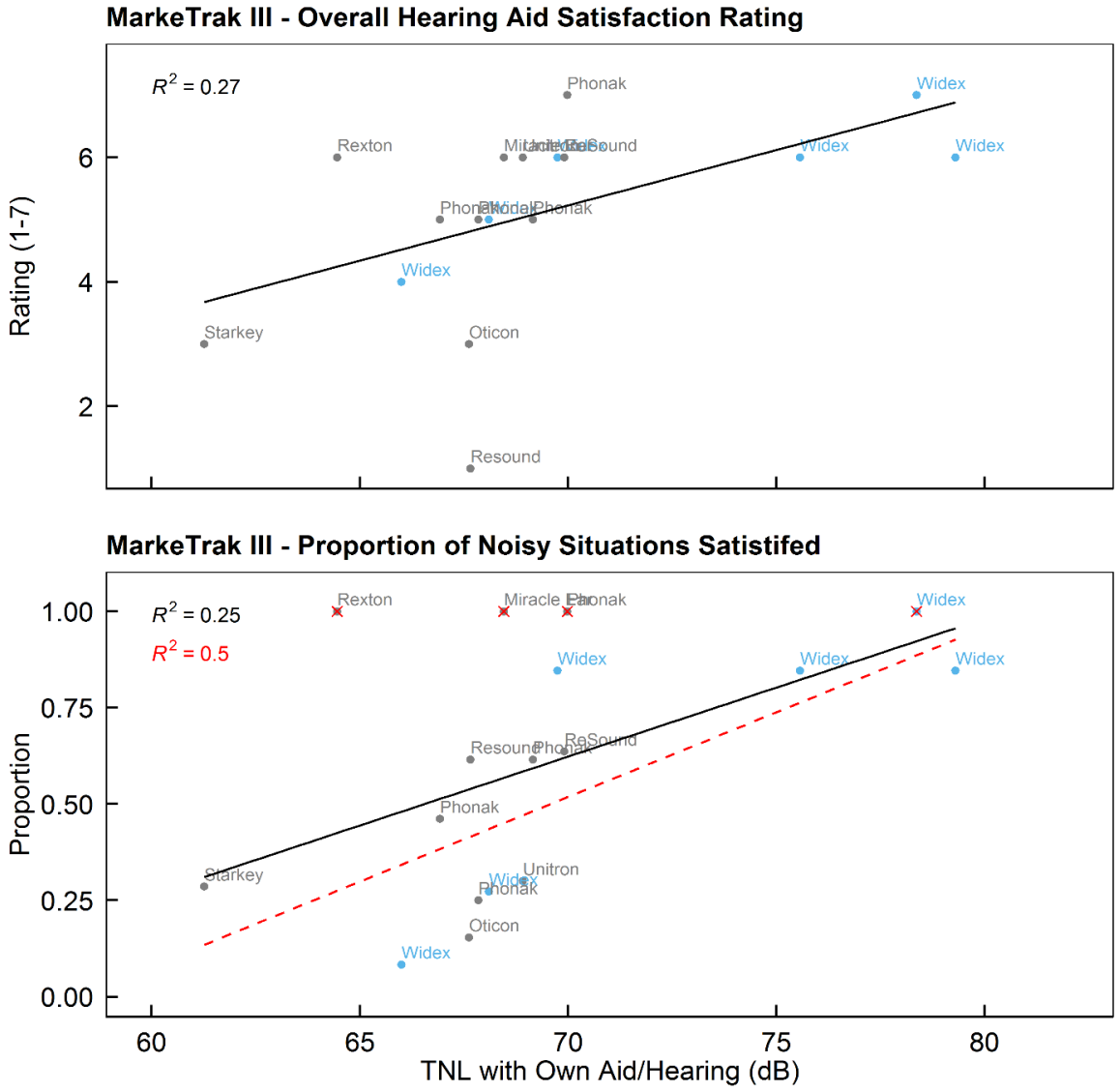
COMPARISON **BETWEEN HEARING AIDS**



PREDICTION OF **HEARING AID SATISFACTION** IN NOISE



MANY **UNEXPLORED QUESTIONS**

- Why are normal-hearing and hearing-impaired listeners behaved differently on the TNT even with the same instructions?
- Can the TNT differentiate among people who over-and/or under-estimate their hearing ability?
- What does the TNT peak represent? Comfort?
- What does the excursion mean? What determines that?
- What determines the HI listeners' subjective criteria?
- Why HI showed more differences between subjective and objective intelligibility? Does the Dunning-Kruger effect apply?
- Could TNT be a test for special populations such as people with noise-induced hearing loss, hidden hearing loss or King-Kopetzky syndrome or other disease processes?

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Thanks for listening !

Email francis.kuk@wsa.com for link to TNT;
or interest in studying/using TNT