Changing the Frequency-dependent Weighting of the Localization Cues

Norbert Kopčo[1], Peter Lokša, Ondrej Spišák, René Šebeňa
Perception and Cognition Lab, Institute of Computer Science
P. J. Šafárik University in Košice ([1] also BU HRC)

Bernhard Laback, Maike Ferber
Acoustics Research Institute, Austrian Academy of Science, Vienna

Aaron Seitz
University of California, Riverside

Erick Gallun
VA RR&D NCRAR, Portland

Ecological Need for Plasticity in Spatial Hearing

- Maturation of auditory localization cues
  (King and Carlile, 1995)
- Physiological changes, e.g. due to middle-ear infection or occlusion of one ear
  (Keating and King, 2013; Knudsen and Mogdans, 1992)
- Changes in acoustical environment
  (e.g., Siveke *et al*., 2012; Zahorik *et al*., 2009)

Examples of Binaural Cue Plasticity / Modification

- Sensitivity to single cue (ITD or ILD) improves with feedback training (e.g., Wright, 2001)
- Auditory localization recalibrates fast to spatially disparate visual stimuli (*ventriloquism aftereffect)* (Recanzone, 1998, Kopčo et al, 2009)
- Listeners adapt to new mapping of binaural cues using visual feedback (Shinn-Cunningham et al., 1998)
- Frequency-dependent factors and grouping also influence how binaural cues are combined. E.g., binaural interference is influenced by grouping (Best et al., 2007)

Asymmetry in Binaural Cue Use with Cochlear Implants (CI)

- Envelope-based high-rate CI strategies convey no meaningful ITD cues for practical stimuli (e.g., Laback et al., 2004)
- Poor ITD sensitivity and left/right localization performance, even when stimuli are accurately controlled with a CI research system
- Hypothesis: Chronic lack of ITD cues or inconsistency between ITD cues and more reliable localization cues (ILD or visual) reduces perceptual weight and sensitivity to ITD
- In Oculus-VR environment, visual feedback training can be used to train listeners to increase / decrease the ITD-ILD weighting (Ferber et al., 2018)

Overview

Goal:

Examine 3 approaches to binaural cue reweighting:

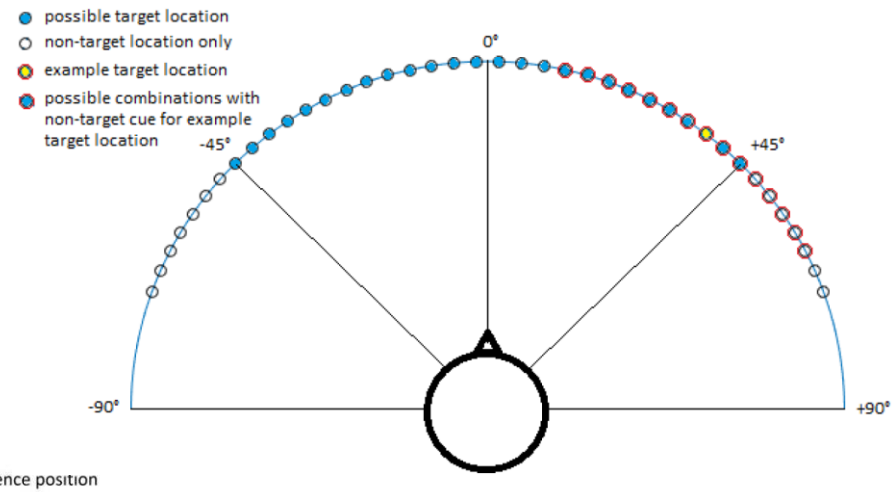
1. **Oculus VR environment: s**ummarize Ferber et al. (2018)

