AAT Seminar

Perceptual quality evaluation of spatial sound

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4.3.2024

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"We define* (perceptual) *quality as the outcome of an individual's comparison and judgment process.

It includes perception, reflection about the perception, and the description of the outcome".

Le Callet et al. (2012)

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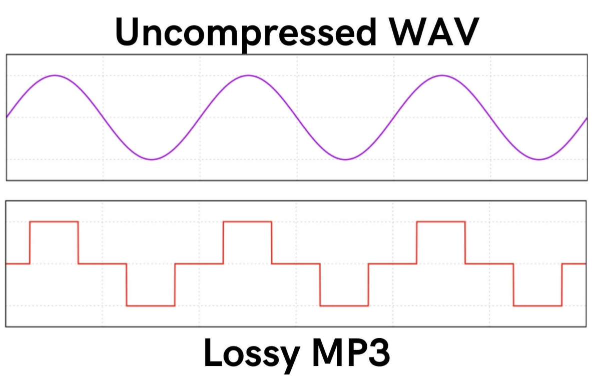

Le Callet et al. (2012)

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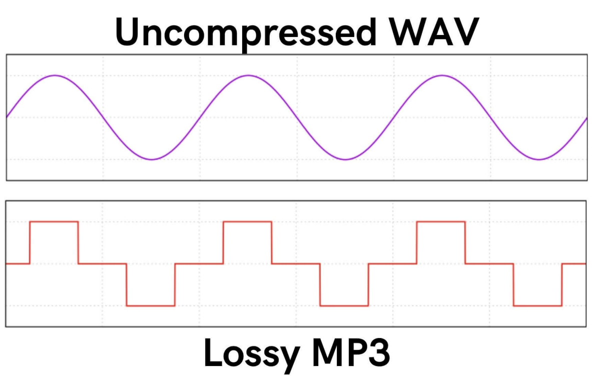
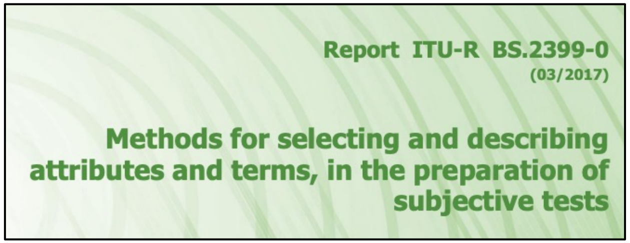


Le Callet et al. (2012)

Sound quality depends on several attributes

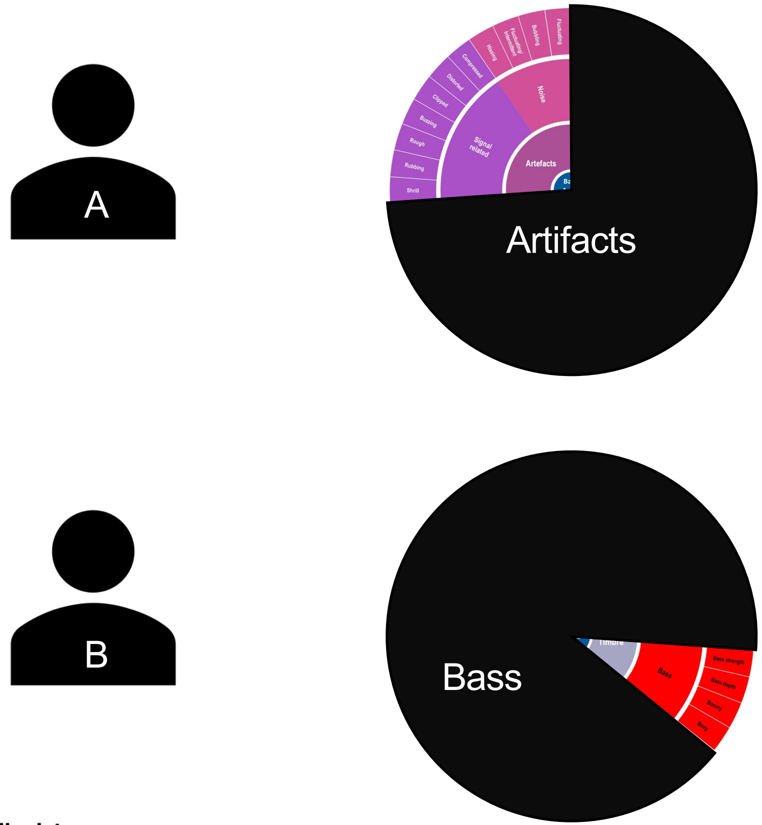

Report ITU-R BS.2399-0
(03/2017)

Methods for selecting and describing attributes and terms, in the preparation of subjective tests

Descriptive sensory analysis

Rating overall sound quality is hard and unstable

day 1



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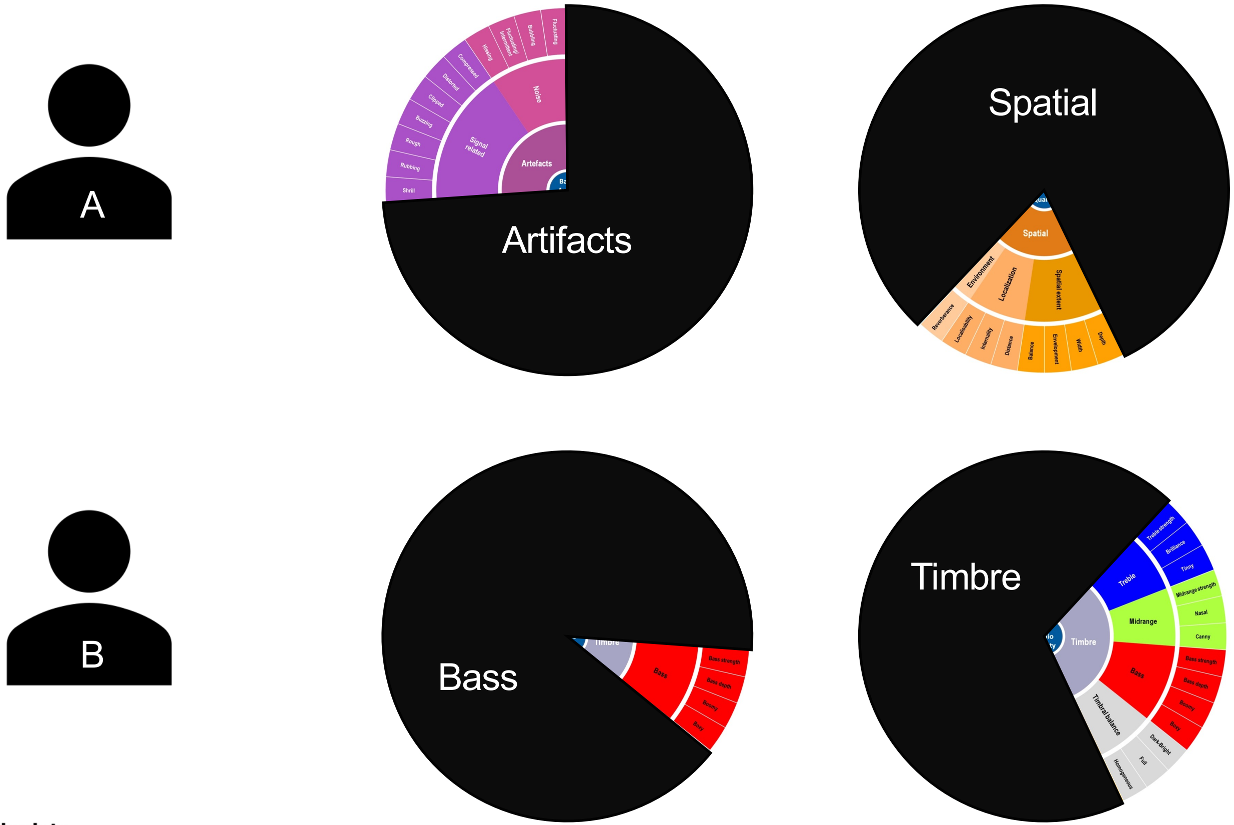
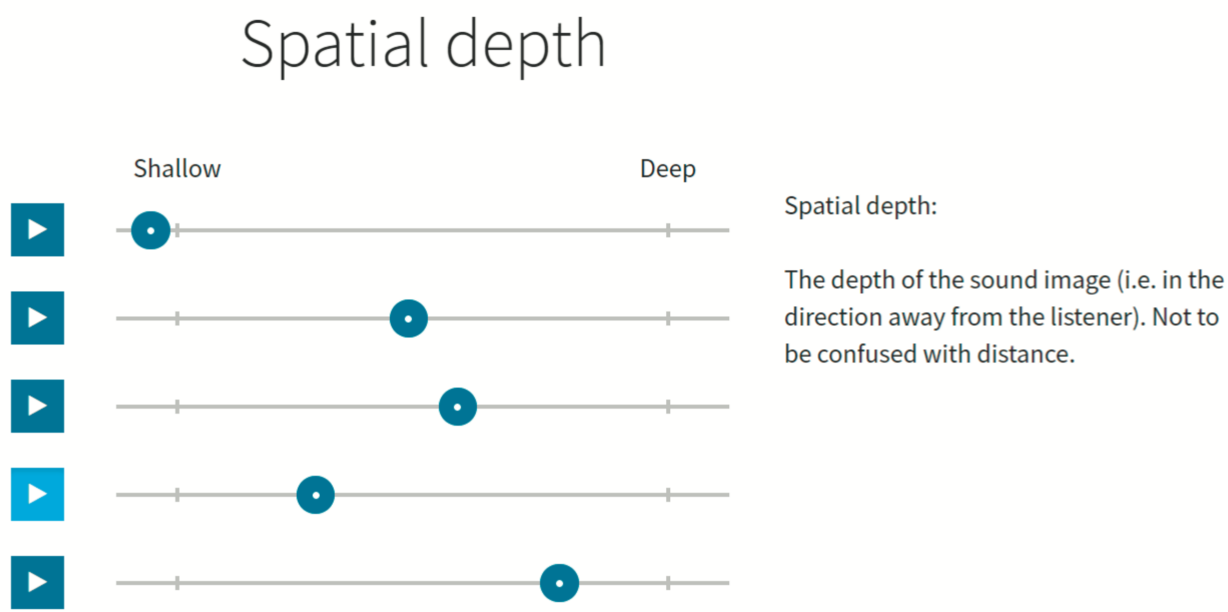
Rating overall sound quality is hard and unstable

day 1

day 2



Comparing sounds within a single attribute is relatively easy and repeatable



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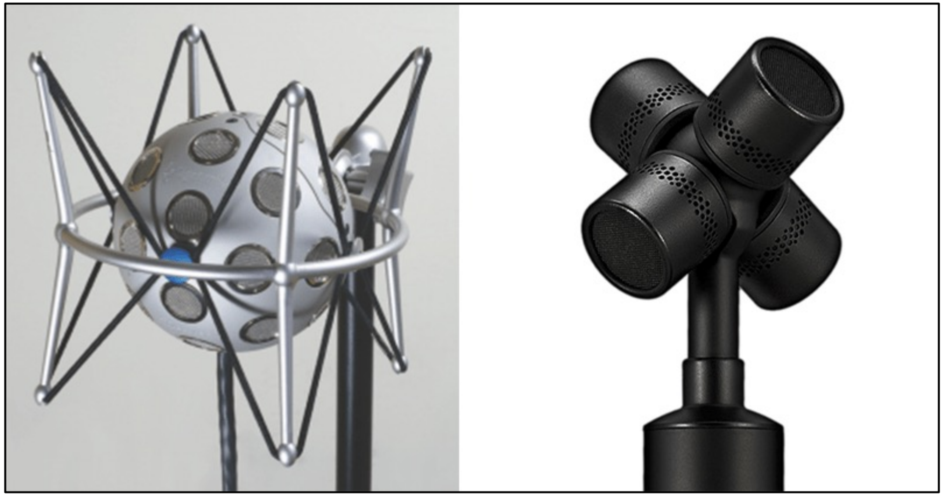
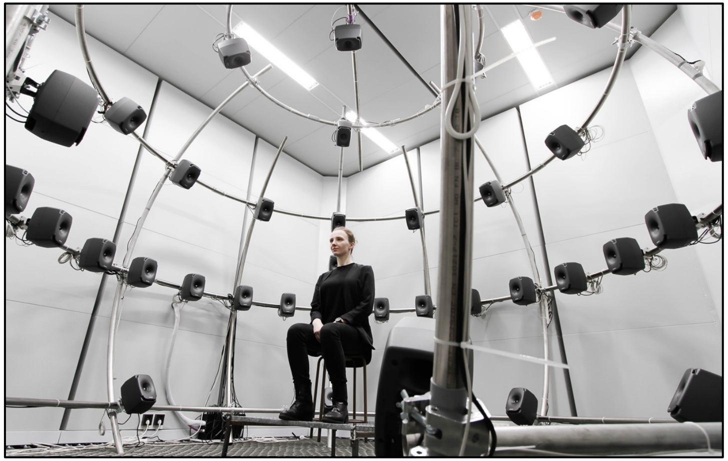
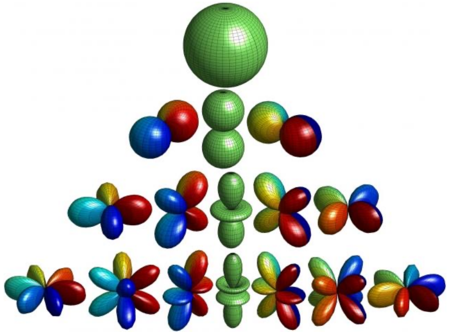
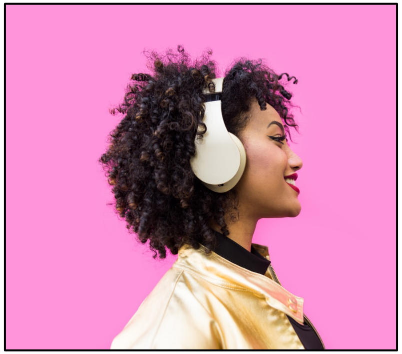
Zacharov et al. (2012)

Spatial audio recording, processing and reproduction is prone to introduce artifacts









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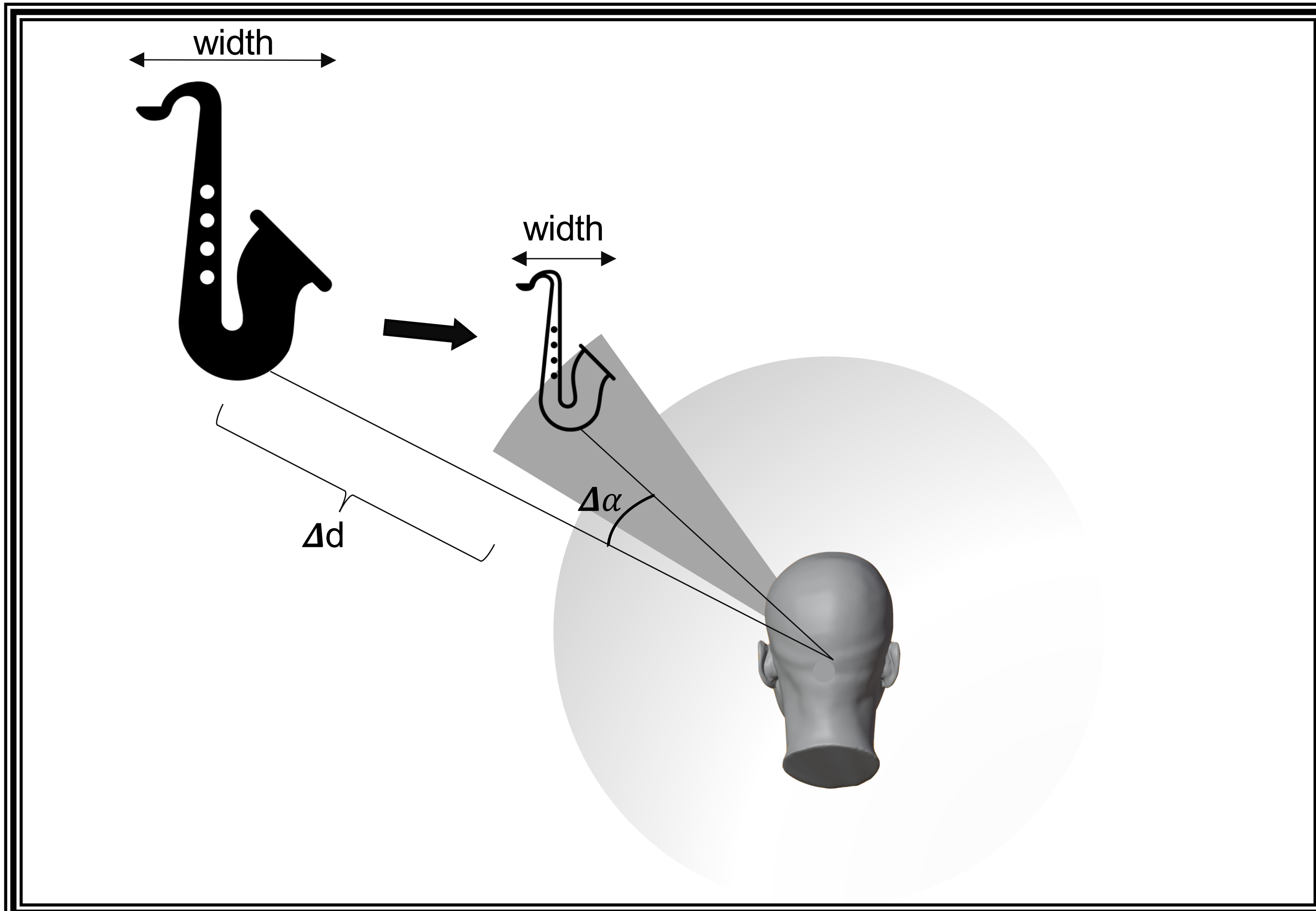
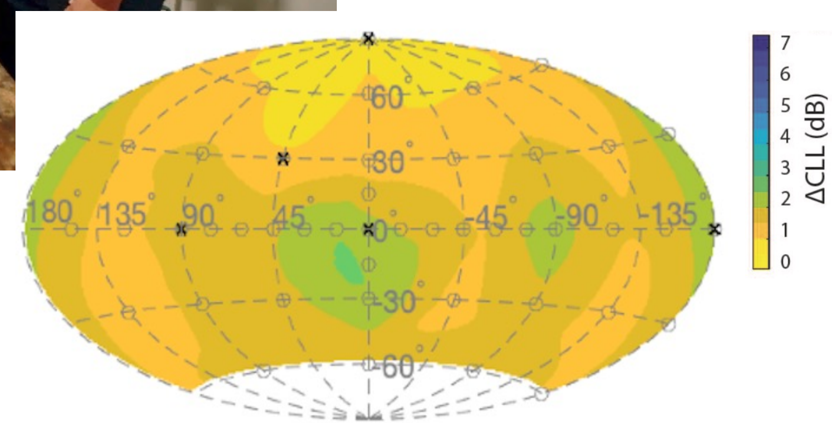
Spatial perception is often distorted



