Imperial College London

Personalised HRTFs for hearing aids

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HATS 1 856-02-600-05
Seriel number: 2036104

Overview

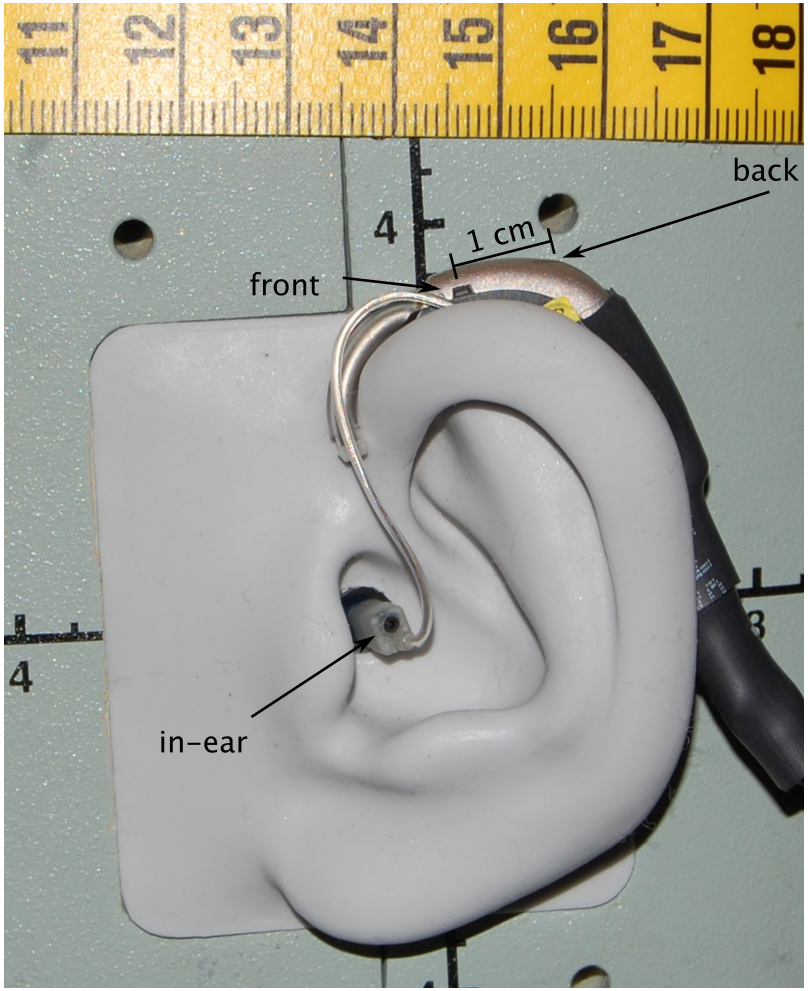
- Context
- Database
- Evaluation
  - Beampatterns
  - Binaural speech intelligibility metric
  - Matrix speech intelligibility

Database

- 46 sets of acoustic measurements
  - 27 male, 14 female, 4 mannequins
  - HATS mannequin measured twice
- Basic anthropometric measurements
  - HATS head circumference (55.9 cm) small compared to population

	Circumference [cm]		
Percentile	Male	Female	Human
0	56.4	54.6	54.6
25	58.7	56.1	56.7
50	59.8	56.4	58.9
75	60.4	57.3	60.1
100	62.7	59.2	62.7