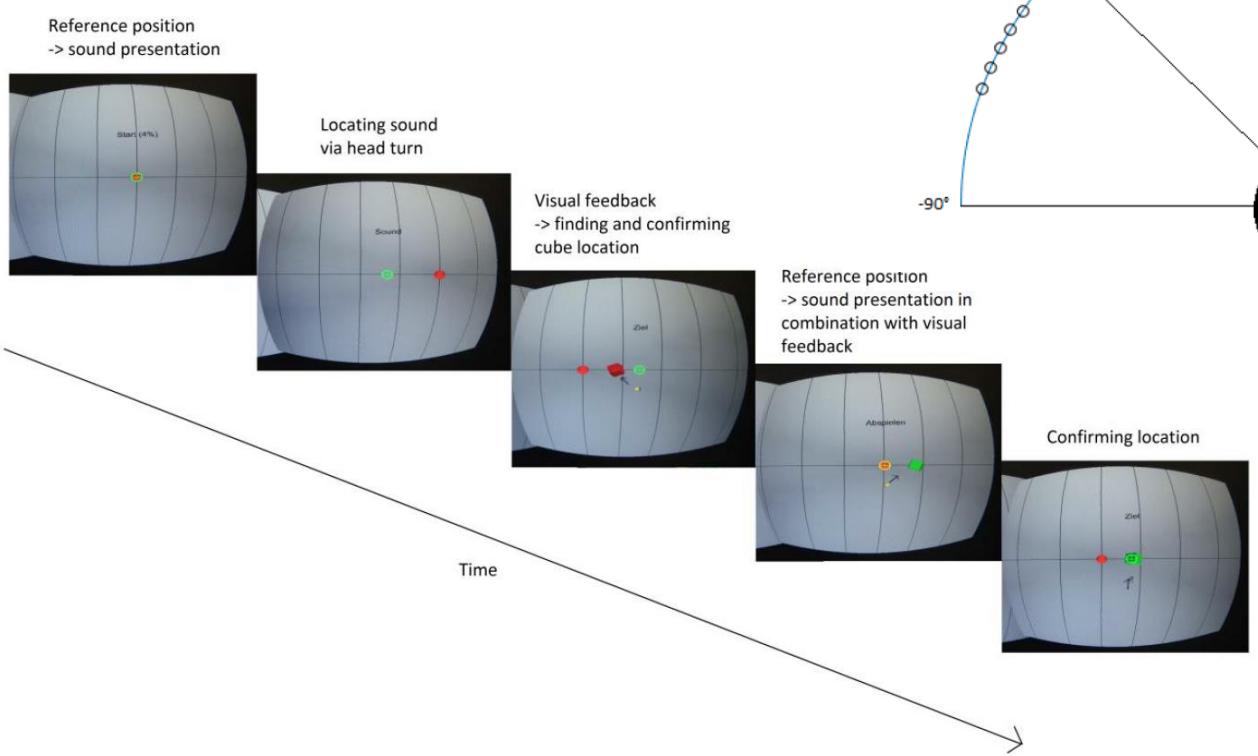
2. **Real environment:** experiment examining spectral reweighting of localization (and generalization to binaural cues)

3. **Headphones (Adaptive Game):** preliminary results about reweighting for brain-training games