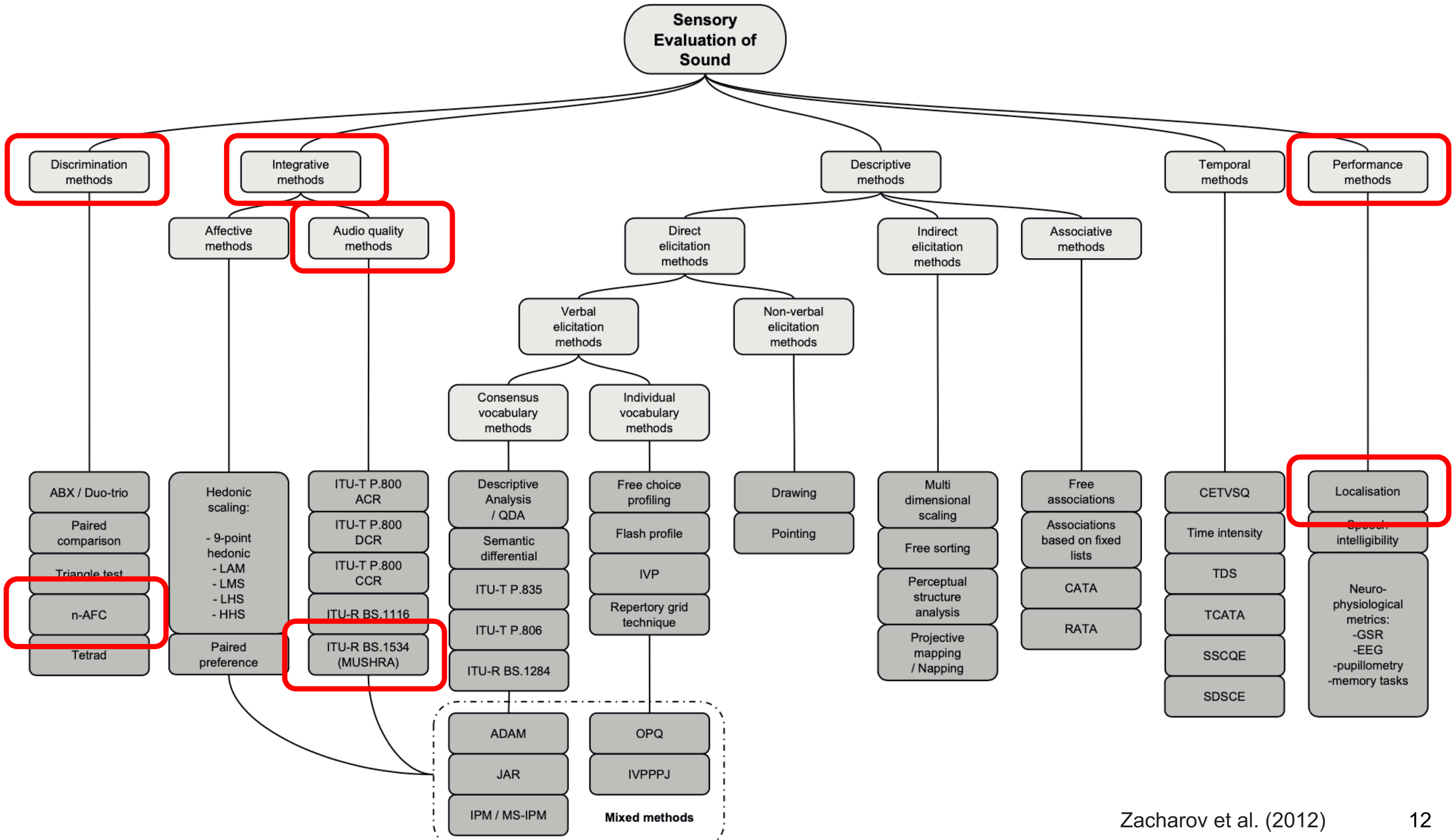
Timbral differences are specially problematic when we have a reference, e.g. augmented reality

Direction dependent colouration



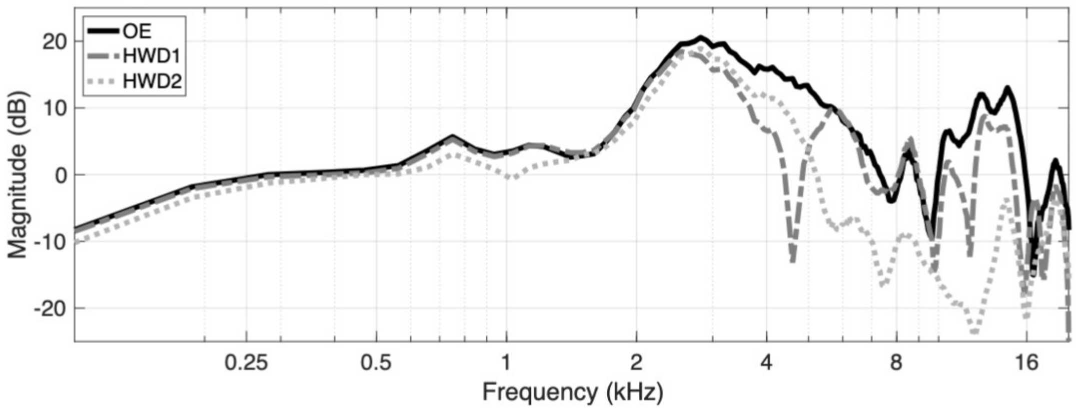
Lladó et al. (2022)

Listening experiments are the best option to achieve <u>objective</u> results



Zacharov et al. (2012)

Listening experiments are not always feasible



Majdak et al. (2022)

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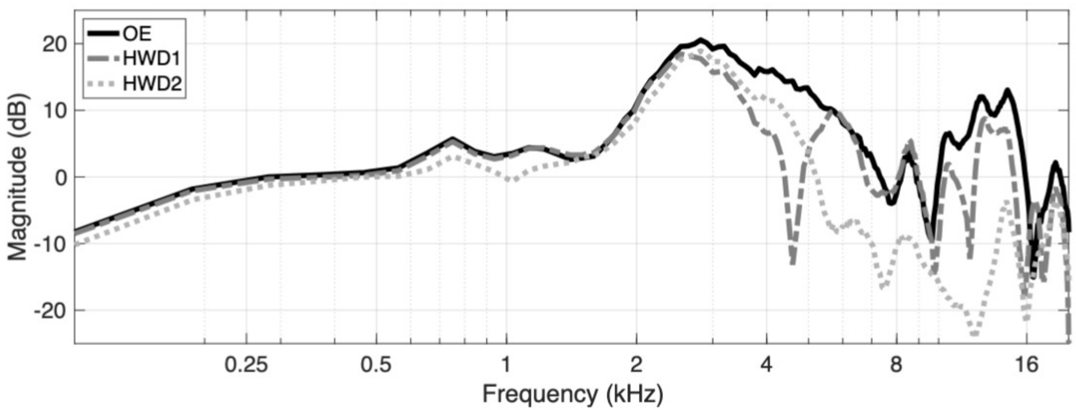

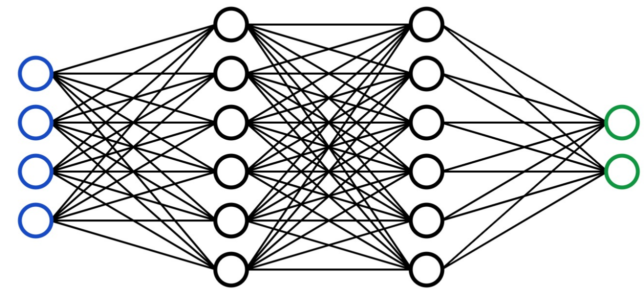

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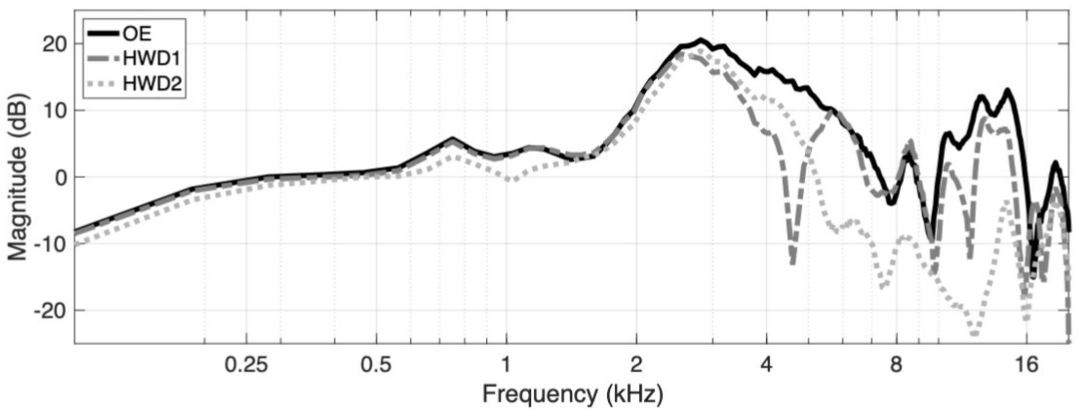

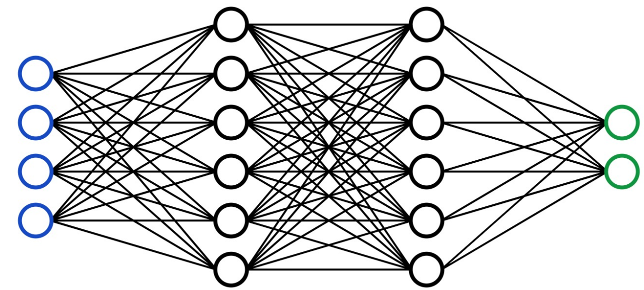

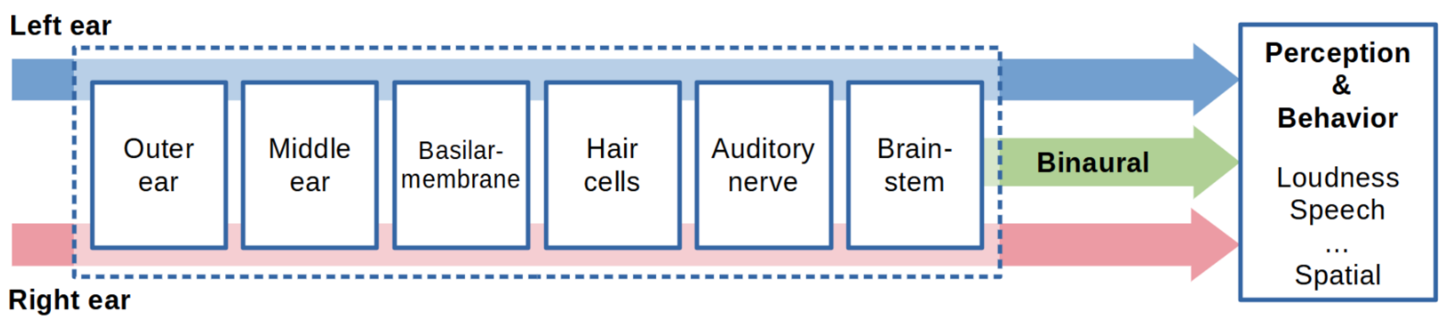

The Auditory Modelling Toolbox

EXP_BAUMGARTNER2014 - Results from Baumgartner et al. (2014)

Usage:

```
data = exp_baumgartner2014(flag)
```

Description:

`exp_baumgartner2014(flag)` reproduces figures of the study from Baumgartner et al. (2014).

The following flags can be specified

`'fig2'` Reproduce Fig.2: Binaural weighting function best fitting results from Morimoto (2001) labeled as [1] and Macpherson and Sabin (2007) labeled as [2] in a least squared error sense.

`'fig3'` Reproduce Fig.3: Prediction examples. Actual responses and response predictions for three exemplary listeners when listening to median-plane targets in the baseline condition. Actual response angles are shown as open circles. Probabilistic response predictions are encoded by brightness according to the color bar to the right. Actual (A:) and predicted (P:) quadrant error rates (QE) and local polar RMS errors (PE) are listed above each panel.

`'fig4'` Reproduce Fig.4: Model parametrization. Partial and joint prediction residues as functions of the degree of selectivity and the motoric response scatter. Residuum functions are normalized to the minimum residuum obtained for the optimal parameter value.

The Auditory Modelling Toolbox

Categories
- Main
- Core functions
- Models
- Model stages
- Demos
- **Experiments**
- Common functions
- Plot
- Signals
- Data
- Auxdata
- Cache

EXP_BAUMGARTNER2014 - Results from Baumgartner et al. (2014)

Usage:

```
data = 
```

Descript

`exp_baum`

The followi

'fig2'

'fig3'

'fig4'

Categories
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See also
- baumgartner2014_pmv2ppp
- baumgartner2014_virtualexp

BAUMGARTNER2014 - Localization in saggital planes (robust, linear periphery)

Usage:

```
[p,rang] = baumgartner2014( target,template )
[p,rang,tang] = baumgartner2014( target,template )
[p,rang,tang] = baumgartner2014( target,template, varargin )
[err,pred] = baumgartner2014( target,template,errorflag )
```

Input parameters:

`target`	binaural impulse response(s) referring to the directional transfer function(s) (DFTs) of the target sound(s). Option 1: given in SOFA format -> sagittal plane DTFs will be extracted internally. Option 2: binaural impulse responses of all available listener-specific DTFs of the sagittal plane formatted according to the following matrix dimensions: time x direction x channel/ear
`template`	binaural impulse responses of all available listener-specific DTFs of the sagittal plane referring to the perceived lateral angle of the target sound. Options 1 & 2 equivalent to *target*.

Output parameters:

`p`	predicted probability mass vectors for response angles with respect to target positions 1st dim: response angle 2nd dim: target angle
`rang`	polar response angles (after regularization of angular sampling)
`tang`	polar target angles (usefull if sagittal-plane HRTFs are extracted directly from SOFA object)
`err`	predicted localization error (acc. to performance measure defined in *errorflag*
`pred`	structure with fields *p*, *rang*, *tang*

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The Auditory Modelling Toolbox

Peripheral models
Gammatone filterbank
Linear filtering for monaural masking (basic)
Linear filtering for monaural masking (improved)
Invertible Gammatone filterbank
Dual-resonance nonlinear filterbank (DRNL)
Fast acting compression (CARFAC) model
Cochlear transmission-line model (basic)
Cochlear transmission-line model (improved)
Cochlear transmission-line model (improved, incl. brainstem)
Auditory-nerve spike generation
Auditory-nerve filterbank (basic)
Auditory-nerve filterbank (improved)
Auditory nerve filterbank (improved, ready for brainstem)
Compression in the simultaneous masker phase effect

Binaural processing
Binaural processing
Binaural masking level difference
Binaural masking level difference (dynamic sources)
Binaural activity (based on cross-correlation)
Binaural signal detection
Binaural detection model based on interaural coherence
ITDs of hearing-aid users
Binaural activity map

Temporal-modulation sensitivity
Brainstem processing (CN and IC)
Auditory brainstem responses
Modulation filterbank (based on EPSM)
Modulation filterbank (based on nonlinear processing)
Modulation filterbank (based on DRNL)
Modulation (leaky-integrator model)
Non-linear adapation network

Monaural speech perception
Intelligibility in noise
Intelligibility in noise
Intelligibility with harmonic-cancellation
Short-time objective intelligibility

Binaural speech perception
Blind equalization-cancellation model
Binaural intelligibility in stationary noise (from BRIRs)
Binaural intelligibility in stationary noise
Binaural intelligibility of a reverberated speech target
Binaural intelligibility in non-stationary noise considering audibility
Binaural intelligibility in non-stationary noise (NH listeners only)

Perceptual similarity
Monaural perceptual similarity
Binaural perceptual similarity
Binaural perceptual similarity

The Auditory Modelling Toolbox

Loudness models
Stationary sounds
Time-varying sounds
Binaural hearing impaired
Binaural loudness
Spatial models
Sound lateral direction
Lateralization, supervised training
´Lateralization in cochlear-implant listeners
Contextual lateralization based on interaural level differences
Median-plane localization
Vertical-plane localization (simple)
Sagittal-plane localization (simple)
Sagittal-plane localization (robust)
Sagittal-plane localization (nonlinear, for hearing impairements)
Sound externalization (ILD based)
Sound externalization (multi-cue)
Sound externalization (reverberant spaces)
Distance perception
Bayesian spherical sound localization (basic)
Bayesian spherical sound localization (multi-feature)
Bayesian sound localization (dynamic, ITD-based)
Lateralization in sound reproduction systems
Directional time-of-arrival (on-axis only)
Directional time-of-arrival in HRTFs (off-axis, robust)