Measurement system



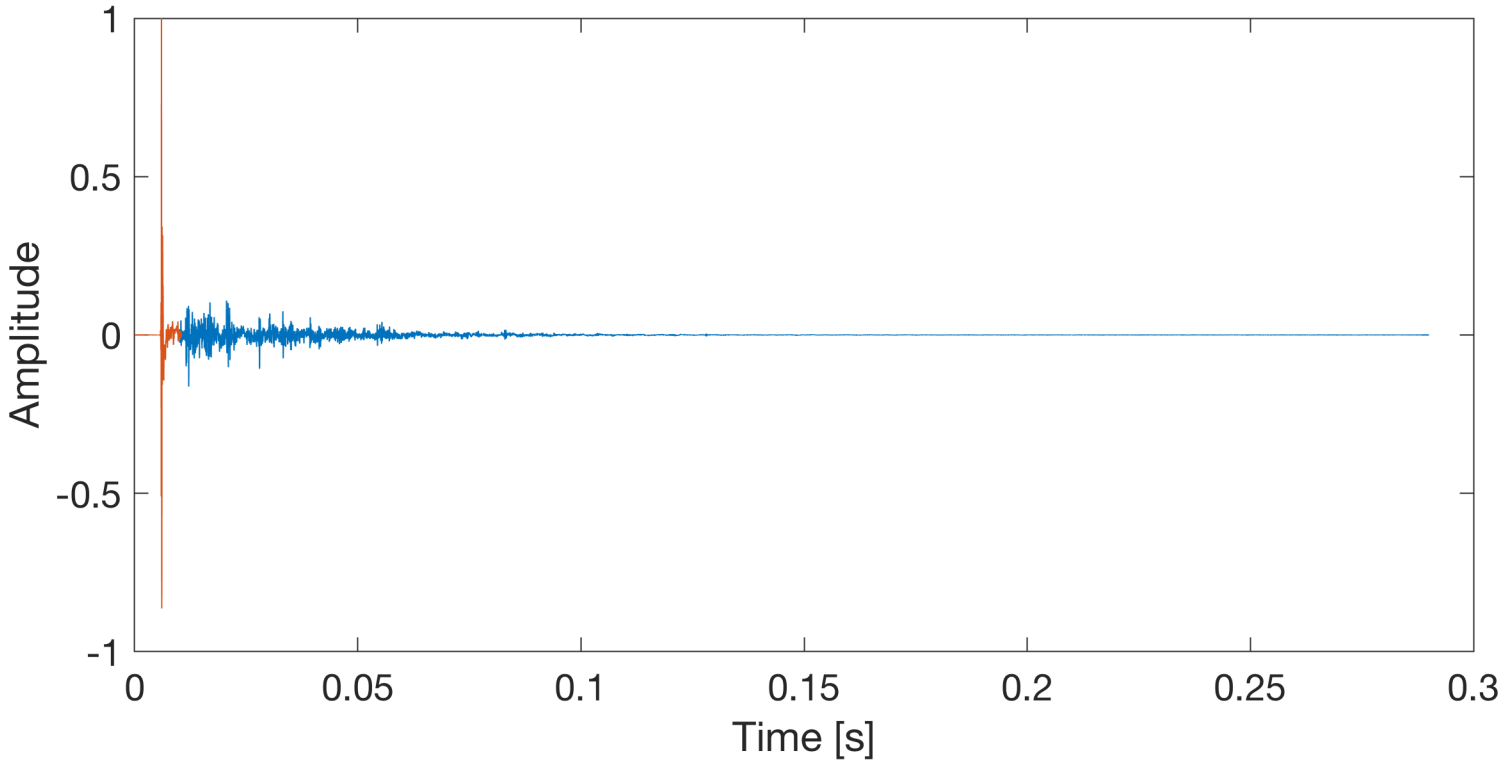
Measurement system

- 29 speakers
  - 16 in horizontal plane with 22.5 degree spacing
  - + 6 at ±45 degrees elevation + 1 overhead

- $7.9 \times 6.0 \times 3.5$ m room
  - Reverberation time: 250 ms
- Chair rotated
  - 0, -15, -30 degrees

Post processing (study)

- Full room impulse response – 290 ms
- Windowed, direct-path only – 11 ms



Signal-independent beamforming

- Minimum variance distortionless response (MVDR)

$$\tilde{\mathbf{w}} = \frac{\mathbf{R}_{\mathbf{y}}^{-1}\mathbf{h}(\Omega)}{\mathbf{h}(\Omega)^{H}\mathbf{R}_{\mathbf{y}}^{-1}\mathbf{h}(\Omega)}$$

- Ω "look" direction
- $\mathbf{h}$ Steering vector (relative transfer function)
  - First ~11 ms of measured HA-RIR for look direction
- $\mathbf{R}_{\mathbf{y}}$ Noise covariance matrix
  - Spatial relationship of the noise between the sensors
  - Obtained empirically by simulating signals due to 1 second of uncorrelated noise incident from 16 horizontal plane directions
  - "Anechoic" steering vectors used (i.e. not including reverberation)
- Filters designed in frequency domain

Beamformer configurations

- Bilateral (2:2)
  - Each ear uses only the 2 microphones from that ear
  - Expect less benefit in SNR
- Binaural (4:4)
  - Each ear uses all 4 microphones
  - Expect more SNR benefit
  - Residual noise is co-located with target

Beamformer personalisation

- Personal
  - Beamformers designed using same cropped versions of HA-RIRs used for simulation
- HATS
  - One specific case of non-personal beamformers representing current hearing aids

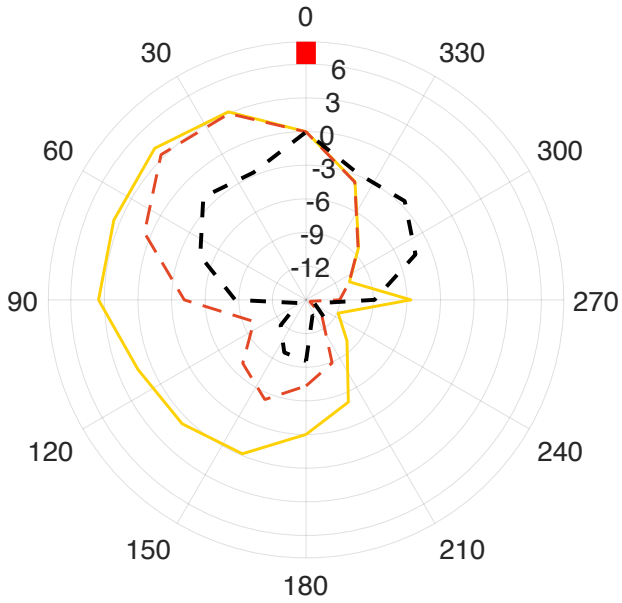
Directivity patterns

- Response power due to a plane wave as a function of azimuth of arrival
- A-weighted
- Normalized with respect to reference plane wave incident from front

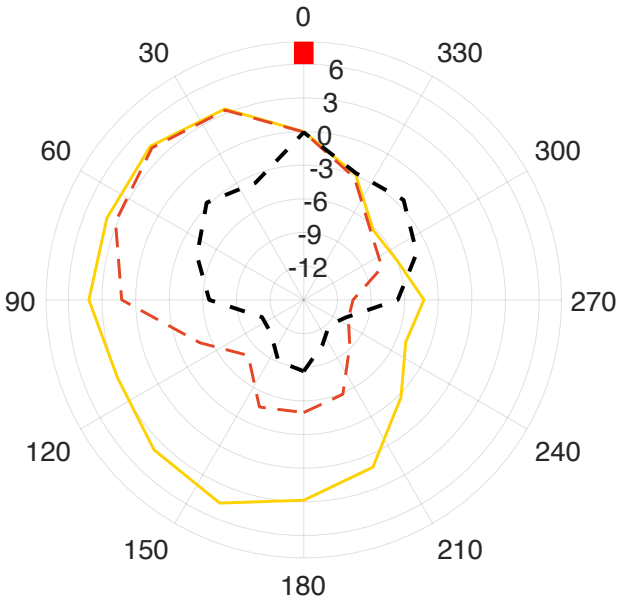
- Distortionless constraint – beamformer power should match reference response in target direction
  - 0 dB response when steered to front
- Minimum variance – total power summed over all directions as low as possible

