NEEDS AND WANTS: SUBJECTIVE INTELLIGIBILITY AND CRITERIA AFFECTING NOISE TOLERANCE

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INTRODUCTION

- The Tracking of Noise Tolerance (TNT) test is a Békésy-tracking noise acceptance measure developed to evaluate hearing aid feature efficacy (Kuk et al., 2023a).
- TNT studies have observed notable variability in overall noise acceptance and patterns of noise tracking in both normal hearing (NH) and hearing-impaired (HI) older adults.
- Here, we use the Noise Tolerance Domains Test (NTDT; Mackersie et al., 2021) to study which of four subjective noise domain criteria (*loudness, annoyance*, *distaction*, and *speech interference*) might be weighted most heavilty by older NH and HI listeners when making noise tolerance judgments during the TNT.
- NTDT results were further integrated with estimates of subjective intelligibility for the TNT speech materials (Kuk et al., 2023b) across a range of signal-to-noise ratios (SNRs) covering the average excursion of tracked noise levels (TNLs).

METHODS

Participants and Study Aids

- **STUDY SAMPLE**:
  - NH Group: N = 22 (mean age = 63.9 yrs, SD = 8.2, 16 female).
  - HI Group: N = 17 (mean age = 76.9 yrs, SD = 8.4, 6 female).
    - Symmetrical (±10 dB) sensorineural hearing loss *(Fig. 1)*.
    - Normal cognitive function (MoCA > 24).
  - All native speakers of American English.
- **STUDY HEARING AIDS**:
  - Signia AX RIC multichannel WDRC hearing aids.
  - Fitted to listeners' audiometric thresholds with appropriate ear-tips according to NAL-NL2 at 100% gain (autoREM verified).
  - HA features (e.g., split-processing, adaptive DM and NR systems) left to manufacturer's defaults.
  - Two weeks of at home acclimatization prior to in-lab testing.

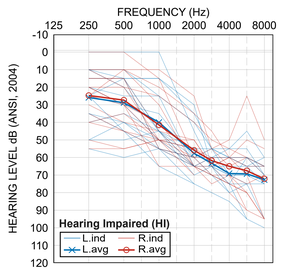

Fig. 1. Individual (thin lines) and average (bold lines) audiograms for the left (blue; X's) and right (red; O's) ears of the HI participant sample.

Stimuli, Noise Configuration, and Test Conditions

- Each of the following tests presented speech materials developed for the TNT. Materials were adapted from Simple English Wikipedia entries based on 8 different topics to generate 8 unique passages.
  - Speech was presented at two fixed levels of 75 and 82 dB SPL from a single loudspeaker located at 1 m in front of the listener (0° azimuth).
- Co-located (0° azimuth) continuous speech-shaped ICRA noise was used as the masker.
- NH Listeners were tested in the unaided mode; HI listeners were tested in unaided and aided modes.

Tracking of Noise Tolerance (TNT)

- The TNT test asks listeners to adjust the level of an ongoing background noise while listening to a continuous speech passage (*Fig. 2*).
- All listeners are given the following instructions:

" You will hear some noise in the background while you listen to the male talker. As the talker speaks, the background noise will automatically get louder. I want you to monitor this noise level and maintain the loudest noise level you can put up with while still understanding more than 90% of the words in the story. If the noise becomes too loud, where you can no longer put up with it or where you understand less than 90% of the words, you can turn the noise down by pressing and holding the space bar on your keyboard. If the noise feels softer than before, where you can easily understand >90% of the words, you should release the space bar and allow the noise volume to increase. If the noise once again becomes too loud, you should press and hold the space bar to decrease the noise. By controlling the volume of the background noise in this way, I want you to maintain the maximum noise level that you can put up with where your ability to understand speech never drops to below 90%. The test will run for two minutes and then stop."

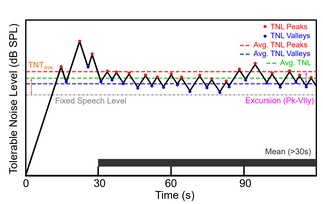

Fig. 2. An example of listener performance on the TNT test. The tolerable noise level (TNL) is tracked while the listener attempts to follow speech produced by a male talker. The TNT_{Ave} outcome measure is defined by the difference between the average TNL and the fixed speech level. The Excursion outcome measure is defined by the difference between the average of TNLs measured at the peaks and valleys of the TNL tracing.