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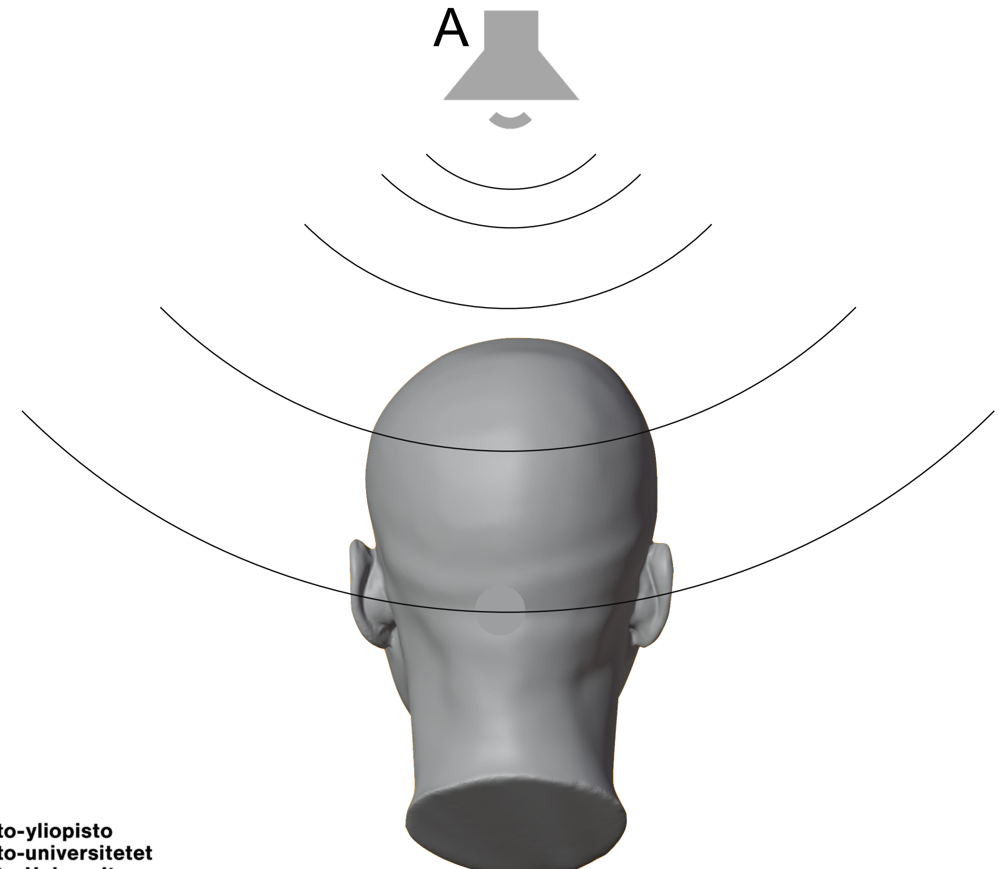
Assessment of spatial attributes

The position of a sound source in the left-right dimension generates interaural differences



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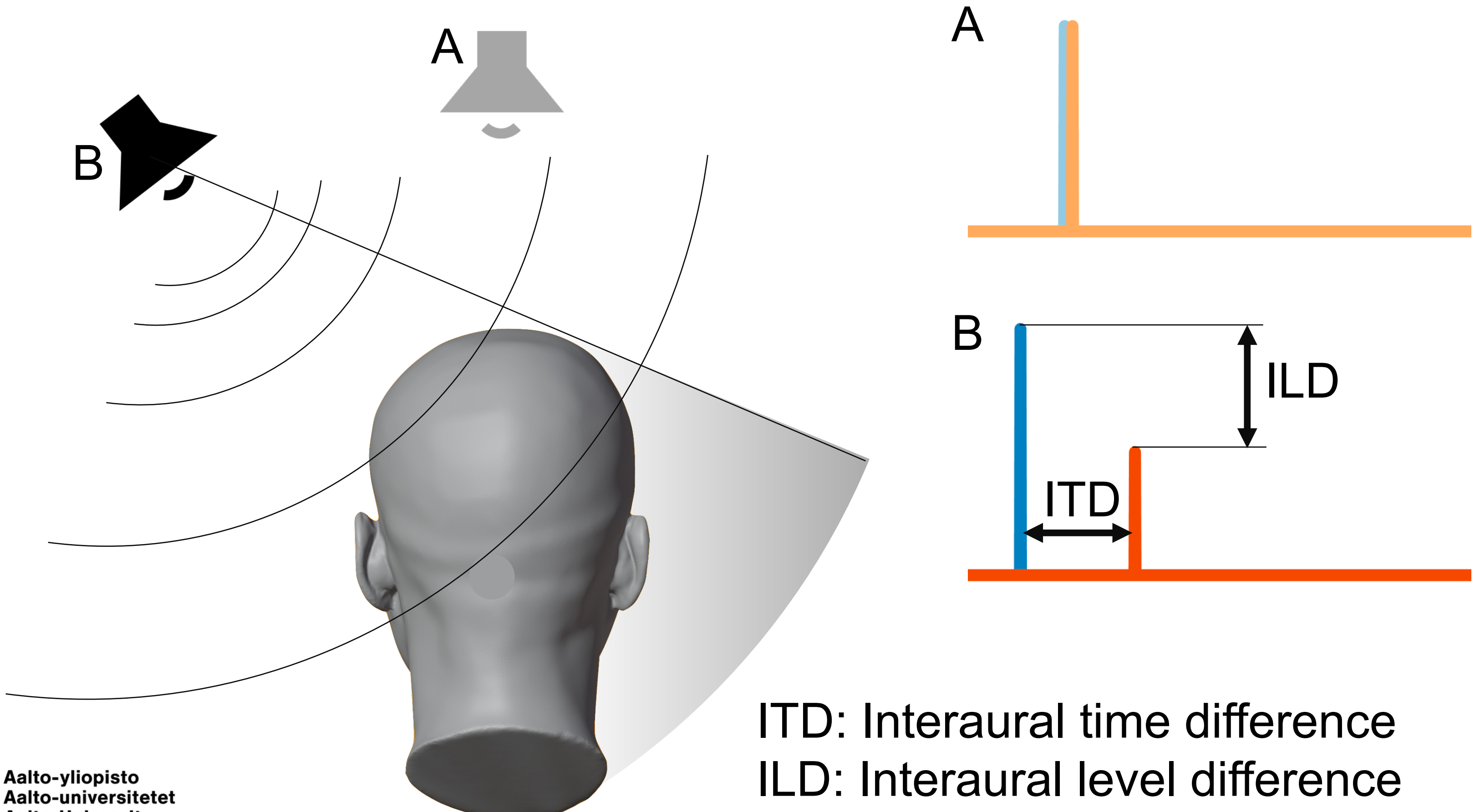
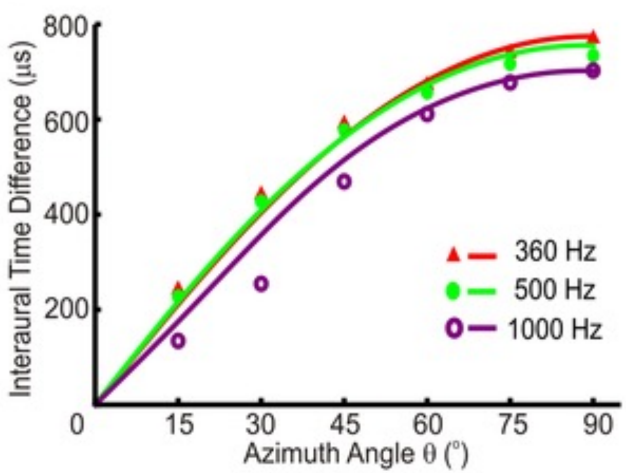


ITD: Interaural time difference
ILD: Interaural level difference

Interaural time differences are dominant at lower frequencies (< ~ 1.5 kHz)

JND*: ~ 10 μs
ITD for lateral sources: ~ 600 - 700 μs



* JND: Just noticeable difference

Smith et al. (2014)

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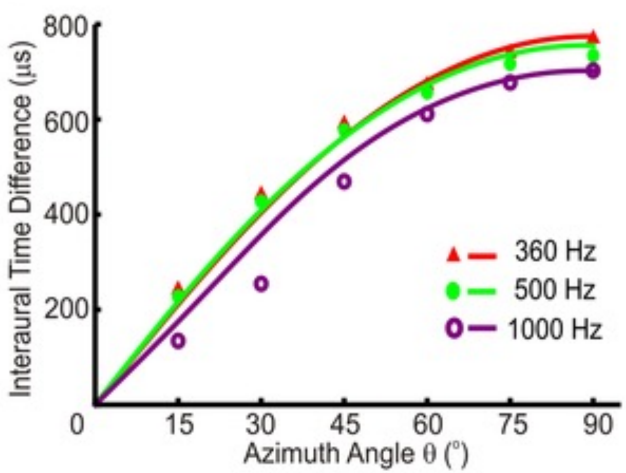
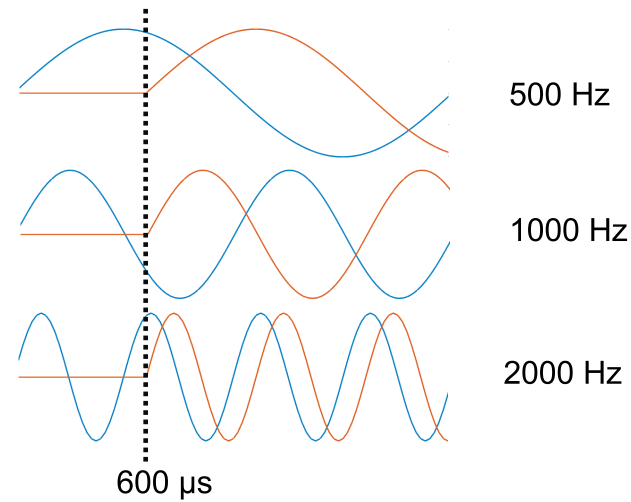
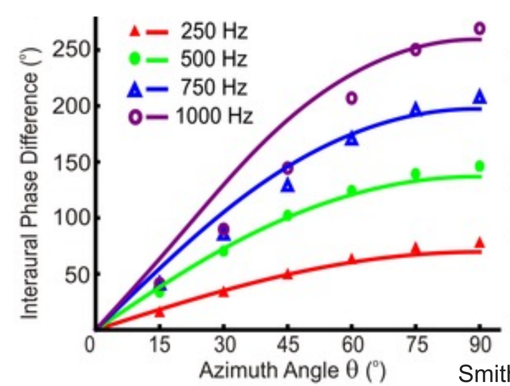


Interaural phase difference (IPD)



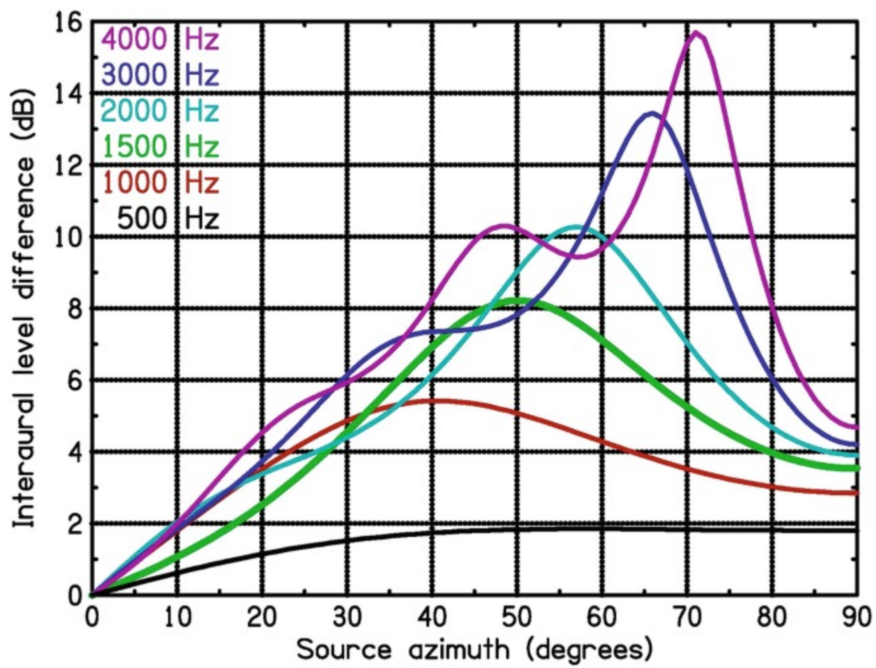


Smith et al. (2014)

* JND: Just noticeable difference

The importance of interaural level differences grows with frequency

They are dominant above ~ 1.5 kHz
JND: ~ 0.5 - 1 dB



These interaural cues are not enough to resolve the location in the three-dimensional space

From Communication Acoustics (V. Pulkki):

“*At least in principle, ITD and ILD do not change when changing the position of a sound source on a cone of confusion.*”

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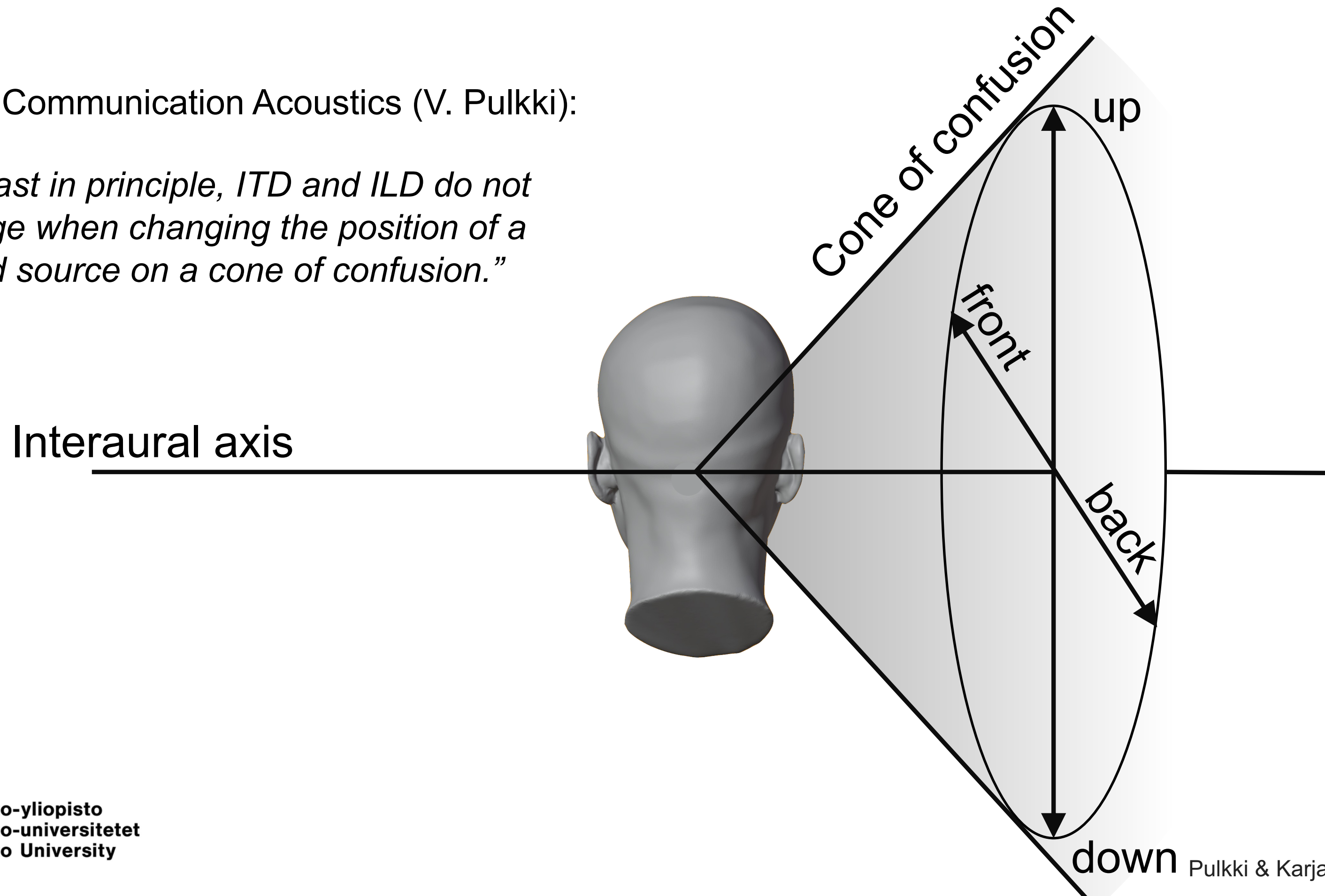
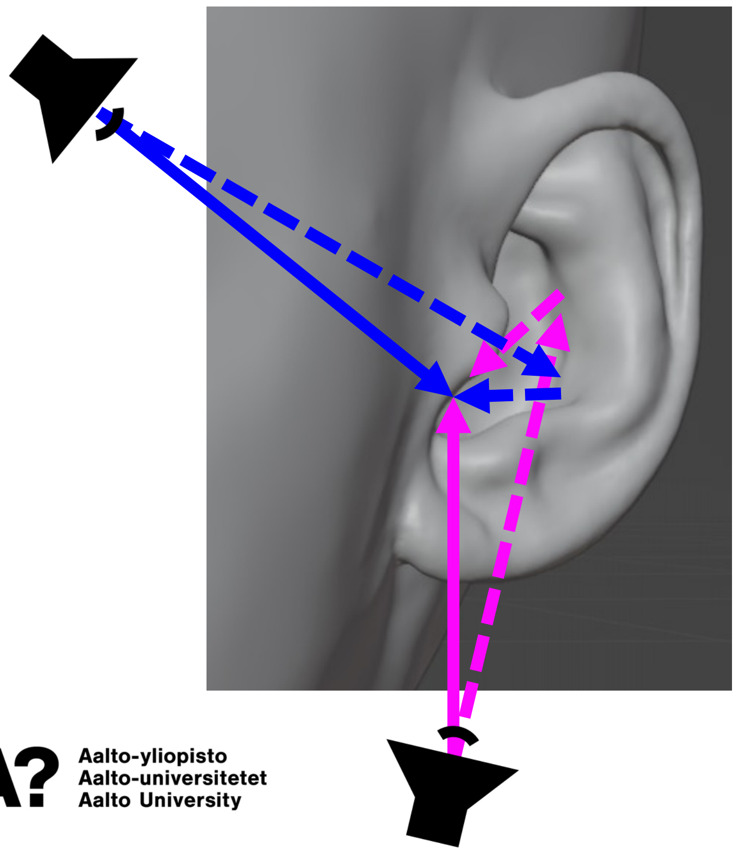
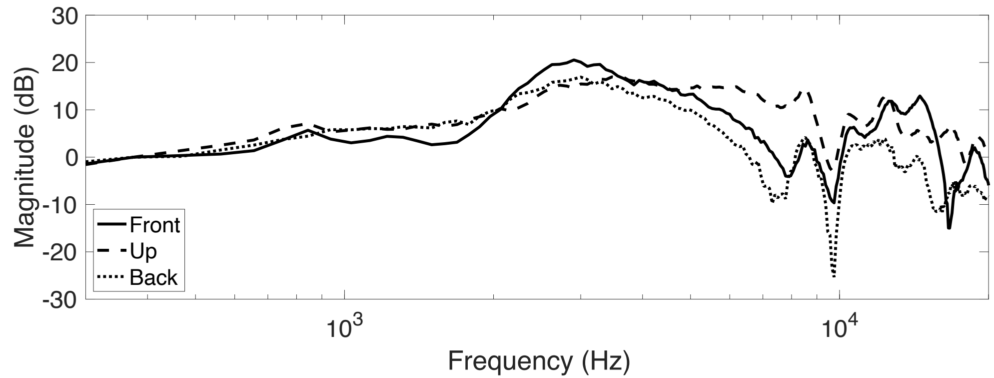