Directivity patterns – frontal target

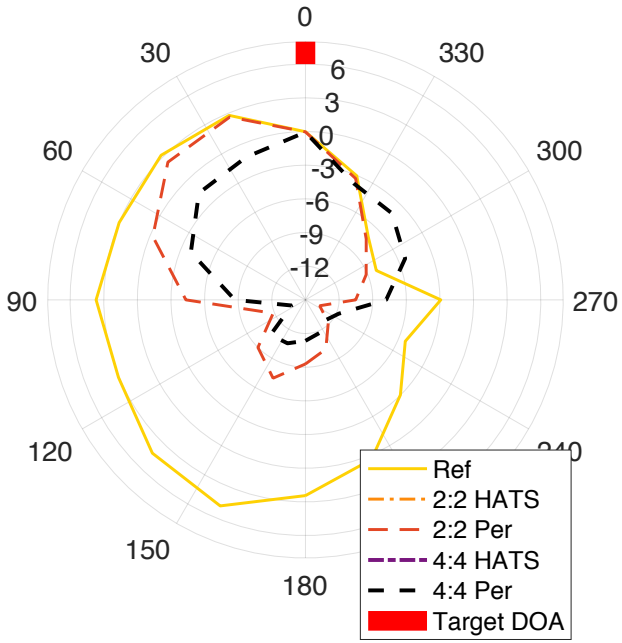
HATS remeasured



Circumference similar to HATS



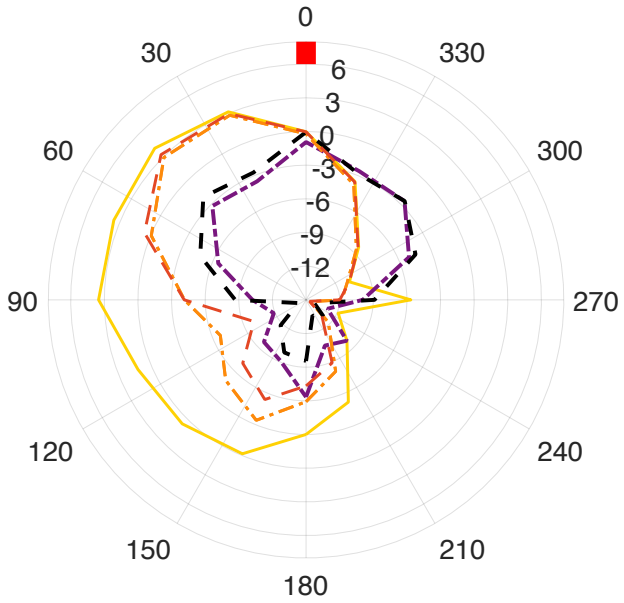
Circumference dissimilar to HATS



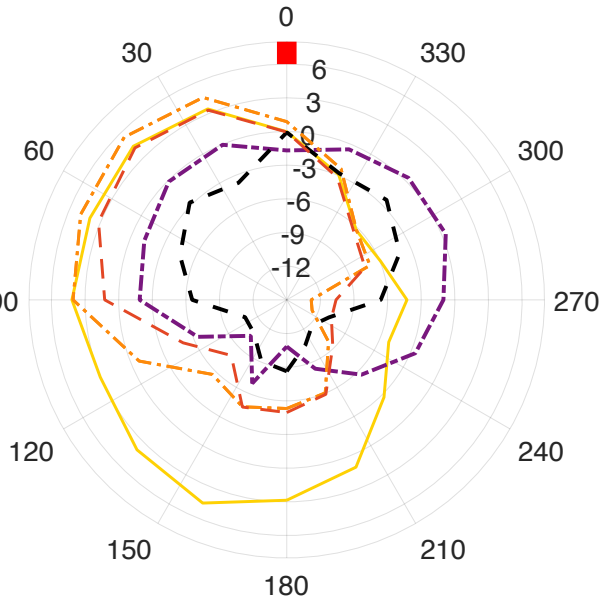
- Binaural (4:4) gives clear benefit over bilateral (2:2)

Directivity patterns – frontal target

HATS remeasured



Circumference similar to HATS



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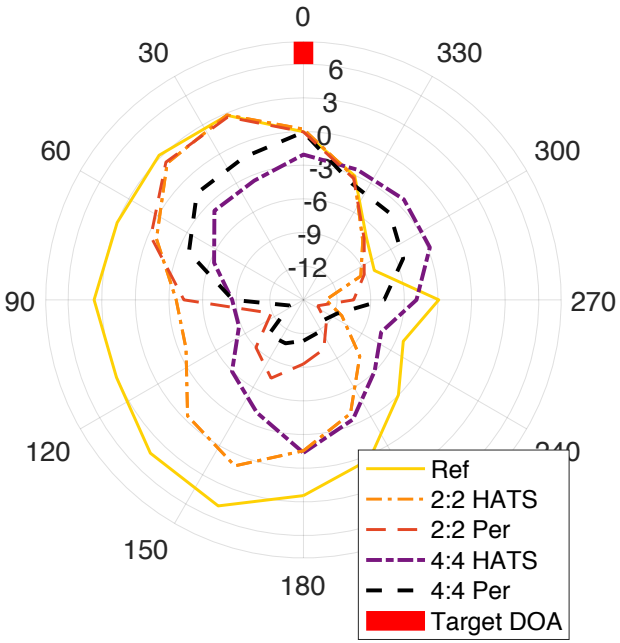
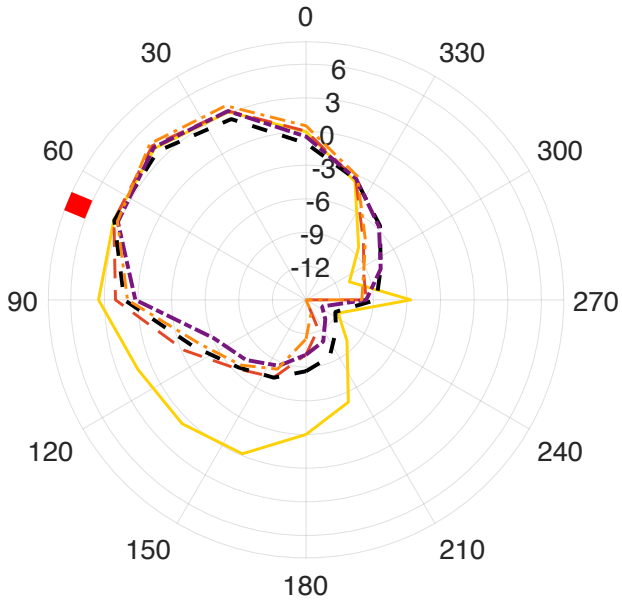


- Binaural (4:4) gives clear benefit over bilateral (2:2)
- HATS beamformers not exactly 0 dB in look direction
- Per beamformers have more compact beampattern