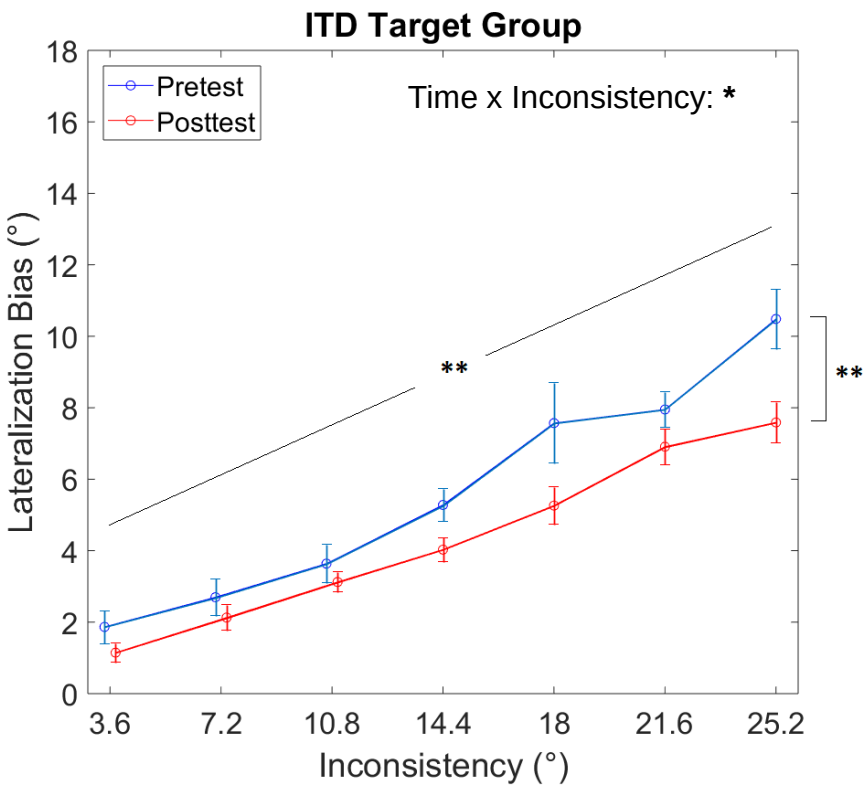
Exp1: Approach

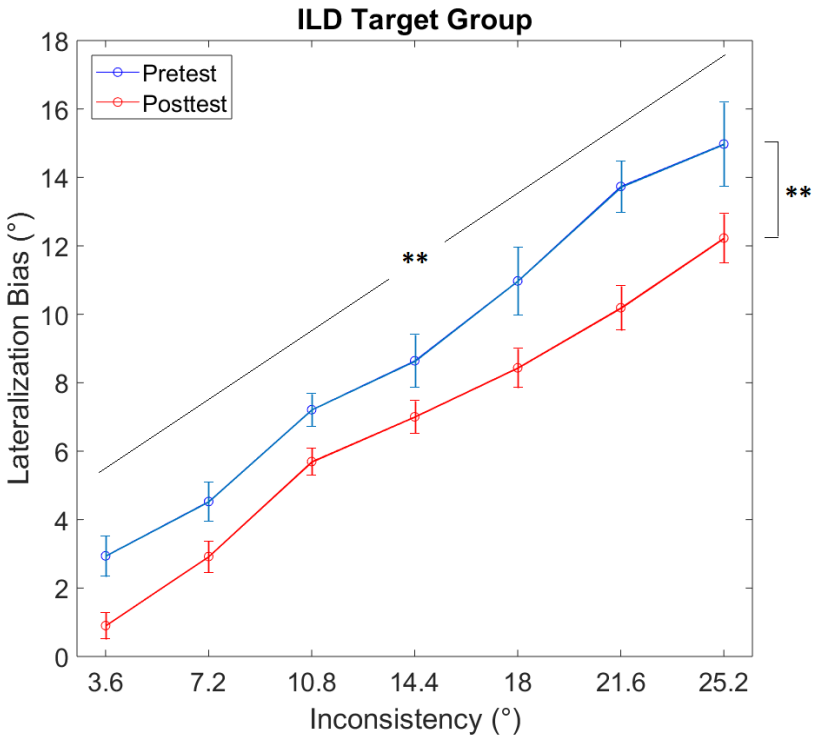
- Stimuli (1-octave noise, Fc=2.8kH) presented with ITD/ILD location inconsistency of up to 25° over a range of target locations.
- Provide VR visual feedback consistent with ITD or ILD.
- 7 days of 1-hr training