Pulkki & Karjalainen (2015)

Moving a up-down or front-back on the cone of confusion modifies the spectrum of the sound





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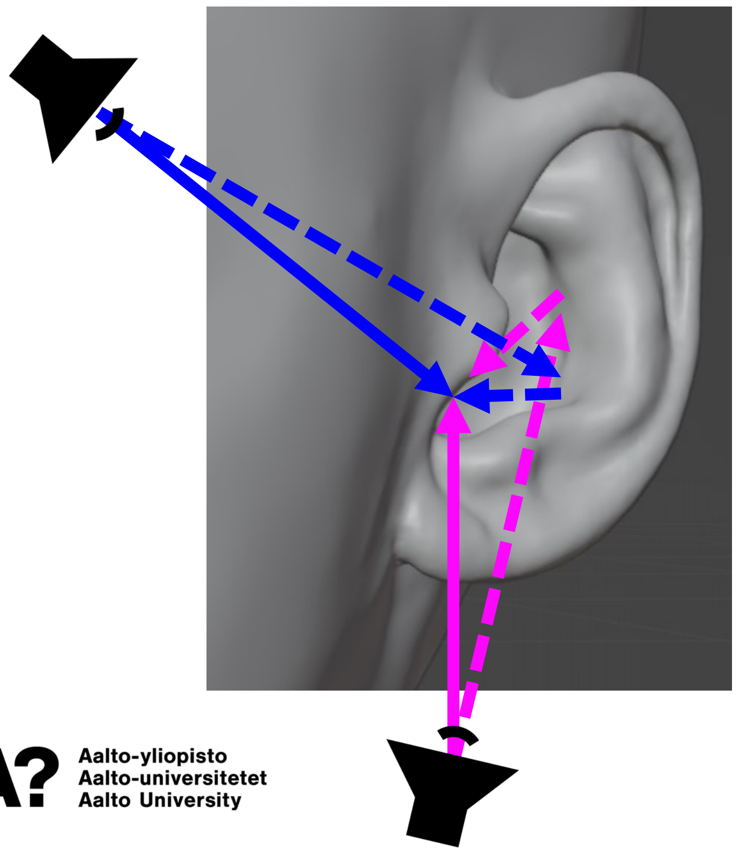
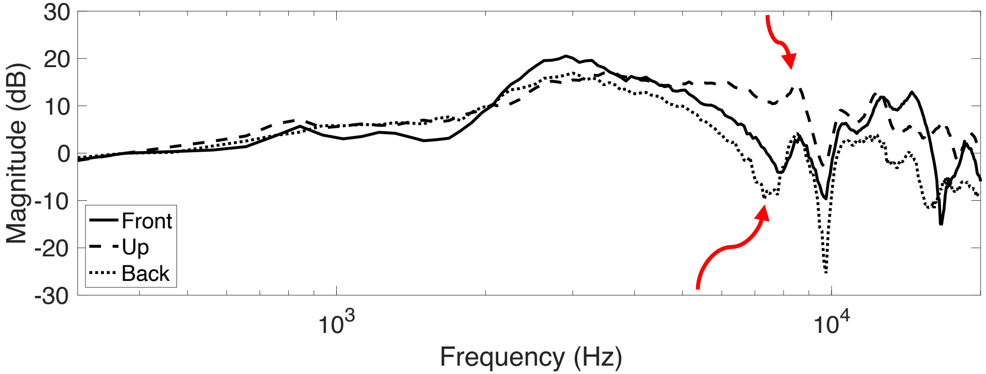


The frequency location of main peaks and notches seems crucial



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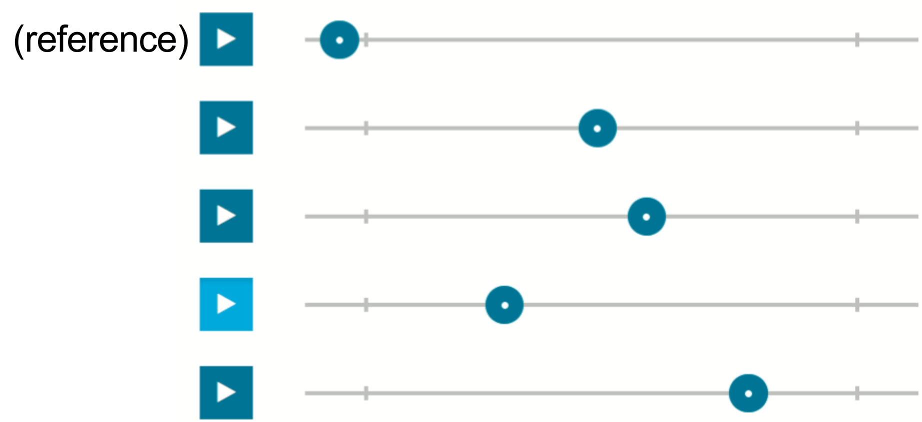
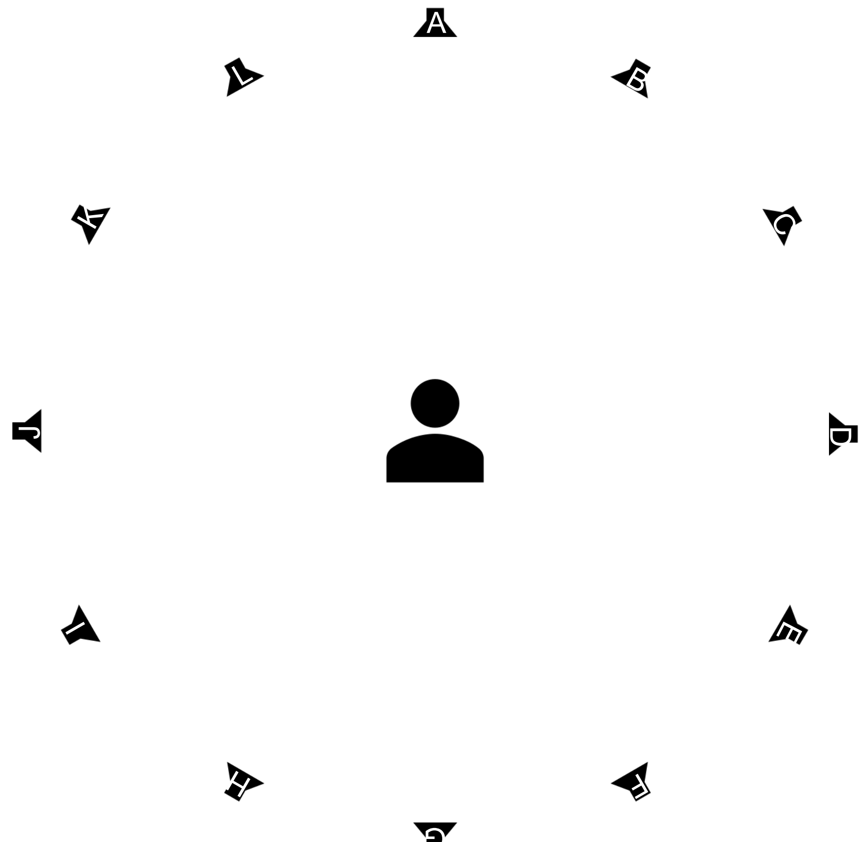
The spatial fidelity can be measured using a more hollistic approach

Rate the spatial fidelity of this samples compared to the reference

10 (very good) 0 (very bad)



Localisation(-like) tasks are useful to measure artifacts in spatial reproduction



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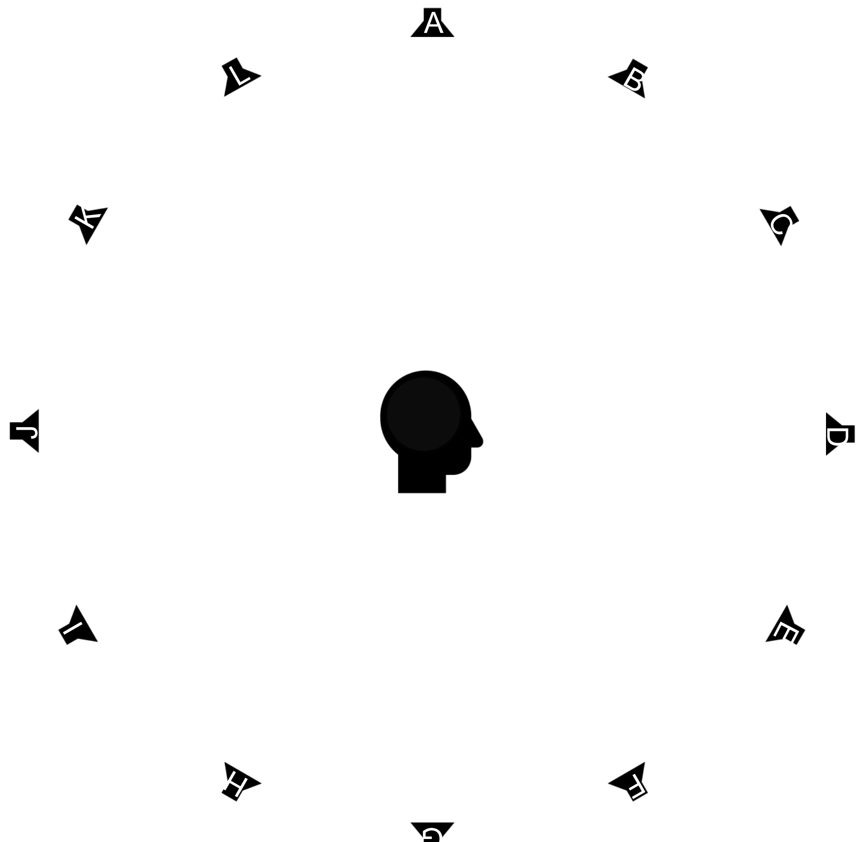
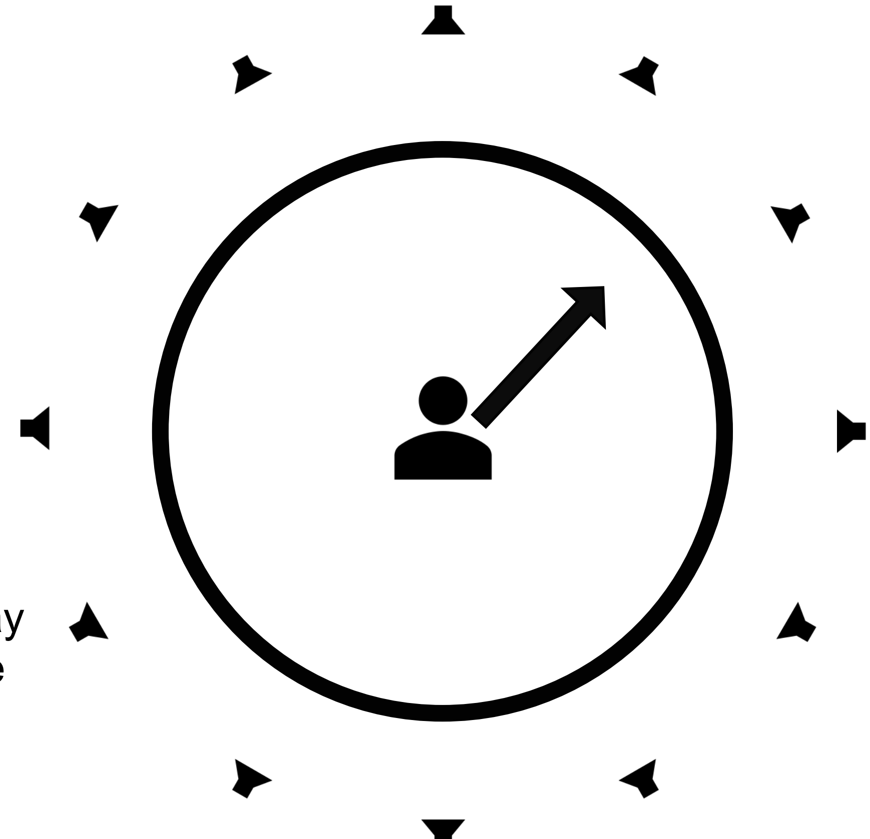


Localisation(-like) tasks are useful to measure artifacts in spatial reproduction

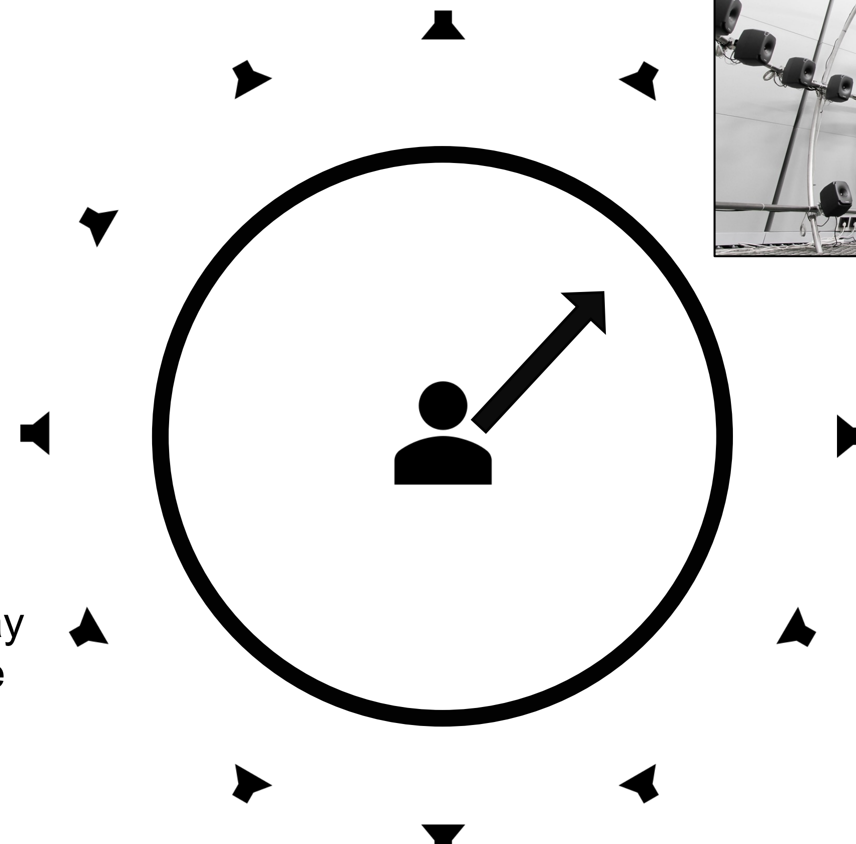
Front/back discrimination

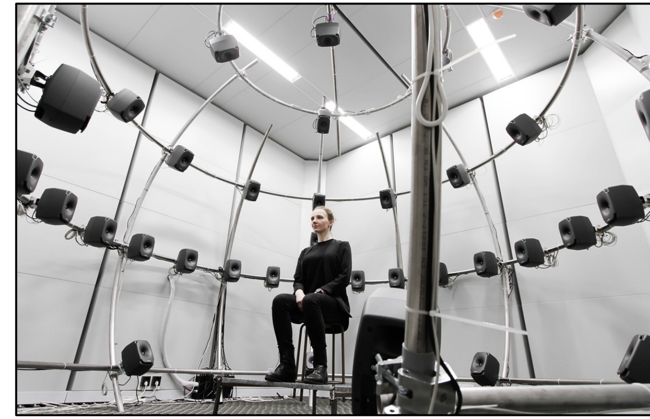
The classic localisation test



The pointing method may change significantly the results

The classic localisation test

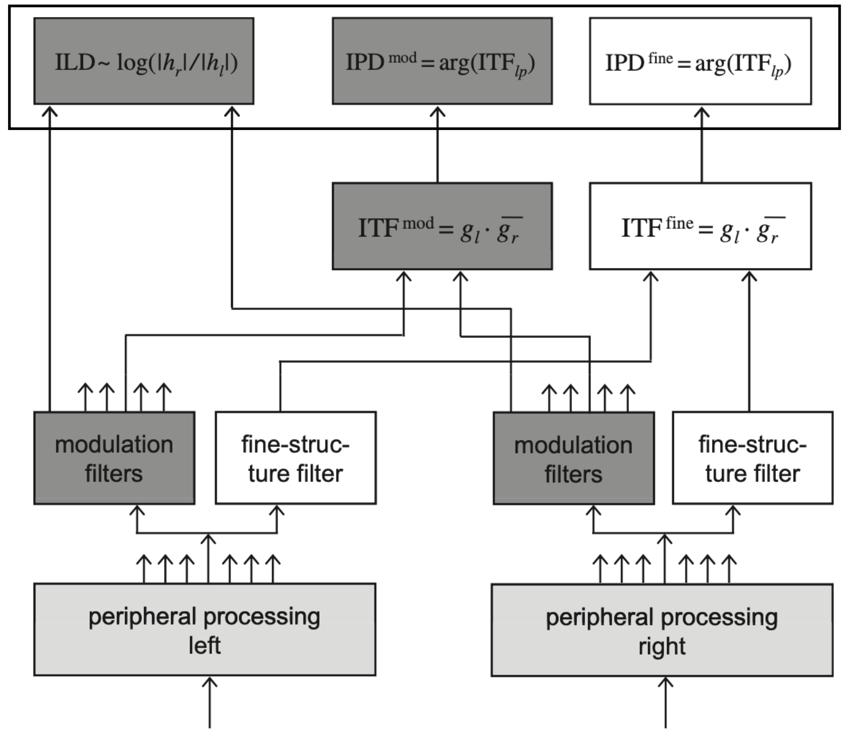




The pointing method may change significantly the results

Auditory models of human localisation estimate experimental data collected in localisation tests