Directivity patterns – lateral target

HATS remeasured



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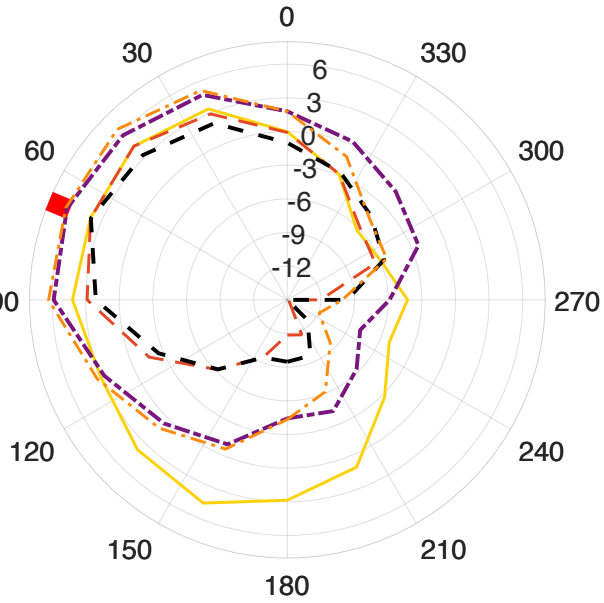
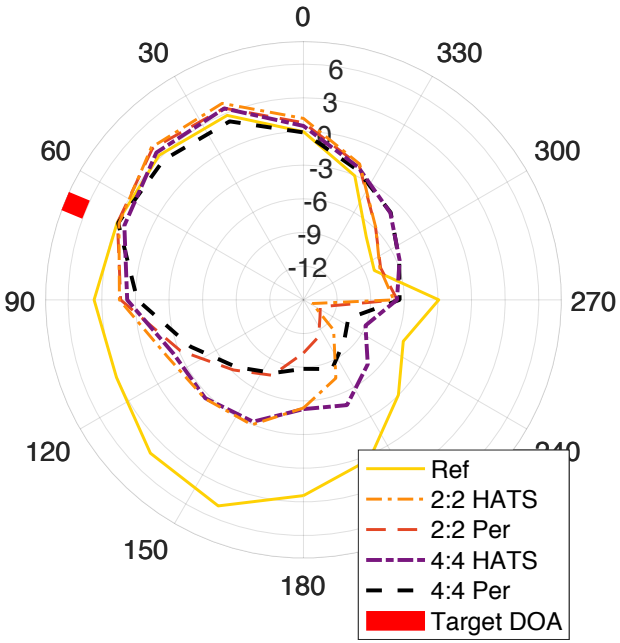


Circumference dissimilar to HATS



- Binaural (4:4) no better than bilateral (2:2)
- Personalised beamformers have slightly better attenuation to rear

How does this affect intelligibility?

- Reverberation
- Diffuse noise
- Binaural hearing

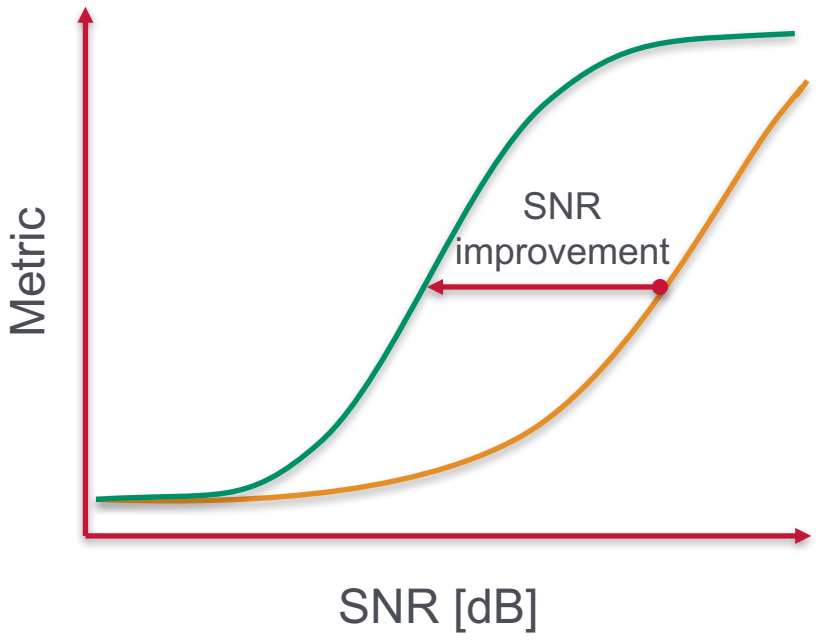
Personalised simulation

- Full hearing aid room impulse response
  - 4 BTE microphones (2 per ear)
  - Reverberation time ~0.25 s
- Target source
  - Frontal – 0 degrees
  - Lateral – 67.5 degrees

- Babble noise
  - 4 male + 4 female talkers from each of
  - 16 directions on horizontal plane