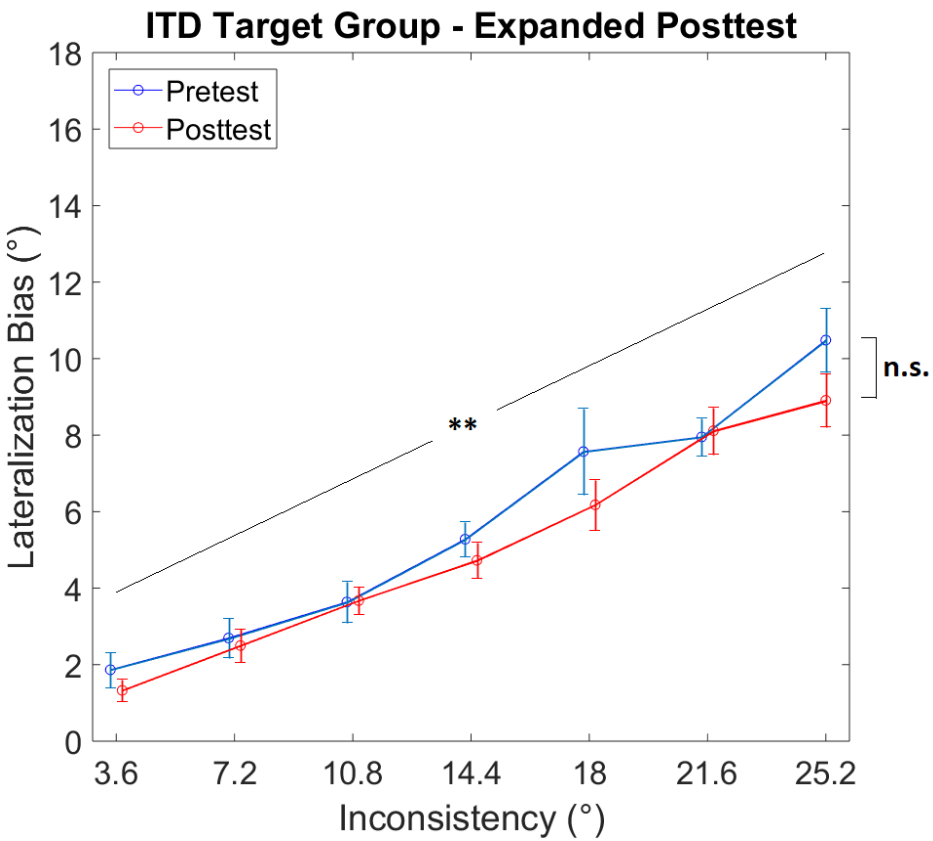
Exp1 Results: Binaural Cue Weights

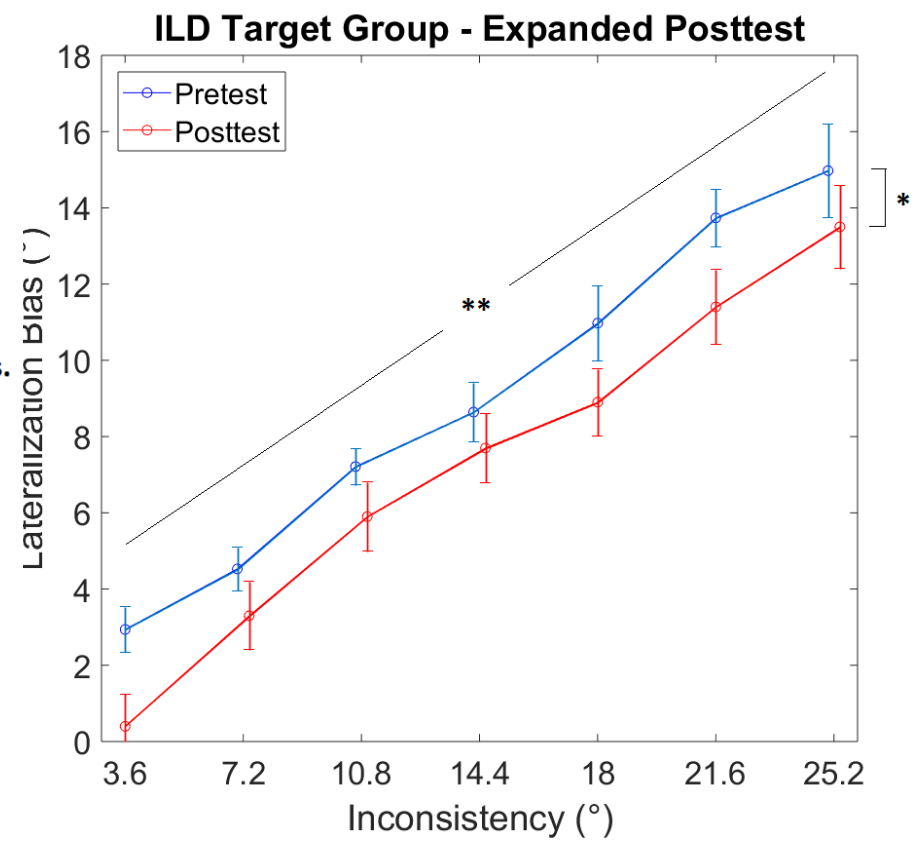




- Re-weighting in both groups: bias re. target-cue decreases significantly from pre- to post-test
- However, post-test data compressed (biased towards middle of response range)

Exp1 Results: Binaural Cue Weights after expansion





- After correcting for compression in post-test, re-weighting visible only in ILD target group

Exp 2: Real environment

Idea:

- Train subjects in real environment to weight more
  - high-frequency (HF) channels (>2.8kHz), or
  - low-frequency (LF) channels (<2.8kHz).
- Test whether the **spectral reweighting can be induced**, and whether it generalizes to
  - new un-trained frequency (2.8kHz),
  - ITD/ILD reweighting (using VR, like in Exp 1).

Benefits of real environment:
- No issues with veridicality/accuracy of localization, externalization, AV binding,
- Easy to generate dynamic cues.

Disadvantage of real environment:
- can’t independently manipulate binaural cues.

Exp 2: Setup

11 spkrs @ -56° to 56°
(11-deg spacing).

Visual stimulus projected above spkrs.

Tracking head orientation/response.

Auditory stimuli:
300ms 0.5-oct noise bursts in channels centered at:
- LF: 0.35 or 0.7 kHz
- HF: 5.6 or 11.2 kHz

Testing:
- 2-ch stimulus (1-HF & 1-LF channel) from locations separated by 1 or 2 spkrs,
- 4-ch stimulus (2-HF & 2-LF channels) from locations 1-2 spkrs apart,
- 2-ch stimulus (1 ch at 2.8 kHz, other ch LF or HF) from locations 1 spkr apart,
- respond by head turn to target, or to middle of the targets if you hear multiple.

Exp 2: Training

Stimuli like in testing.
Visual feedback aligned with HF channels for HF group (LF ch for LF group).

Procedure:

Initial position & stimulus presentation	
Head-turn to 0°	Present stimulus once

Response
Head-turn to perceived target location & press Enter

Visual feedback	
Green dot shows correct location	Present stimulus continuously

Training	
Head-turn to visual feedback & press Enter	Stimulus continues

Training with dynamic cues	
Head-turn to 0° & press Enter	Stimulus stops

Exp 2: Overall procedure & Analysis

Experiment consists of 2-3 hr sessions performed on consecutive days:

Day 1: Oculus pretest, speaker pretest, training session 1

Day 2: Training session 2

Day 3: Training session 3, speaker posttest, Oculus posttest.