DIETZ2011 - Sound lateral direction

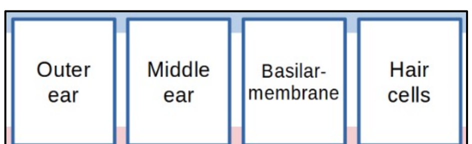


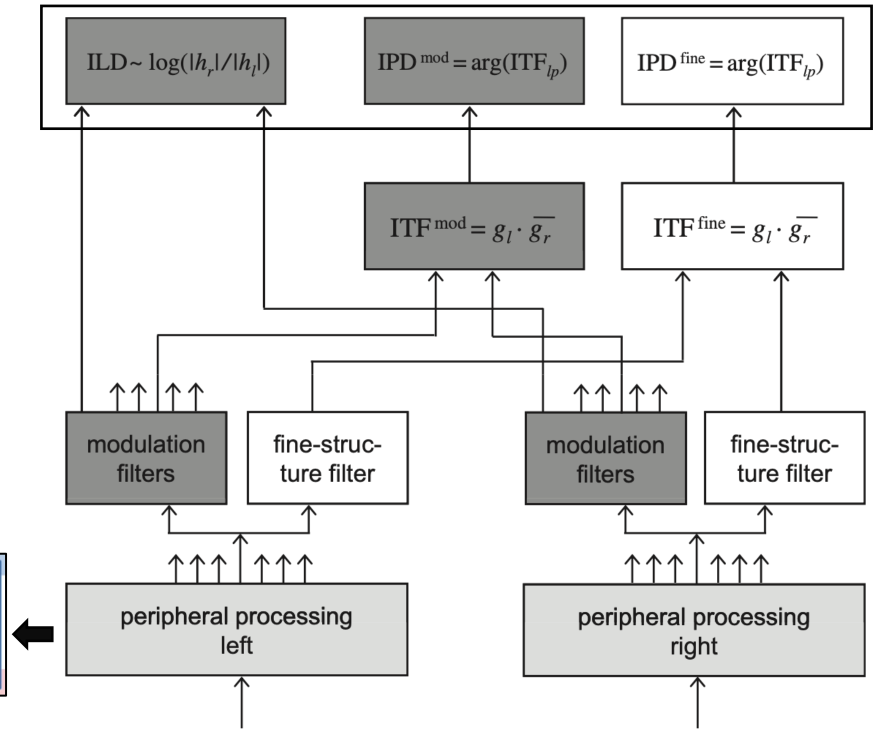
Binaural input signal

Dietz et al. (2011)

Auditory models of human localisation estimate experimental data collected in localisation tests

DIETZ2011 - Sound lateral direction





Binaural input signal

![Aalto University logo]

Dietz et al. (2011)

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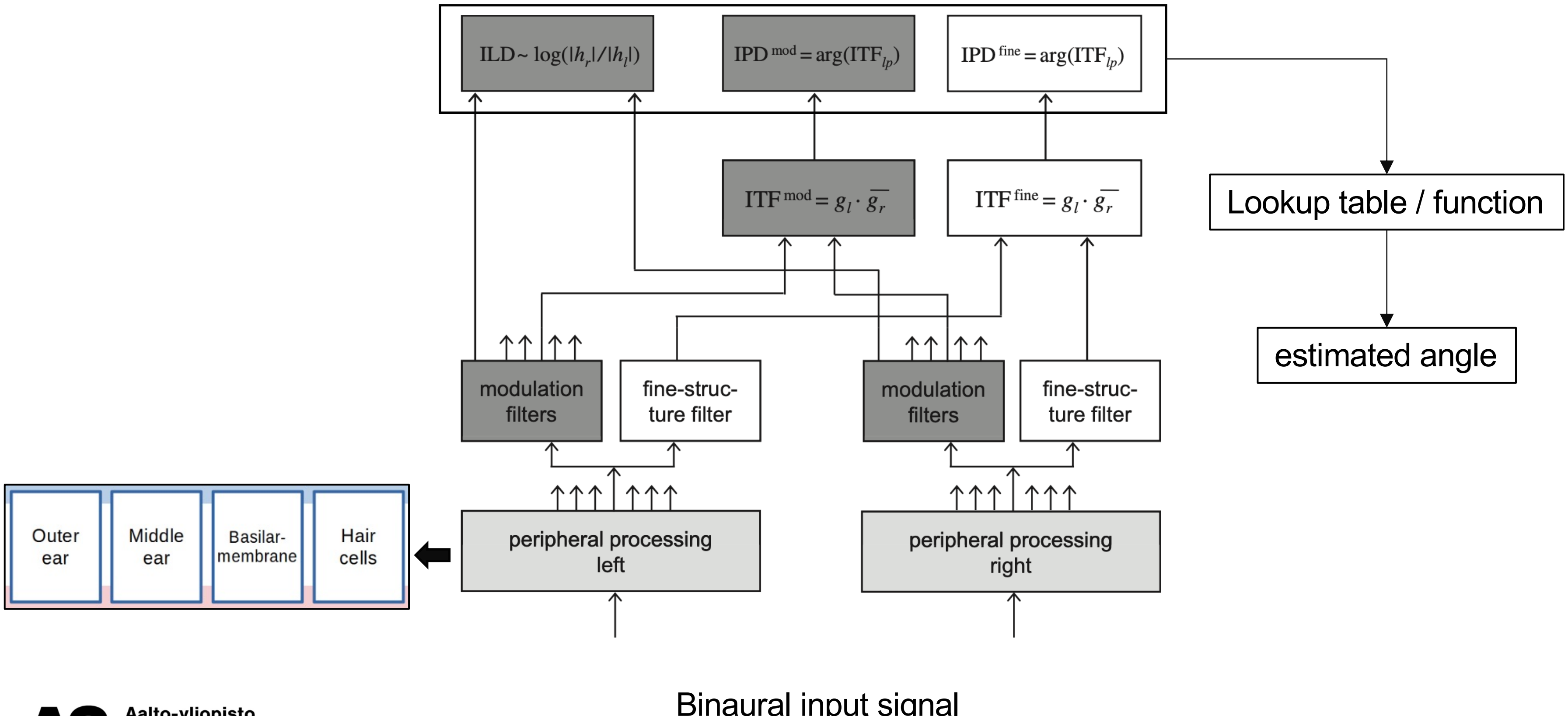
DIETZ2011 - Sound lateral direction



Dietz et al. (2011)

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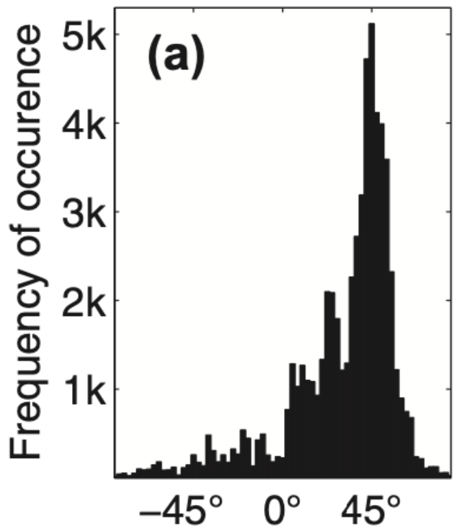
DIETZ2011 - Sound lateral direction

One speaker



Dietz et al. (2011)

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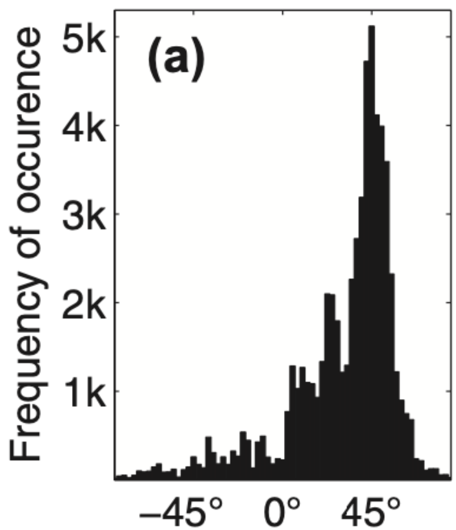
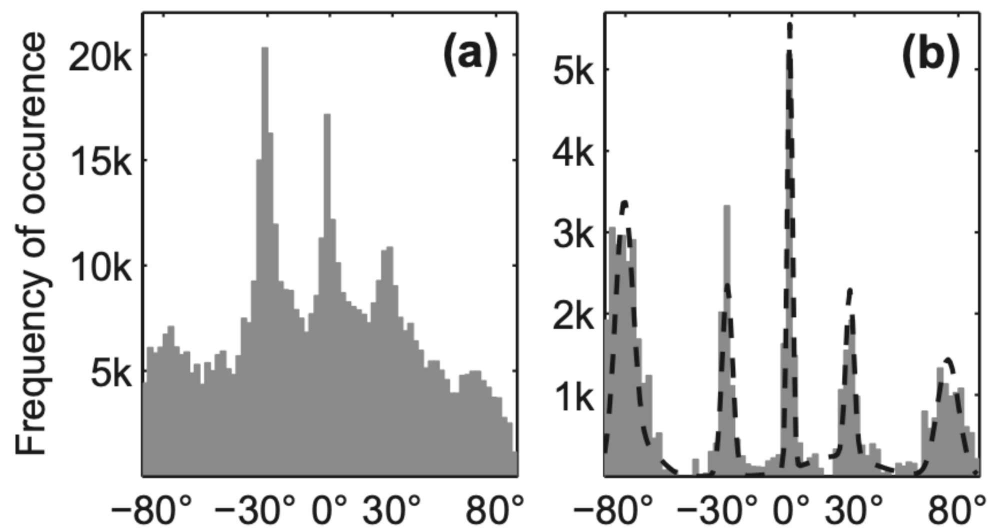


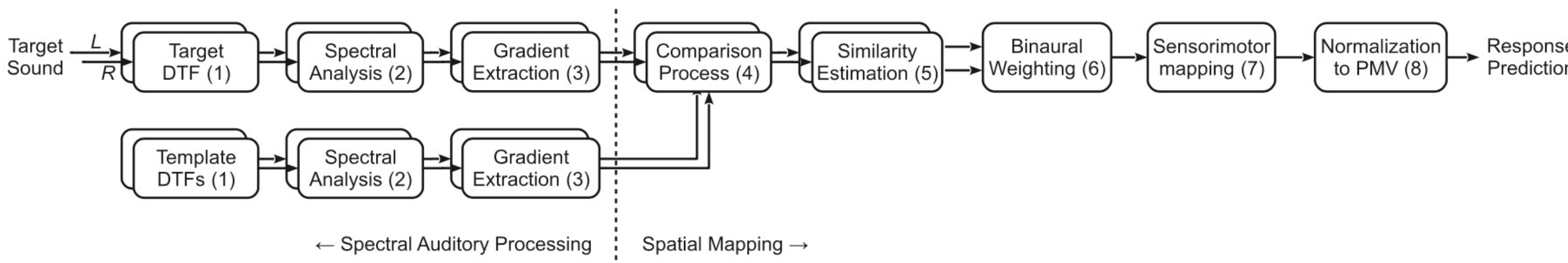
Five speakers



Dietz et al. (2011)

Models of sagittal plane localisation is often used both in research and in industry

BAUMGARTNER2014 - Localisation in sagittal planes



Baumgartner et al. (2014)

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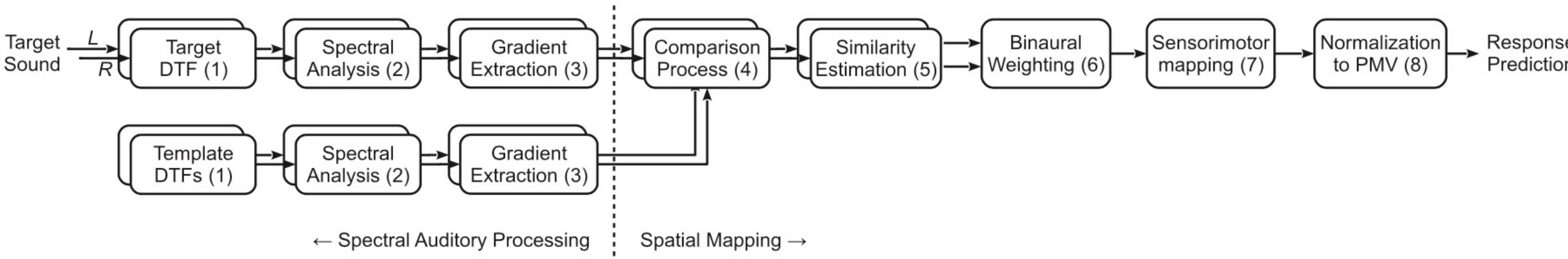
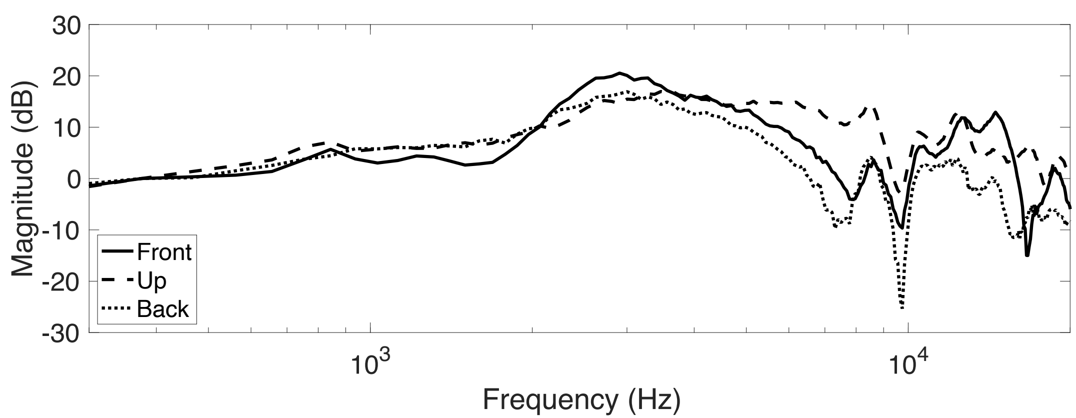


Template



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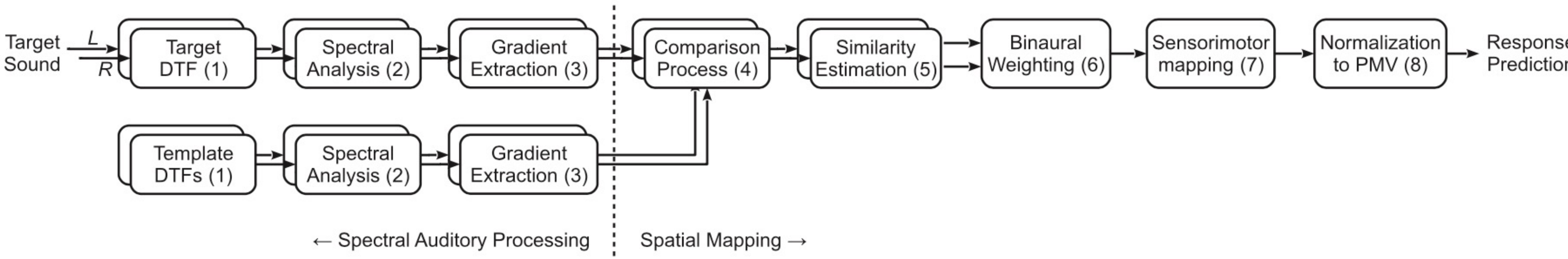
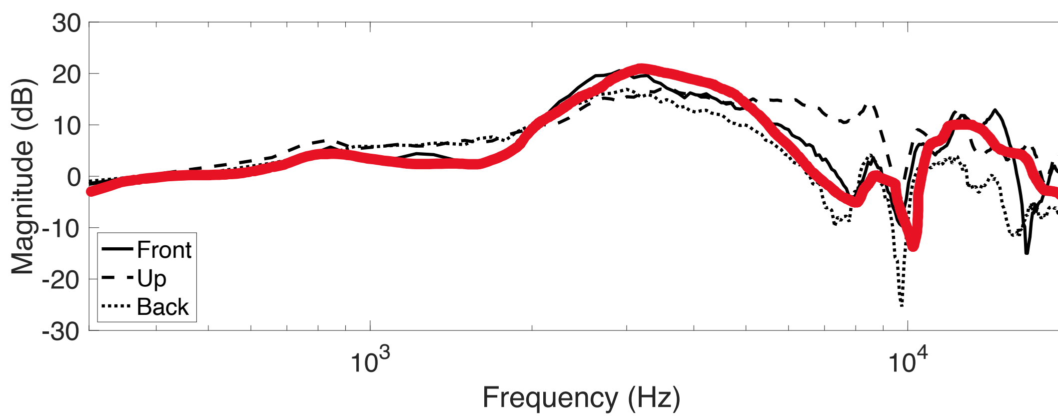
Models of sagittal plane localisation is often used both in research and in industry