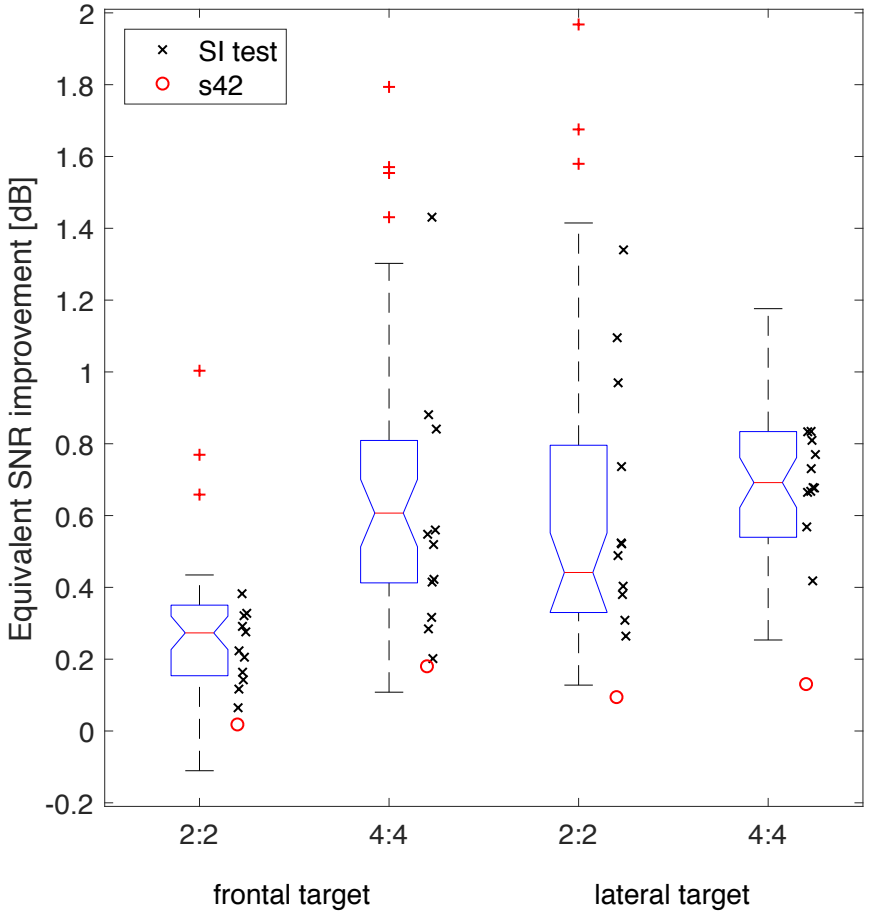
Predicted binaural intelligibility

- MBSTOI - Intrusive metric
- ‘Reference’ signals:
  - direct path target at front microphones
- ‘Degraded’ signals:
  - received noisy, reverberant signals at front microphones
- ‘Enhanced’ signals:
  - output of beamformer
- Report SNR improvement



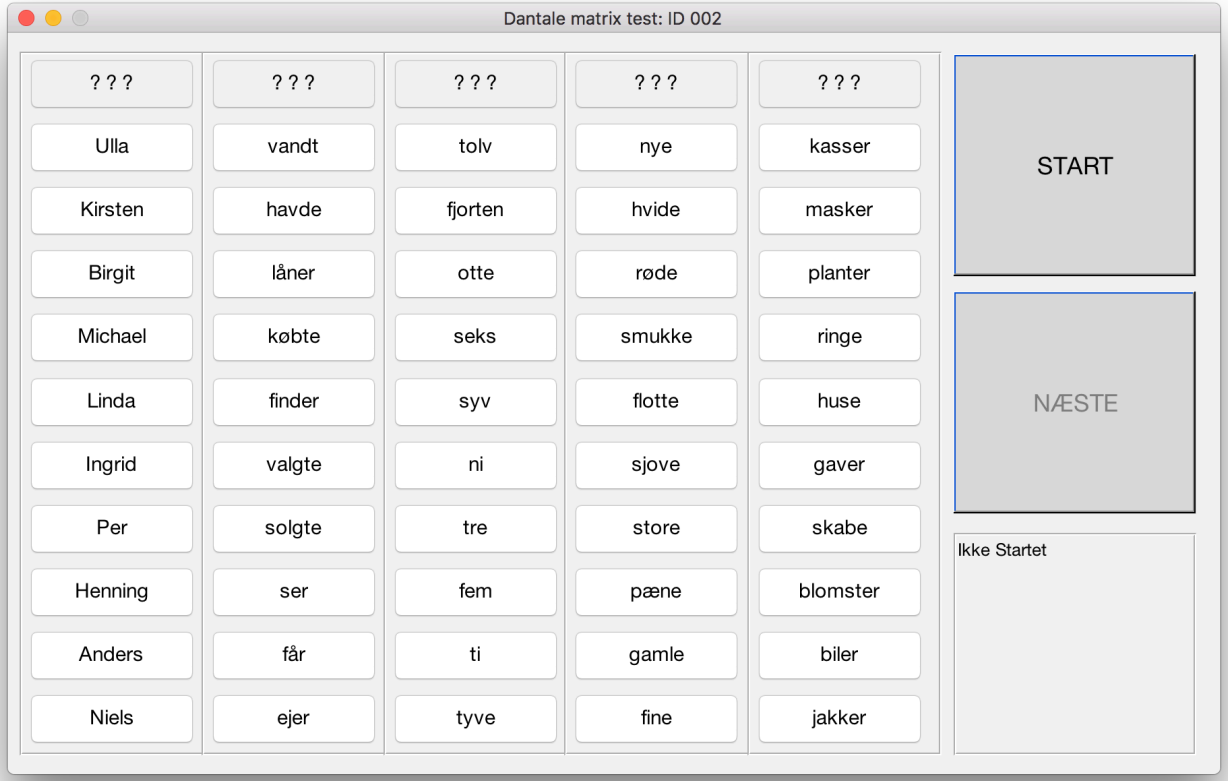
Personalised vs HATS

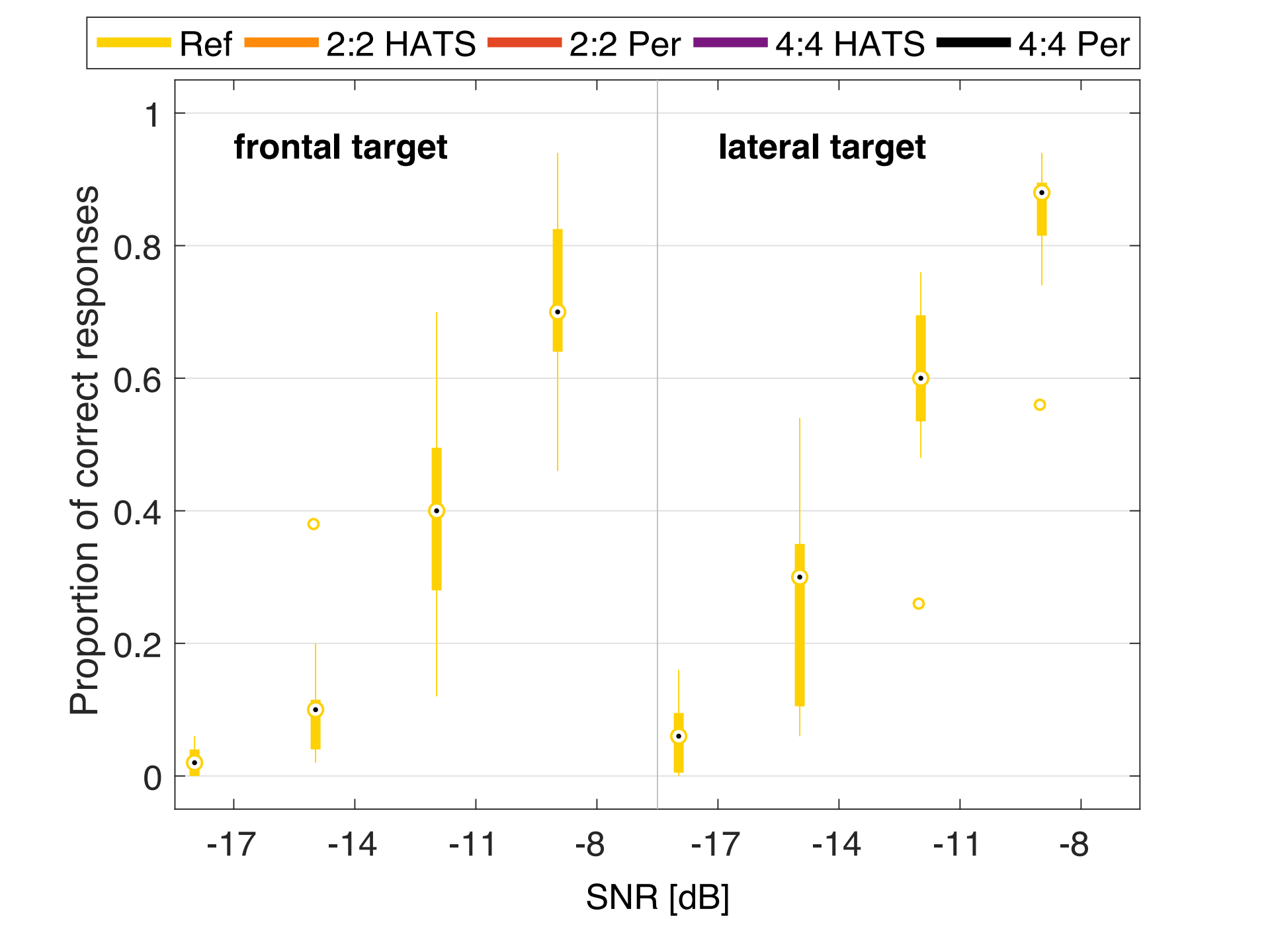
- Many databases based on HATS
- Expected performance benefit of individual measurements
- Median improvement:
  - 0.3 – 0.7 dB
- Maximum improvement:
  - 1 – 2 dB
- Crosses represent SI test participants