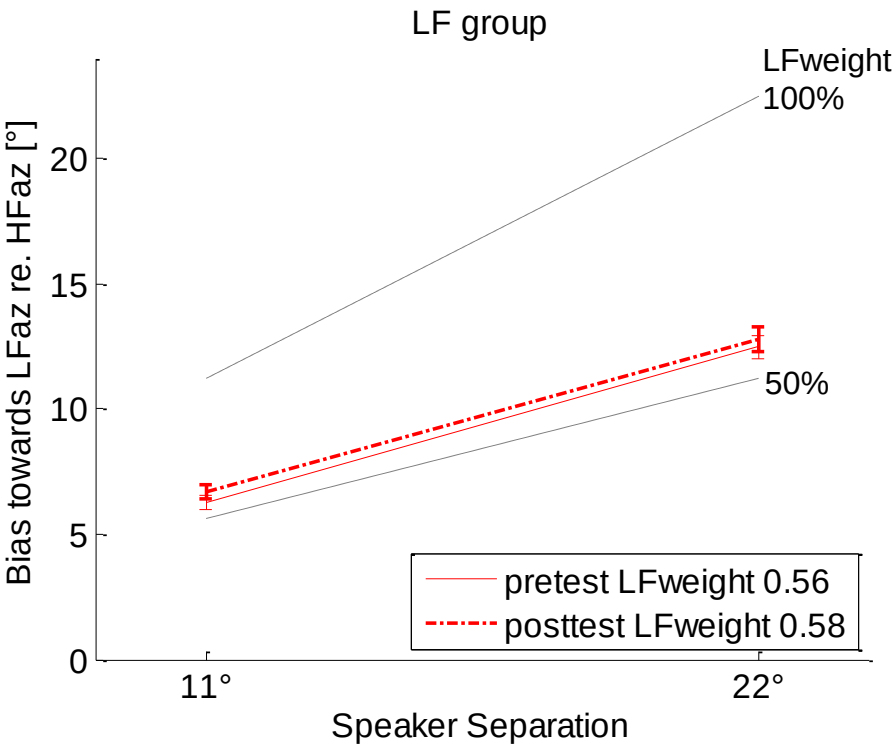
Results analyzed as:

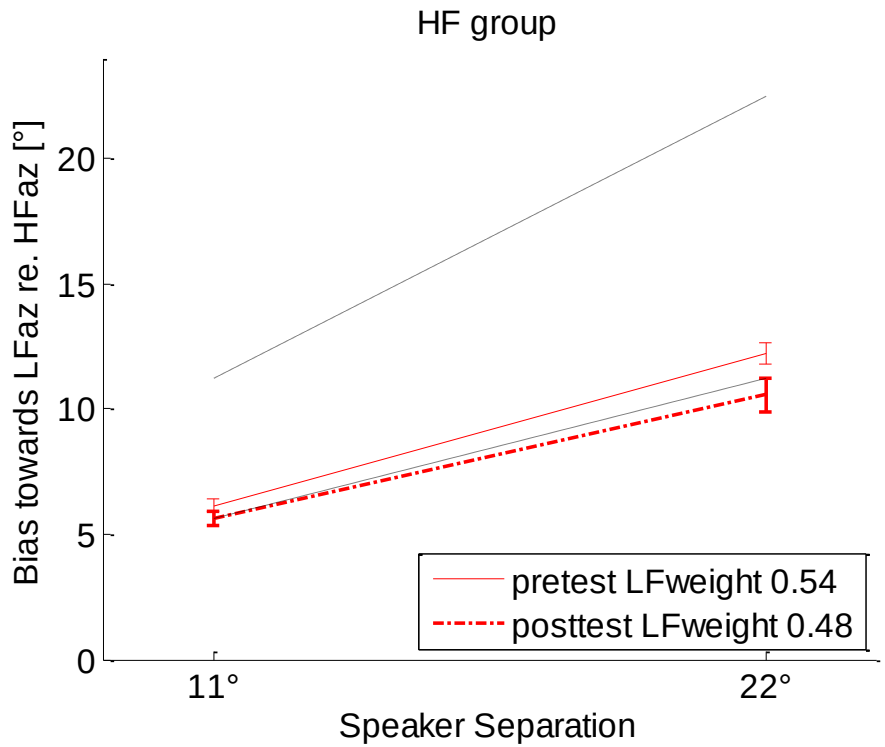
- Loudspeaker data: bias in response re. azimuth of HF component (in direction of LF component),
- Oculus data: bias in response re. azimuth of ILD component (in direction of ITD component).

$$\text{LFweight} = \frac{\text{response - HFaz}}{\text{LFaz} - \text{HFaz}} \qquad \text{ITDweight} = \frac{\text{response - ILDaz}}{\text{ITDaz} - \text{ILDaz}}$$

(HFweight = 1 – LFweight ILDweight = 1 – ITDweight)