BAUMGARTNER2014 - Localisation in sagittal planes



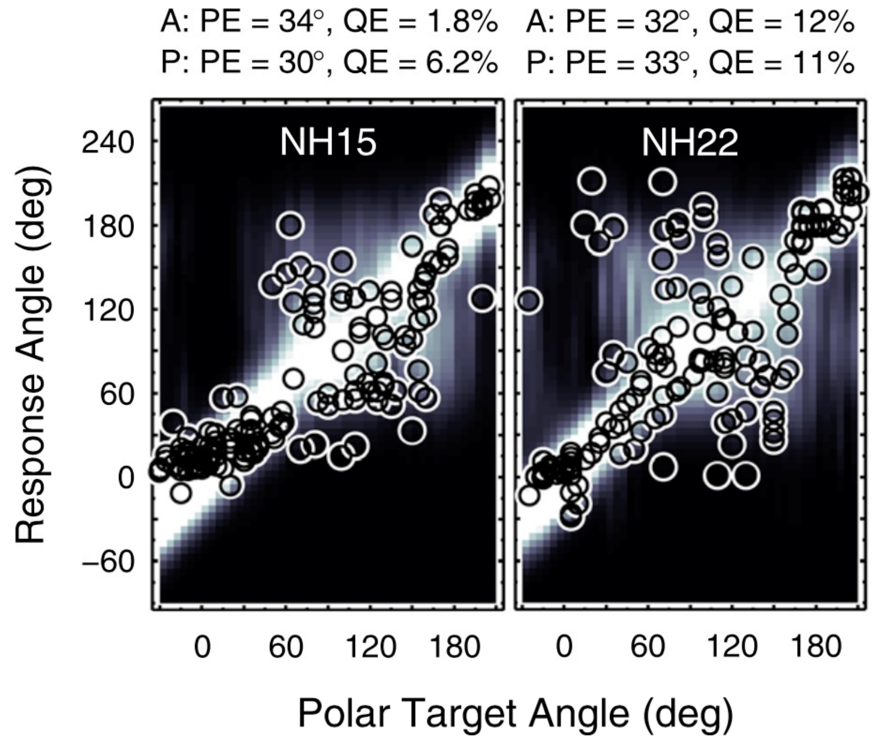
Template

Target sound



Models of sagittal plane localisation are used both in research and in industry

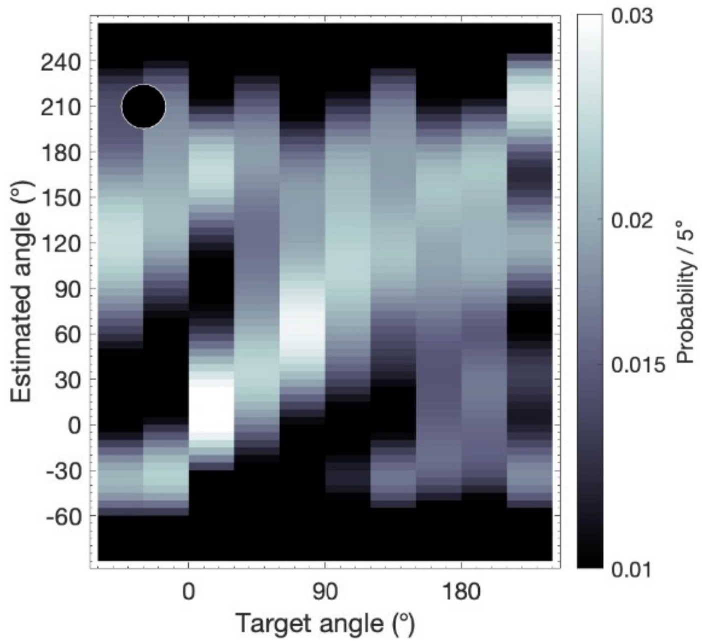
BAUMGARTNER2014 - Localisation in sagittal planes

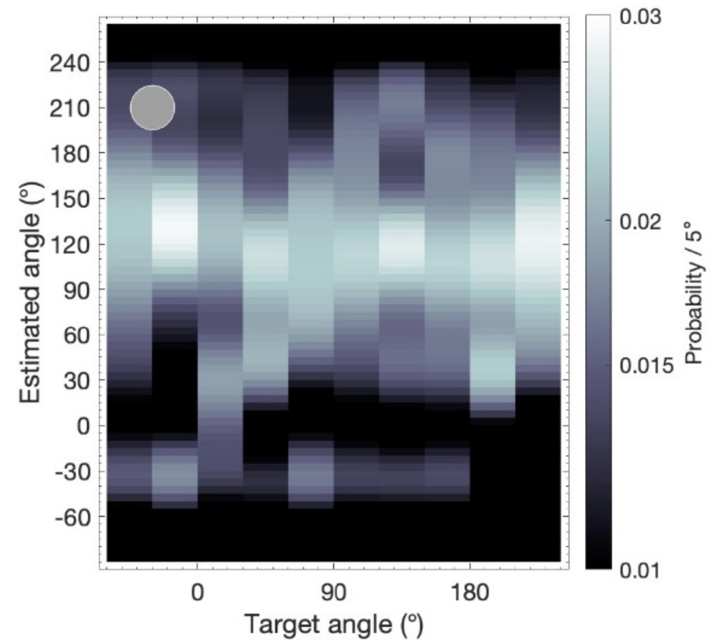


Baumgartner et al. (2014)

They help us estimate the availability of monaural spectral cues

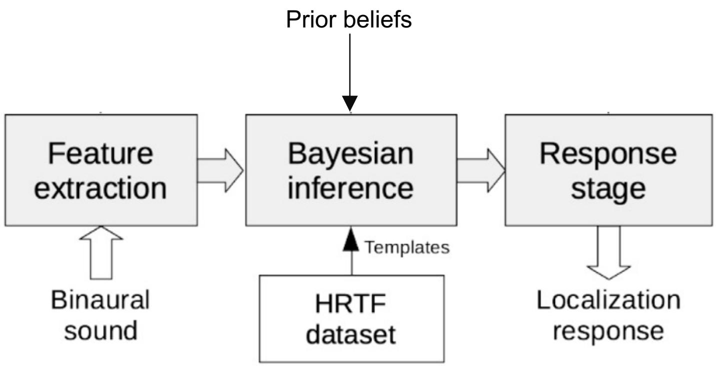
BAUMGARTNER2014 - Localisation in sagittal planes

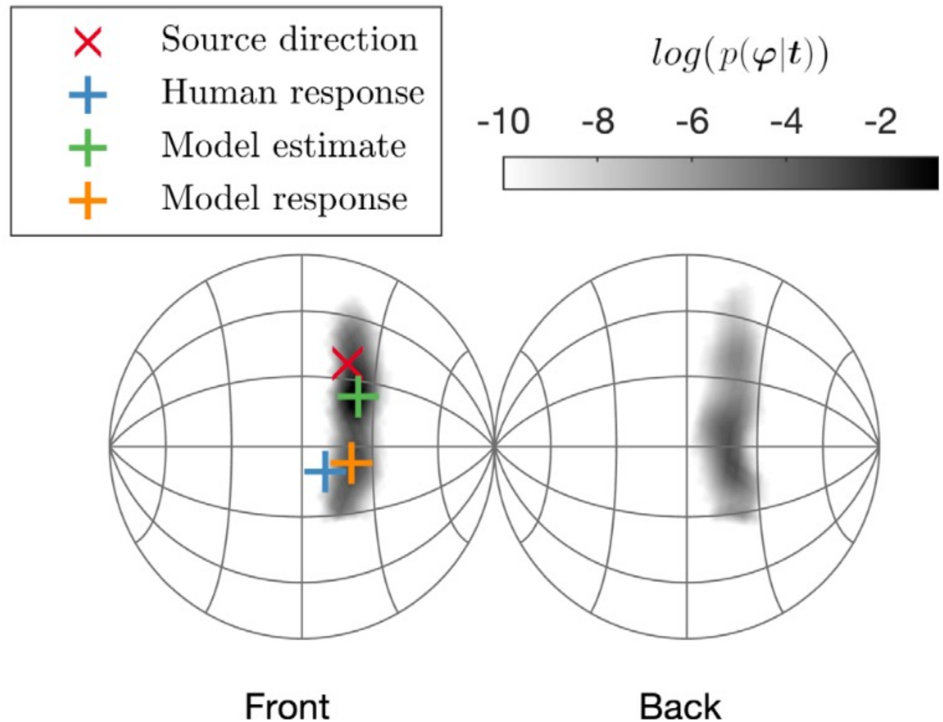




Models of spherical localisation combine the results of the two dimensions

BARUMERLI2023 - Bayesian spherical sound localization model

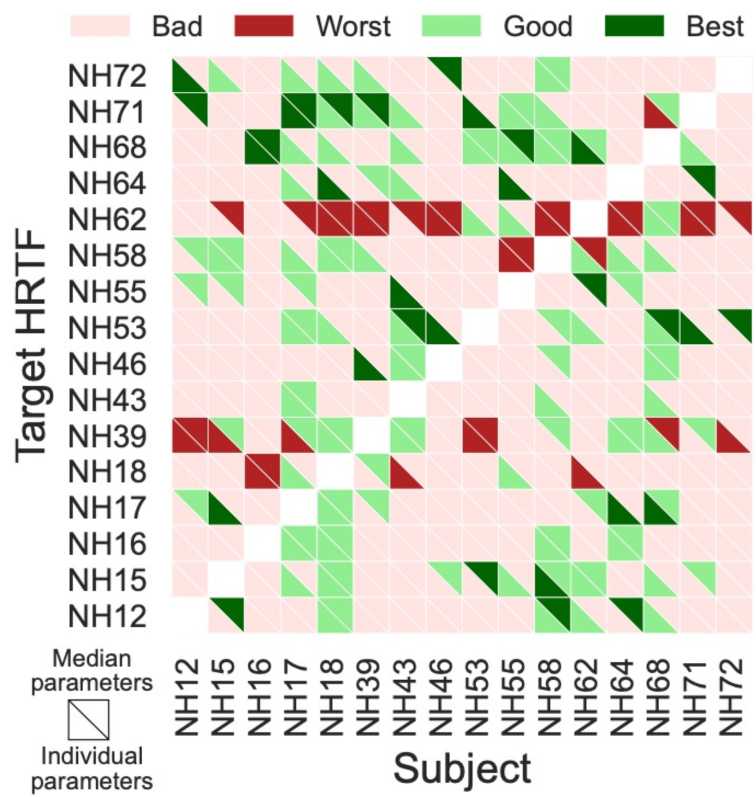




Barumerli et al. (2023)

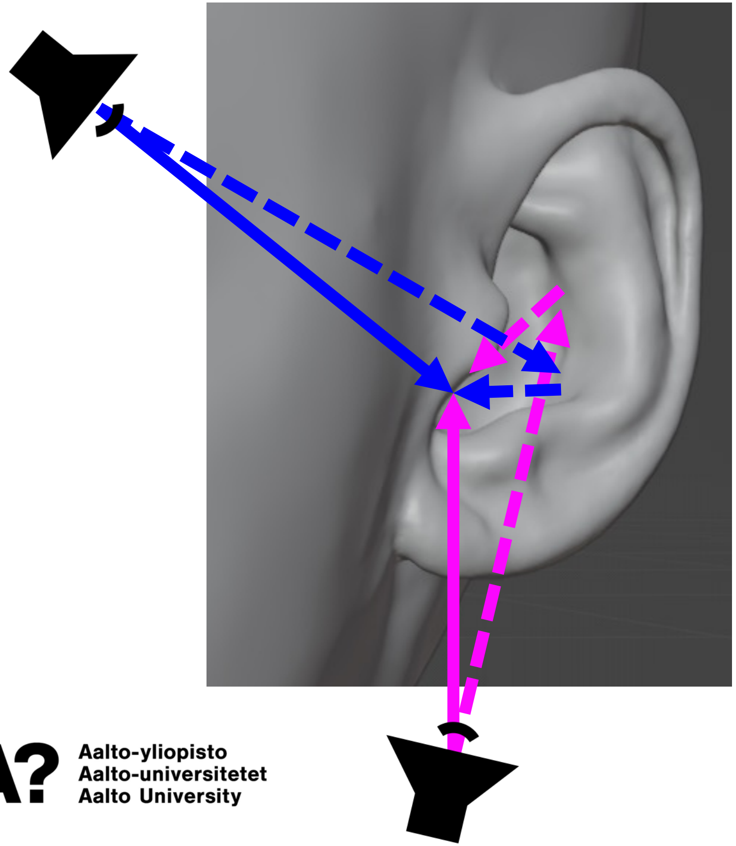
Example of model-based analysis of a dataset for non-individual HRTF selection

BARUMERLI2023 - Bayesian spherical sound localization model

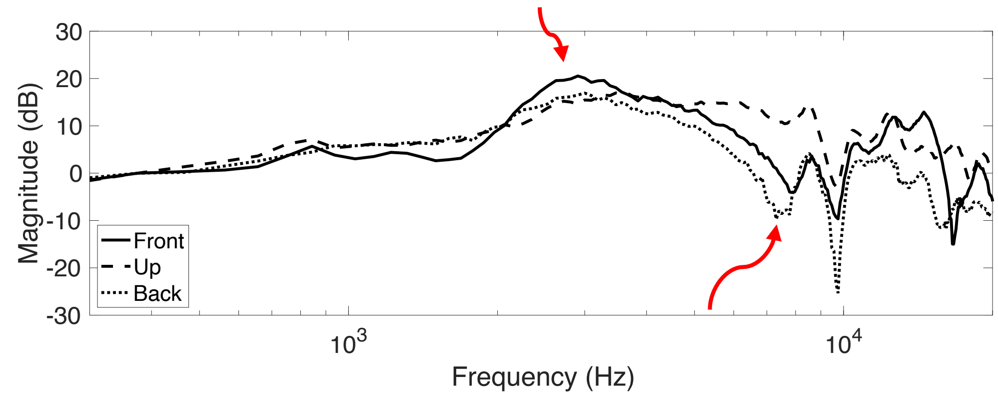


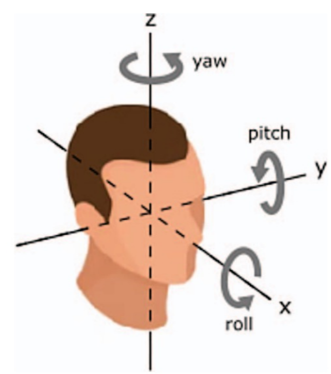
Daugintis et al. (2023)

Artifacts in sound spatial fidelity are less important when the listener can move



The frequency location of main peaks and notches seems crucial

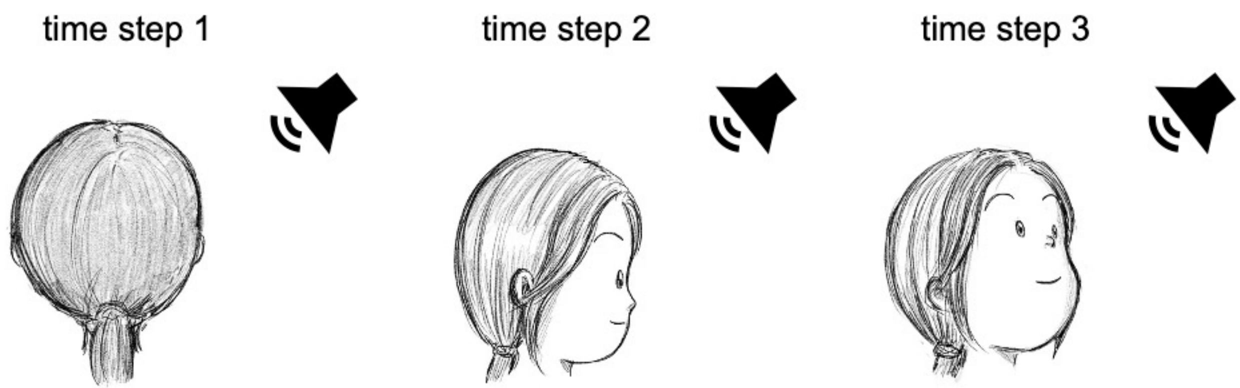




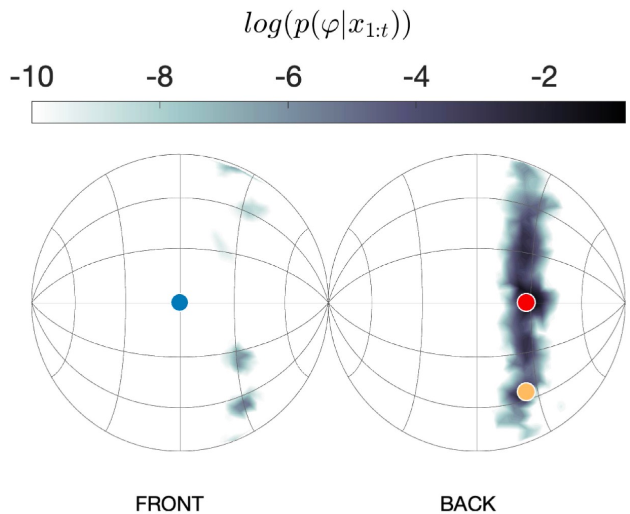
Head motion helps resolving the source location in the cone of confusion, particularly important for front-back discrimination