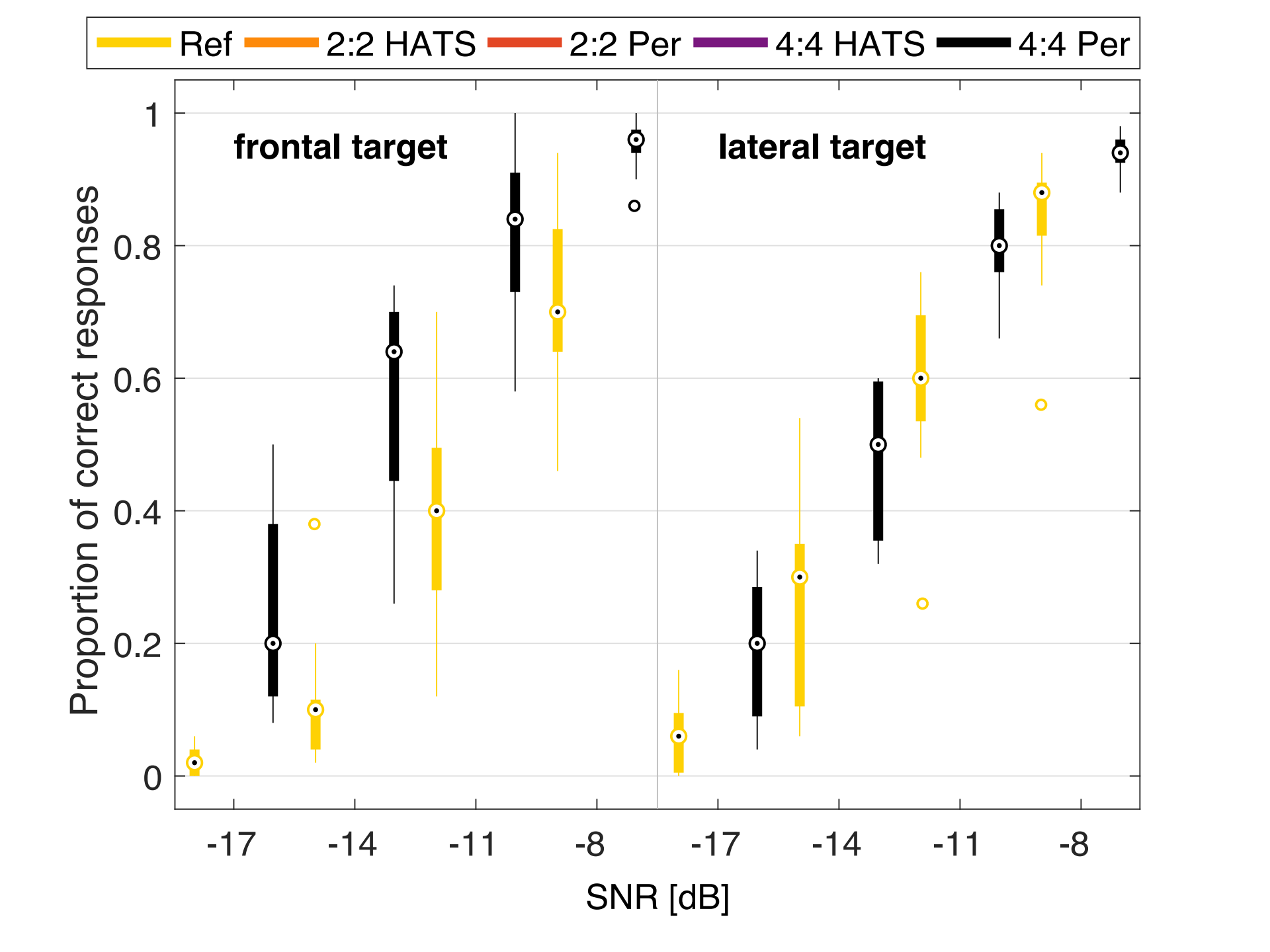


Matrix test speech intelligibility

- 5 words per sentence
- Pick 1 of 10 in each position or ‘Don’t know’