Noise Tolerance Domains Test (NTDT)

- NTDT test followed methods adapted from Mackersie et al., (2021):
  - On each trial, listeners were presented with TNT passages in noise at one of three SNRs (-3, 0, and +3 dB relative to their TNT_{Ave} scores) and asked to compare four subjective noise-tolerance domain criteria, *loudness*, *annoyance*, *distraction*, and *speech interference*, as follows (*Fig. 3*):
    - **(1) PAIRED COMPARISON:**
      - *"Which of the following [domains] was more responsible for non-acceptance of noise?"*
      - Each domain criterion was paired with all others twice per condition (12 total comparisons).
    - **(2) ABSOLUTE DOMAIN WEIGHTING:**
      - *"How much was your impression of the noise affected by each specific domain criterion?"*
      - Rating for each domain provided using visual analog scale of 0–100, where "0" = no effect and "100" = large effect.
      - Domains were independent; summed ratings could exceed 100.
- Outcomes used to calculate Weighted Noise Tolerance Domain Rating (WNTDR) for each criteria:

$$\text{WNTDR} = P_{(\text{Selected in PC})} * \text{Absolute Weighting}$$

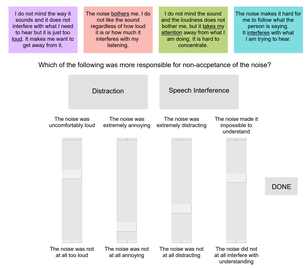

Fig. 3. Screenshot of the NTDT software response interface.

Subjective Intelligibility Test

- Data collected as part of objective-subjective intelligibility difference (OSID) test (Kuk et al., 2023b).
  - On each trial, listeners were presented with TNT speech materials adapted into 5 lists of 3 sentences each.
  - Each set included 3 or 4 target words for scoring (objective intelligibility).
  - List equivalence was evaluated by measuring objective SIN intelligibility in a separate group of 10 NH listeners.
  - Sentences were rearranged based on measure performance so that each list was similar in difficulty.
  - Each list presented at one SNR (randomized order):
    - NH Group tested at SNRs of: -9, -6, -3, 0, +3 dB.
    - HI Group tested at individualized SNRs to capture whole performance-intensity (P-I) function.
  - **SUBJECTIVE INTELLIGIBILITY TASK:**
    - *"Please estimate how much of the speech you can understand."*
    - Estimates provided using visual analog scale of 0–100% via touchscreen monitor.
  - P-I functions were derived for each participant in each condition by fitting logistic regression functions to subjective rating data:

$$\varphi(x) = (1-\lambda)\left(1 + e^{(-\beta*(x-\alpha))}\right)^{-1}$$

Where x is the SNR, α is the threshold parameter (i.e., SRT-50), β is the rate of change parameter, and λ is the lapse parameter (i.e., upper asymptote). Up to 10% lapse was allowed for the HI listeners who did not always reach 100% performance.

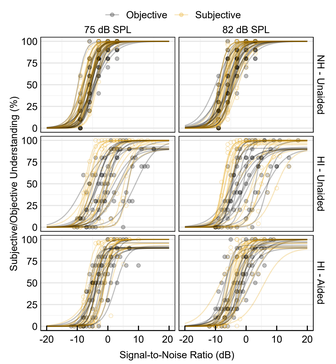

Fig. 4. Individual data and fitted subjective (yellow) and objective (black) performance-intensity (P-I) functions for NH (top), and HI listeners in the unaided (middle) and aided (bottom) conditions.

RESULTS

- *Fig. 5* plots WNTDRs for each domain criterion as a function of estimated subjective speech intelligibility at SNRs around listeners' TNT_{Ave} scores.
- A linear mixed effects (LME) model assessed the fixed effects of *subjective intelligibility* (continuous), *speech input level* (75/82 dB SPL), *listener condition* (NH Unaided, HI-Unaided, HI-Aided), and *domain criteria* (annoyance, distraction, speech interference, and loudness) on WNTDRs. Model coded participants as random effects with unique intercepts.
  - Maximal model containing all fixed effects and possible interactions was refined via backward stepwise elimination using *lmeTest* in R.
  - Results are summarized in *Tbl. 1* and *Fig. 6*.

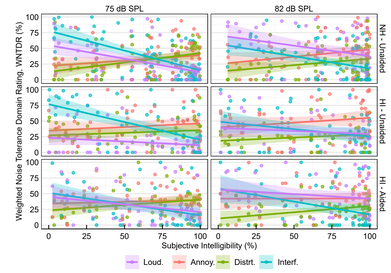

Fig. 5. Raw data showing weighted noise tolerance domain ratings (WNTDR) for each domain criterion (colors) agains subjective speech intelligibility estimated for each test SNR.

Tbl. 1. Summary of reduced LME model assessing fixed effects and interactions on WNTDR for domain criteria used to judge noise tolerance under different listening conditions.

Fixed Effect	F	df	df.res	p	sig.
Domain Criteria	35.40	3	1272.14	<0.001	***
Subjective Intelligibility	16.70	1	923.65	<0.001	***
Speech Input Level	6.33	1	1283.40	0.012	*
Listener Condition	0.11	2	423.95	0.894	n.s.
Criteria:Subj_Intell	42.46	3	1272.14	<0.001	***
Criteria:Level	18.03	3	1272.14	<0.001	***
Criteria:Listener_Cond	4.50	6	1272.14	<0.001	***
Subj_Intell:Listener_Cond	0.11	2	1098.59	0.892	n.s.
Criteria:Subj_Intell:Listener_Cond	2.14	6	1272.14	0.046	*

n.s. = not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

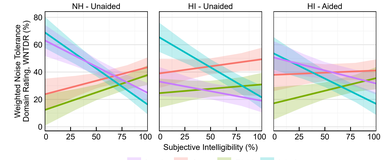

Fig. 6. Linear fits exploring the significant three-way interaction of listener condition (panels), subjective intelligibility (x-axes), and domain criteria (colors) on listeners' WNTDRs for judging noise tolerance.