McLachlan et al. (2021)

New models that account for head motion



New models that account for head motion



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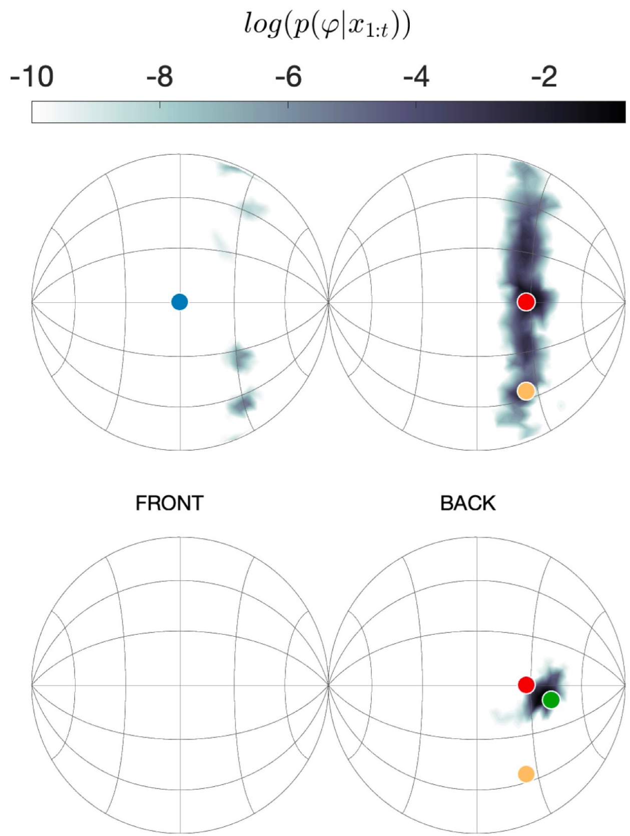
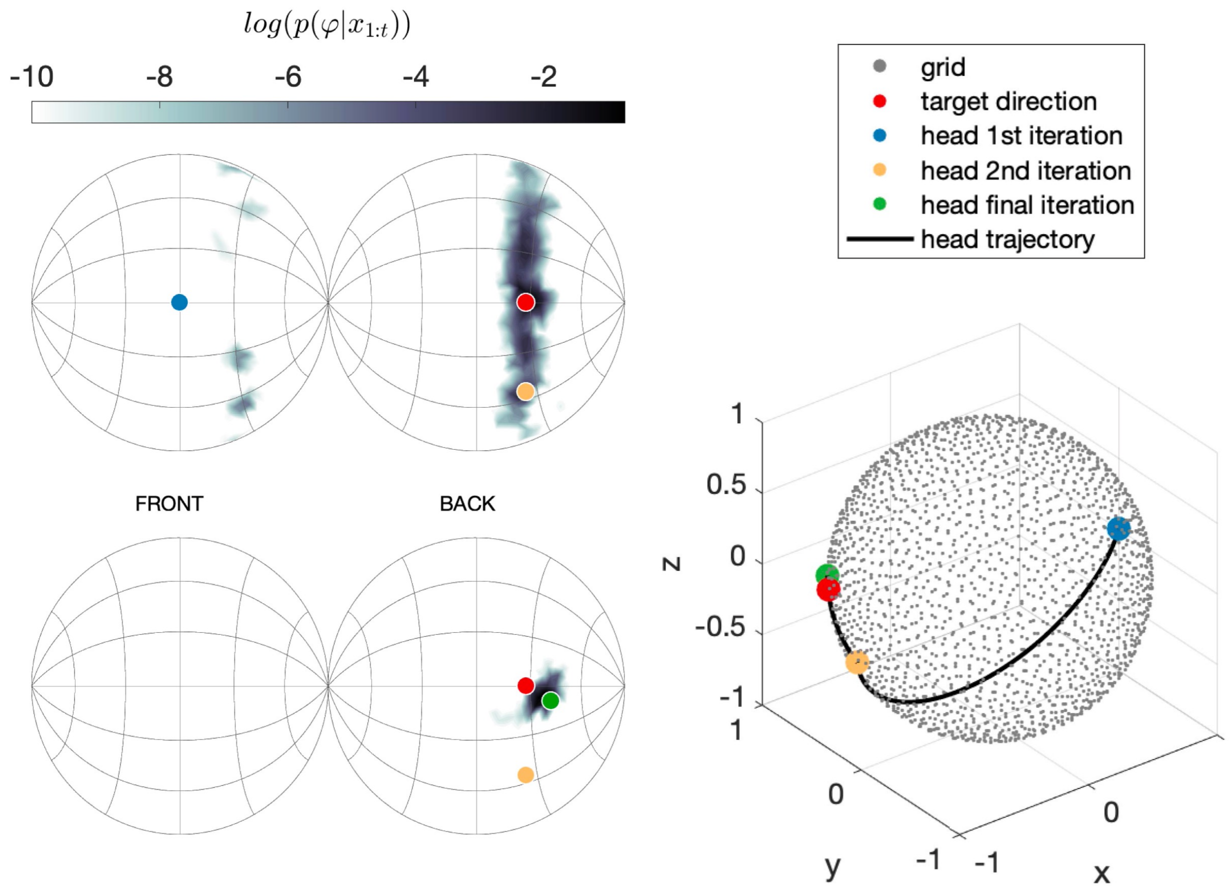


New models that account for head motion



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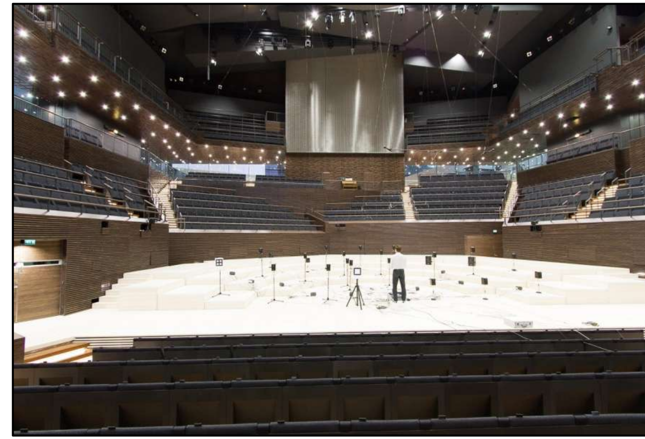
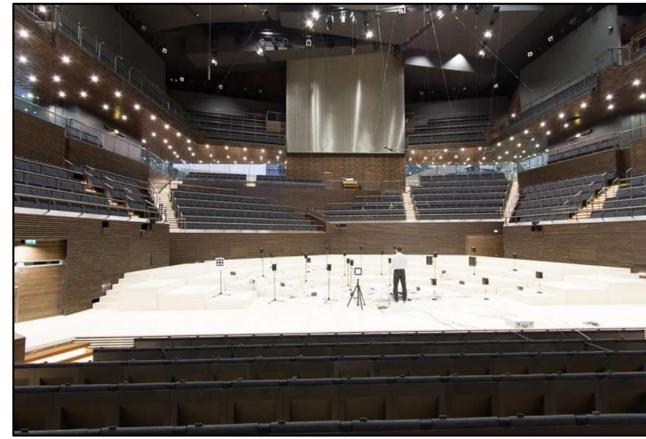
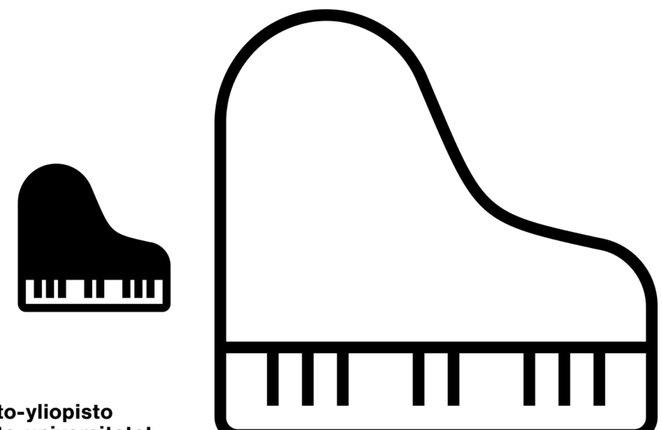
The spaciousness and how to assess it

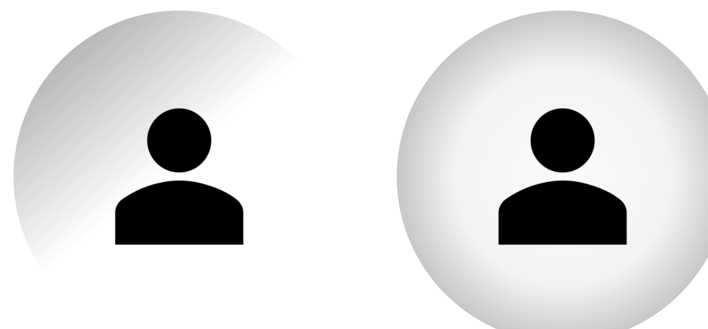


The spaciousness and how to assess it



Apparent source width (ASW) and **Envelopment**





The spaciousness and how to assess it

Which of these samples have more
[**Apparent source width (ASW) / Envelopment**]?

A B

▶ ▶

☐ ☒

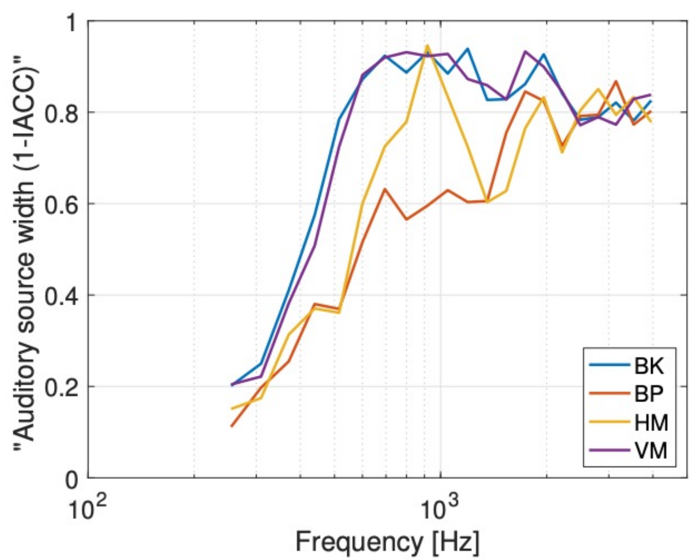
Lokki et al. (2023)

The spaciousness and how to assess it

Which of these samples have more
[**Apparent source width (ASW) / Envelopment**]?

A ☐

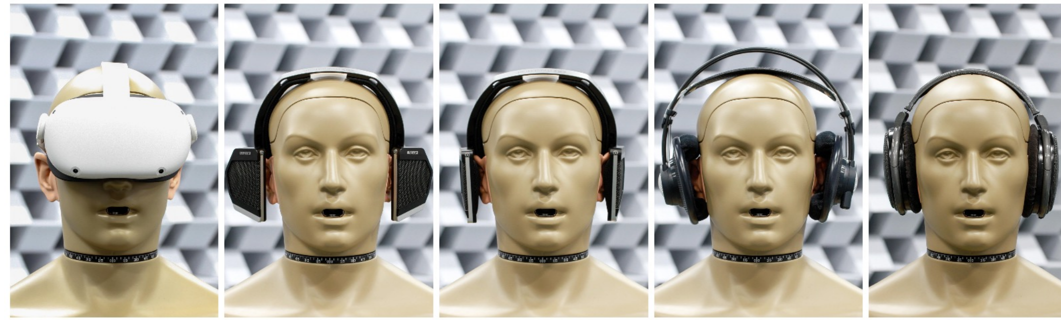
B ☒

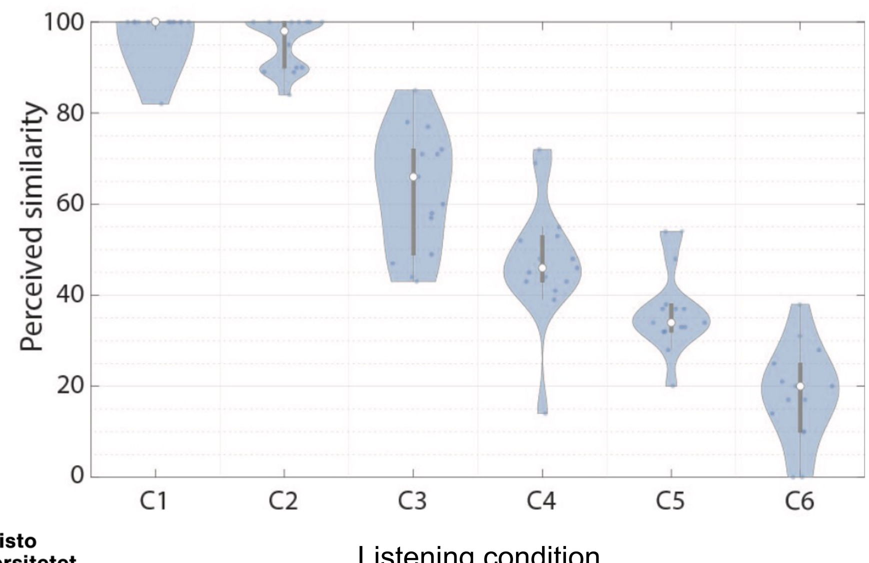


Lokki et al. (2023)

Colouration assessment

Colouration as differences in timbre compared to a reference signal

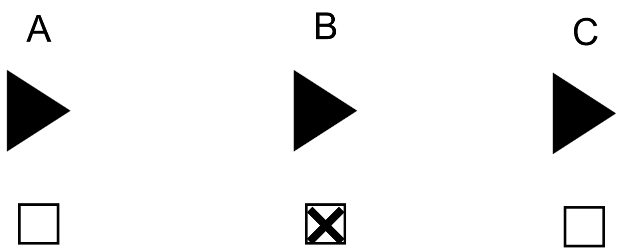


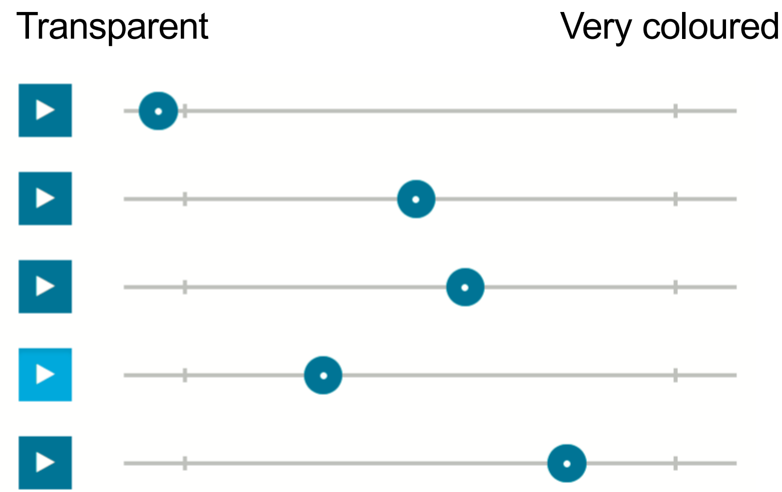


Lladó et al. (2022)

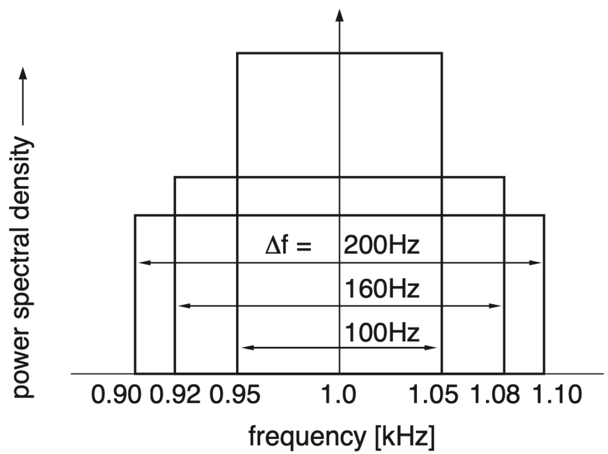
Colouration can be assessed using several methods

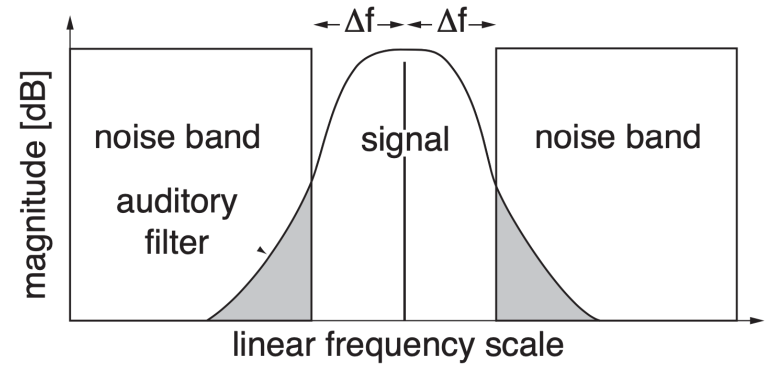
Which of these signals is different?