Ref
2:2 HATS
2:2 Per
4:4 HATS
4:4 Per
frontal target
lateral target
Proportion of correct responses
1
0.8
0.6
0.4
0.2
0
-17
-14
-11
-8
-17
-14
-11
-8
SNR [dB]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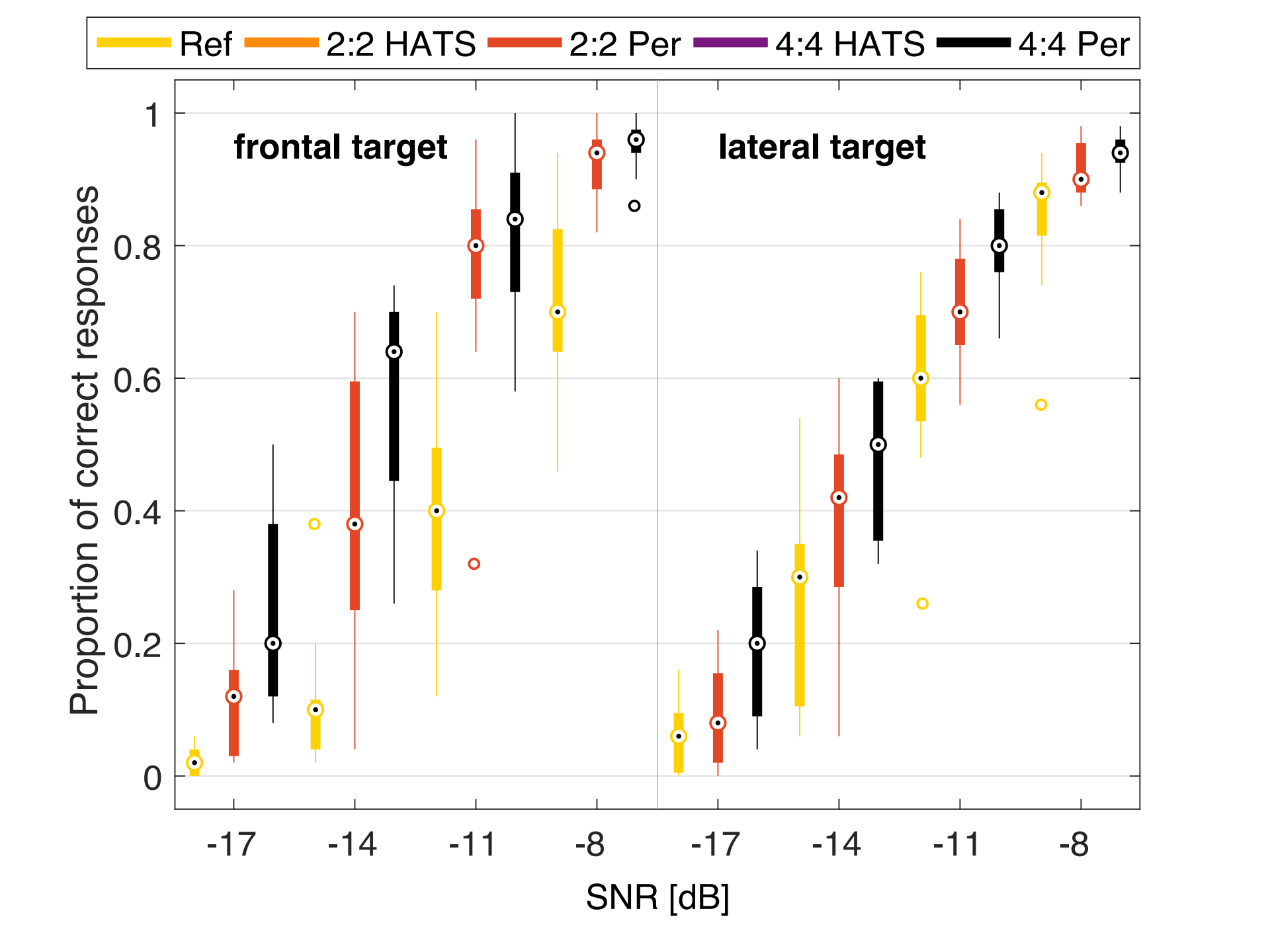
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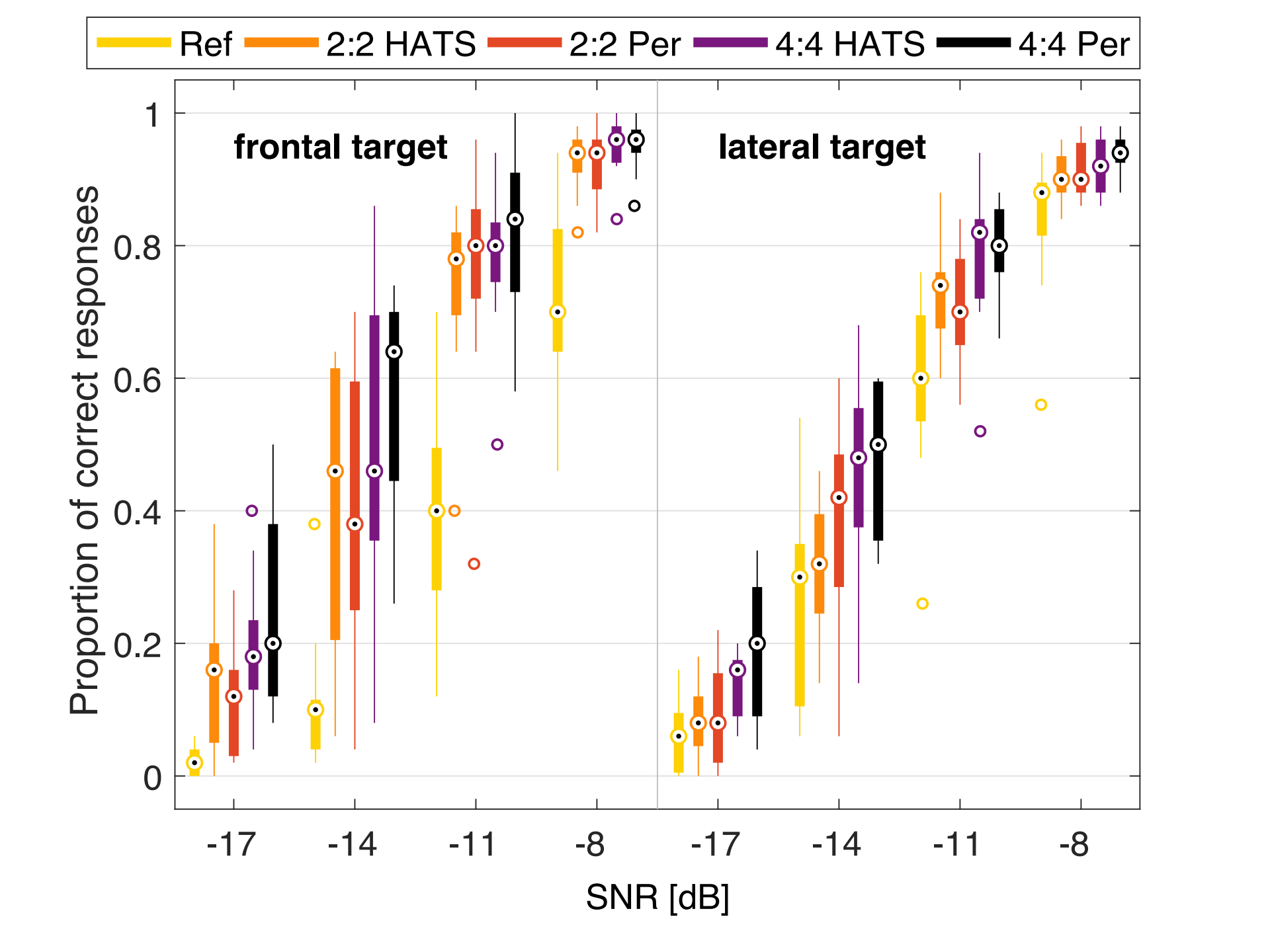
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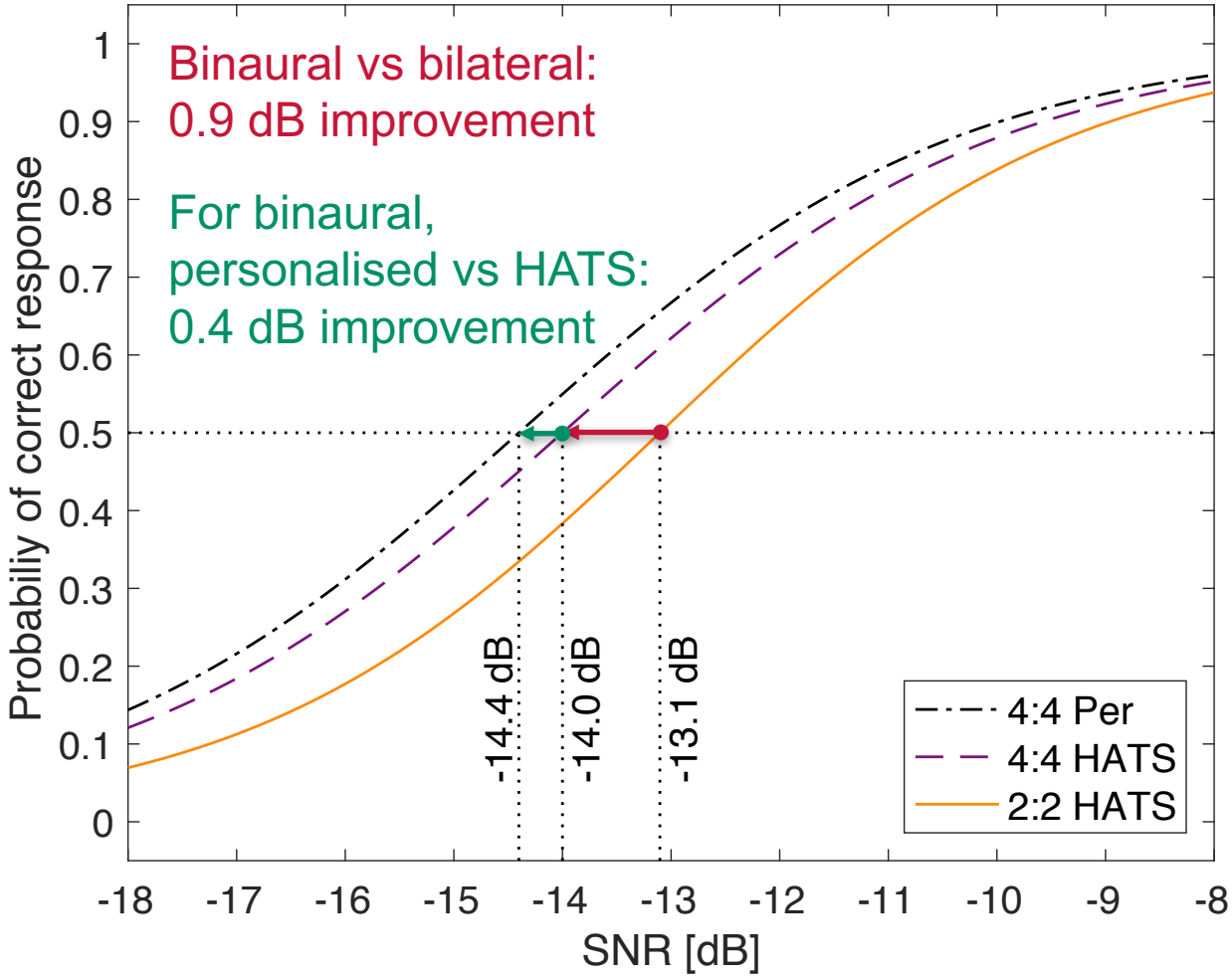
-8
SNR [dB]

Statistical analysis

- Exclude reference condition
- Mixed-effects logistic regression
- Fixed factors
  - SNR (linear: -17...-8)
  - Target direction (binary: frontal / lateral)
  - Configuration (binary: bilateral / binaural)
  - Personalisation (binary: HATS / personal)
- Random factor
  - Participant
- Starting with null model, use likelihood ratio tests to sequentially add significant factors and interactions
- Prune after each addition

Final model

For bilateral, personalised vs HATS: Not significant



Conclusions

- New database allows analysis of the effect of personalisation
- More generally, enables mismatched (realistic!) conditions to be simulated
- Directivity patterns suggest benefit of binaural beamforming vs bilateral is only for frontal sources
- Personalisation improves predicted speech intelligibility for bilateral and binaural beamformers
- Effect is significant for binaural case in matrix speech intelligibility experiment

Thanks to…

- This work was supported by the Engineering and Physical Sciences Research Council [grant number EP/M026698/1].
- Asger Andersen for providing code for MBSTOI and the Dantale matrix text
- Study participants for their enthusiasm