Tbl. 2. Means of predictor variables grouped according to listener group, hearing mode, speech input level, and domain criteria categorization.

GRP	Mode	Level (SPL)	Subj. Criteria Group	Sex (F)	Age (yrs)	4PTA (dB HL)	MoCA (/30)	Obj. Intell. (%)	Subj. Intell. (%)	TNT_{Ave} (dB NSR)	Excur. (dB)	Obj. SRT50 (dB)	Subj. SRT50 (dB)	SRT OSID (dB)
NH	Unaided	75 dB	Acoust.	6	61.3	9.2	28.1	47.0	48.0	7.0	2.8	-6.7	-7.0	0.4
			Cogn.	8	66.3	11.5	26.8	71.7	78.2	2.8	5.0	-5.2	-5.4	0.2
		82 dB	Acoust.	6	65.1	11.0	27.7	74.2	75.2	4.1	4.0	-5.2	-6.1	-0.1
			Cogn.	8	63.3	10.1	26.9	77.7	76.9	1.6	3.8	-6.0	-5.6	-0.6
HI	Unaided	75 dB	Acoust.	3	76.6	46.9	27.2	32.8	48.2	0.7	3.7	1.0	-0.7	1.8
			Cogn.	3	77.3	49.6	27.4	46.4	73.7	0.5	0.6	-0.8	-2.9	2.1
		82 dB	Acoust.	0	80.0	55.9	27.2	32.5	34.2	-2.6	5.3	3.6	3.9	-0.3
			Cogn.	6	75.6	44.9	27.3	49.3	77.5	2.6	4.9	-2.0	-4.7	2.6
	Aided	75 dB	Acoust.	2	79.1	46.4	27.3	52.1	50.3	2.7	5.5	-3.0	-2.7	-0.3
			Cogn.	4	75.3	49.4	27.3	60.5	74.1	2.1	4.9	-2.0	-3.6	1.6
		82 dB	Acoust.	2	81.9	52.6	27.1	59.8	72.4	1.2	4.6	-1.8	-2.2	0.4
			Cogn.	4	71.3	43.2	27.5	51.6	67.3	2.5	4.8	-3.1	-4.2	1.1

- WNTDRs were affected by listeners' subjective speech intelligibility across test SNRs, regardless of their hearing status (NH/HI) given in-situ acoustics were sufficient.
- When subjective intelligibility was poor, the domains of speech interference and loudness were weighted most heavily. As subjective intelligibility improved, weightings assigned to annoyance and distraction increased.
- Based on the most heavily weighted domain at the TNT_{Ave} SNR, it was determined that that listeners could be broadly categorized into those prioritizing acoustic factors or 'needs' (*speech interference* and *loudness*) and those prioritizing emotional/cognitive factors or 'wants' (*annoyance* and *distraction*).
- General linear regression assessing different possible predictor variables (*Tbl. 2*) determined that subjective intelligibility at the TNT_{Ave} SNR best accounted for category membership, over listener demographics, TNT outcome measures, or objective/subjective intelligibility SRT-50s (*Fig. 7*).

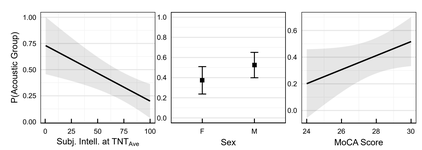

*Fig. 7. Probability associated with three surviving variables (subjective intelligibility at TNT_{Ave}, sex, and MoCA scores) predicting listener categorization into the "Acoustic" (i.e., "needs") group. Only subjective intelligibility at the TNT_{Ave} SNR was determined to be significant in the final model ($t = -3.21$, $p = 0.002$**).*

CONCLUSION

- All listeners are instructed to perform the TNT such that they maintain the loudest level of noise they can "put up with" while understanding > 90% of speech. However, these results suggest that listeners may follow two broadly different strategies, one in which noise tolerance is defined by the perception of acoustic interference and the other in which it is defined by emotional/cognitive judgements made at SNRs where acoustic needs are already satisfied.

REFERENCES

- Kuk, F., Slugocki, C., & Korhonen, P. (2023a). Performance of older normal-hearing listeners on the tracking of noise tolerance (TNT) test. *Int J Audiol*, 1–8.
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- Mackersie, C., Kim, N., Lockshaw, S., & Nash, M. (2021). Subjective criteria underlying noise-tolerance in the presence of speech. *Int J Audiol*, *60*(2), 89–95.