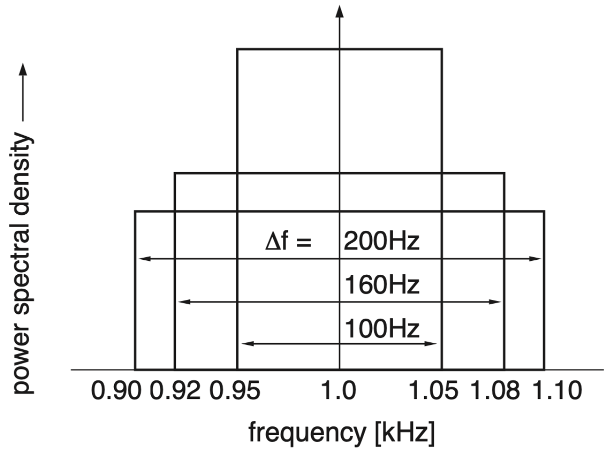


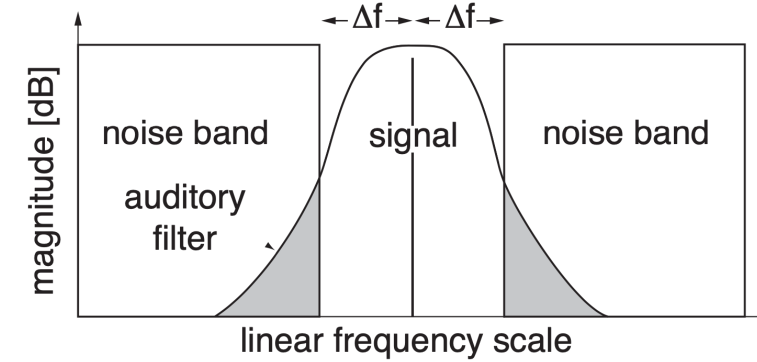
Colouration can be derived from basic concepts related to loudness and auditory filters

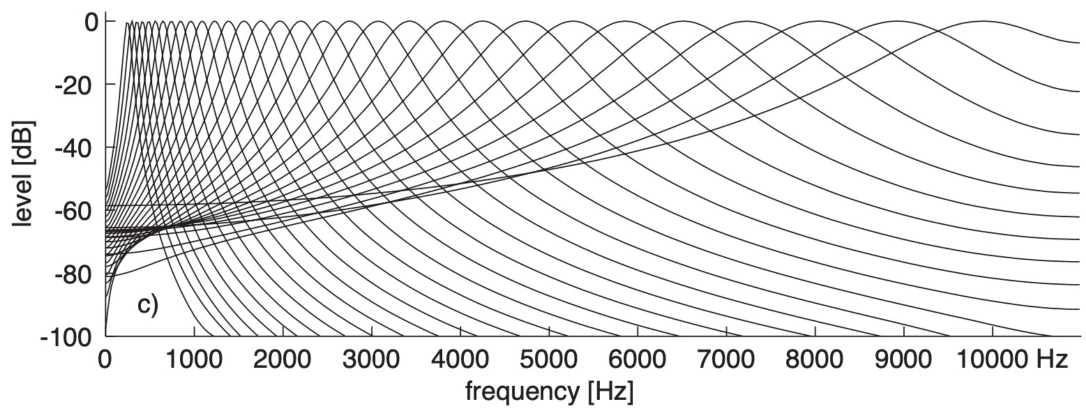




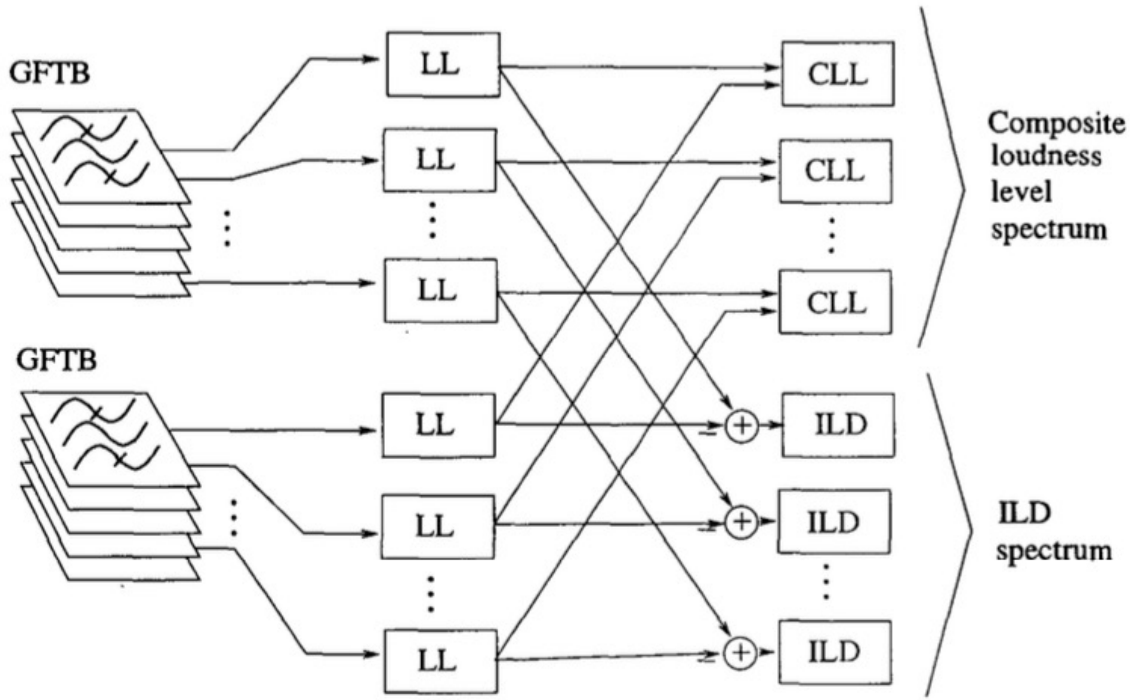
Colouration can be derived from basic concepts related to loudness and auditory filters







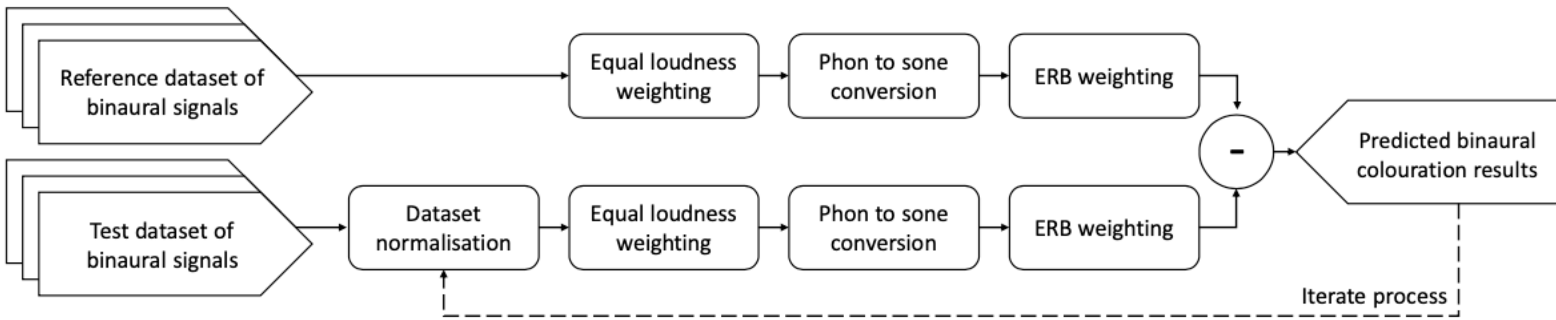
The specific loudness is connected to the perceived colouration



Pulkki et al. (1999)

Model of colouration

MCKENZIE2022 - Binaural perceptual similarity



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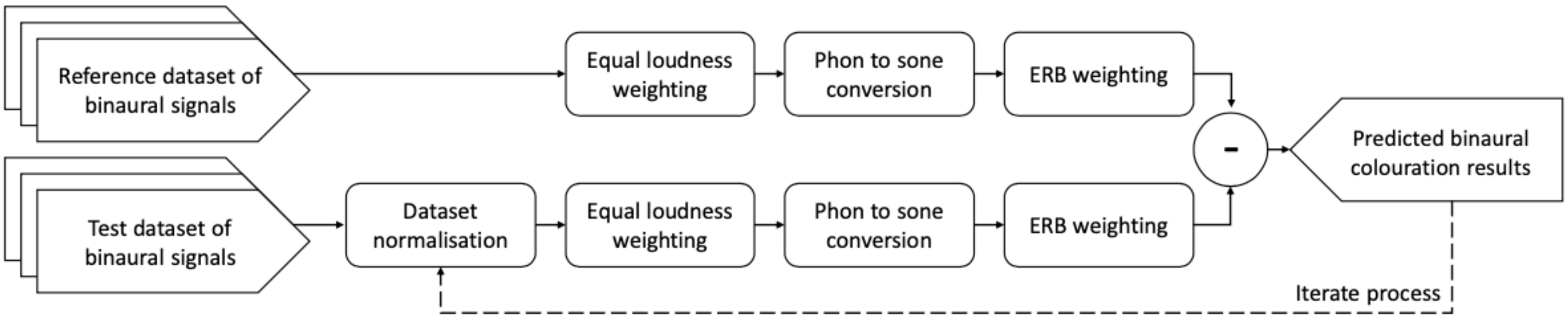
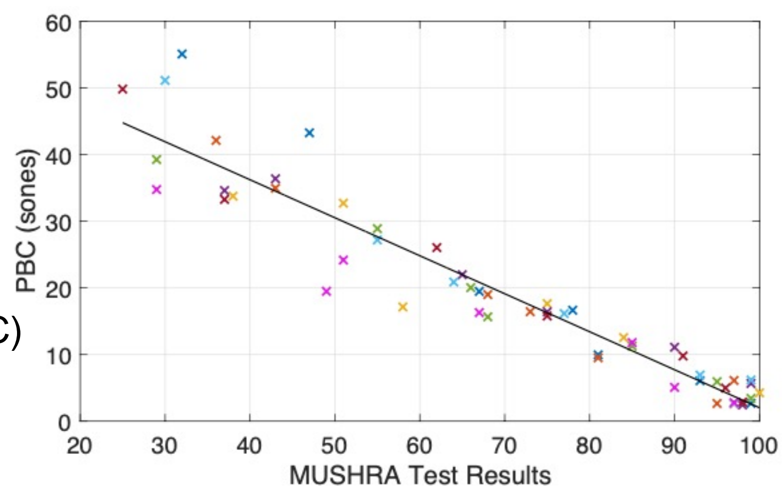
McKenzie et al. (2023)

Model of colouration

MCKENZIE2022 - Binaural perceptual similarity



Predicted binaural colouration (PBC)



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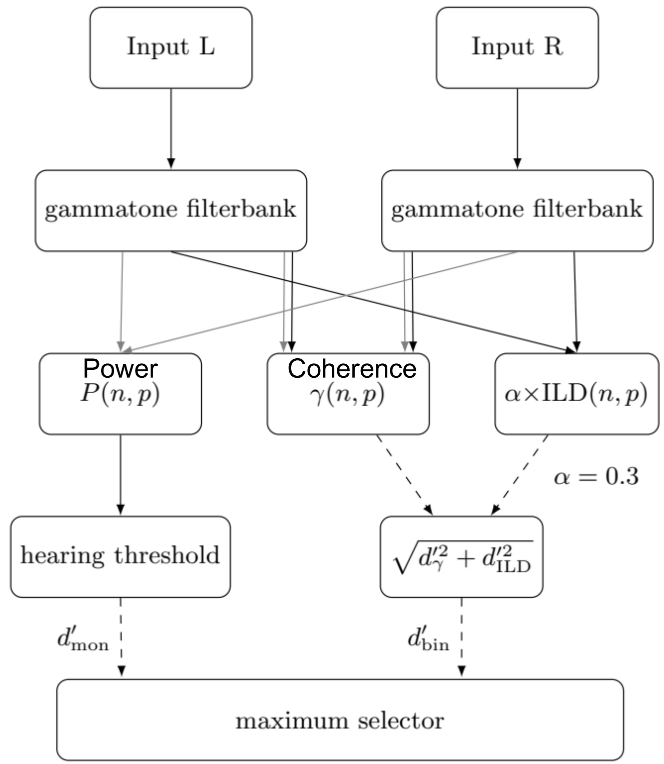
McKenzie et al. (2023)

Assessing the overall quality

Overall binaural quality as a combination of binaural and monaural attributes

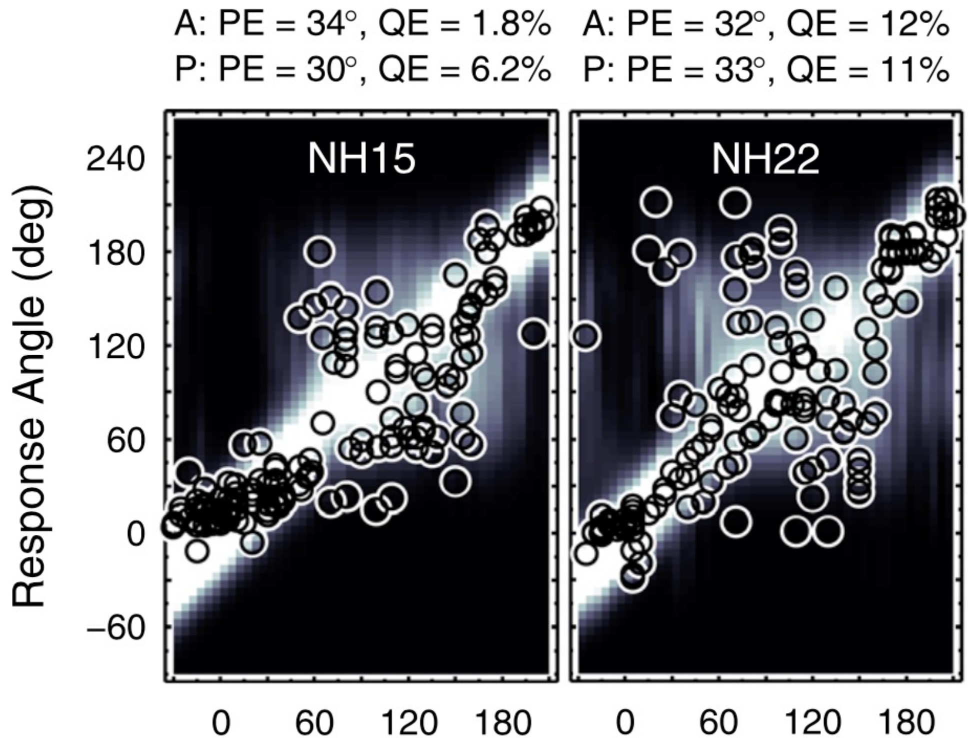


Eurich et al. (2023)

Summary

Listening experiments are the best option to assess sound quality

We can estimate experimental data obtained from listening experiments using auditory models



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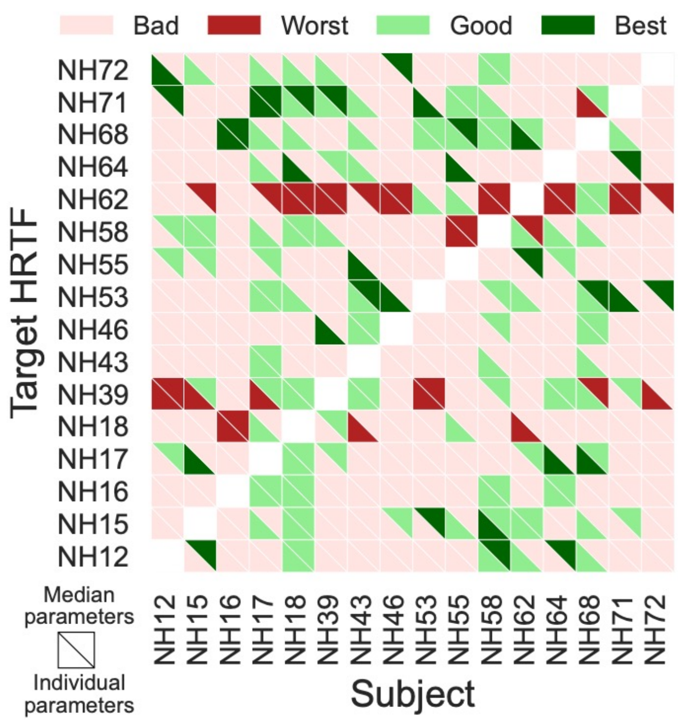
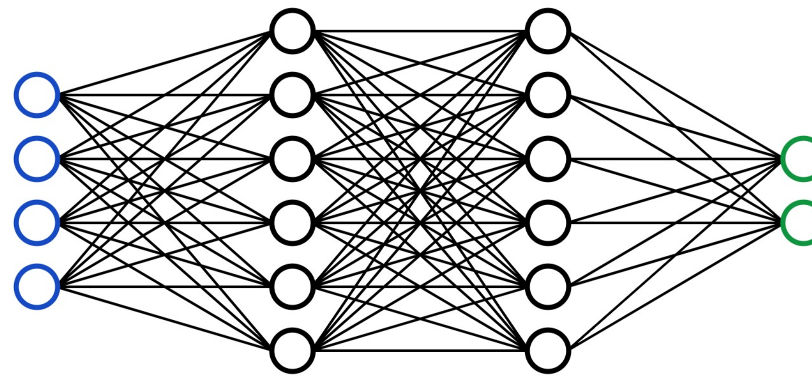
Once these models have been validated, we *can* rely on them





pedro.llado@aalto.fi

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