Exp 2: Results – response bias avgd x-target location

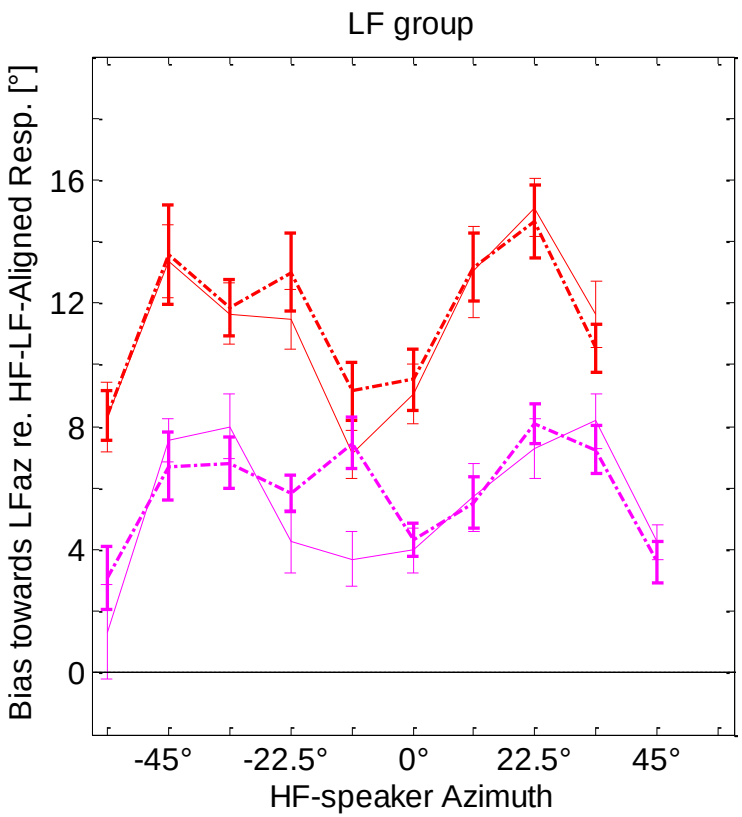


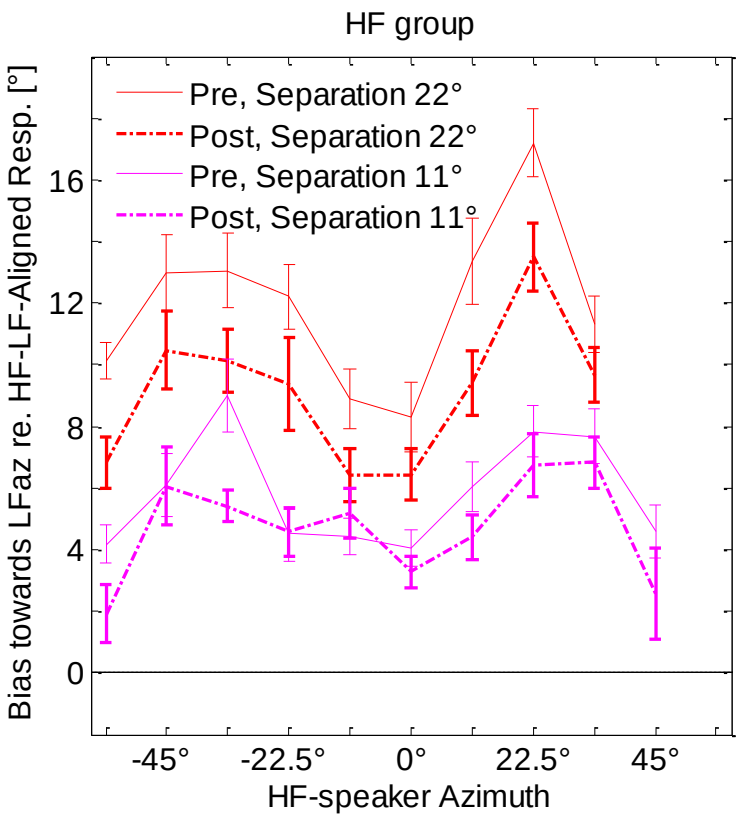


LF group: no significant effect

HF: decrease in LF weighting

Exp 2: Results – Response bias re. HF location

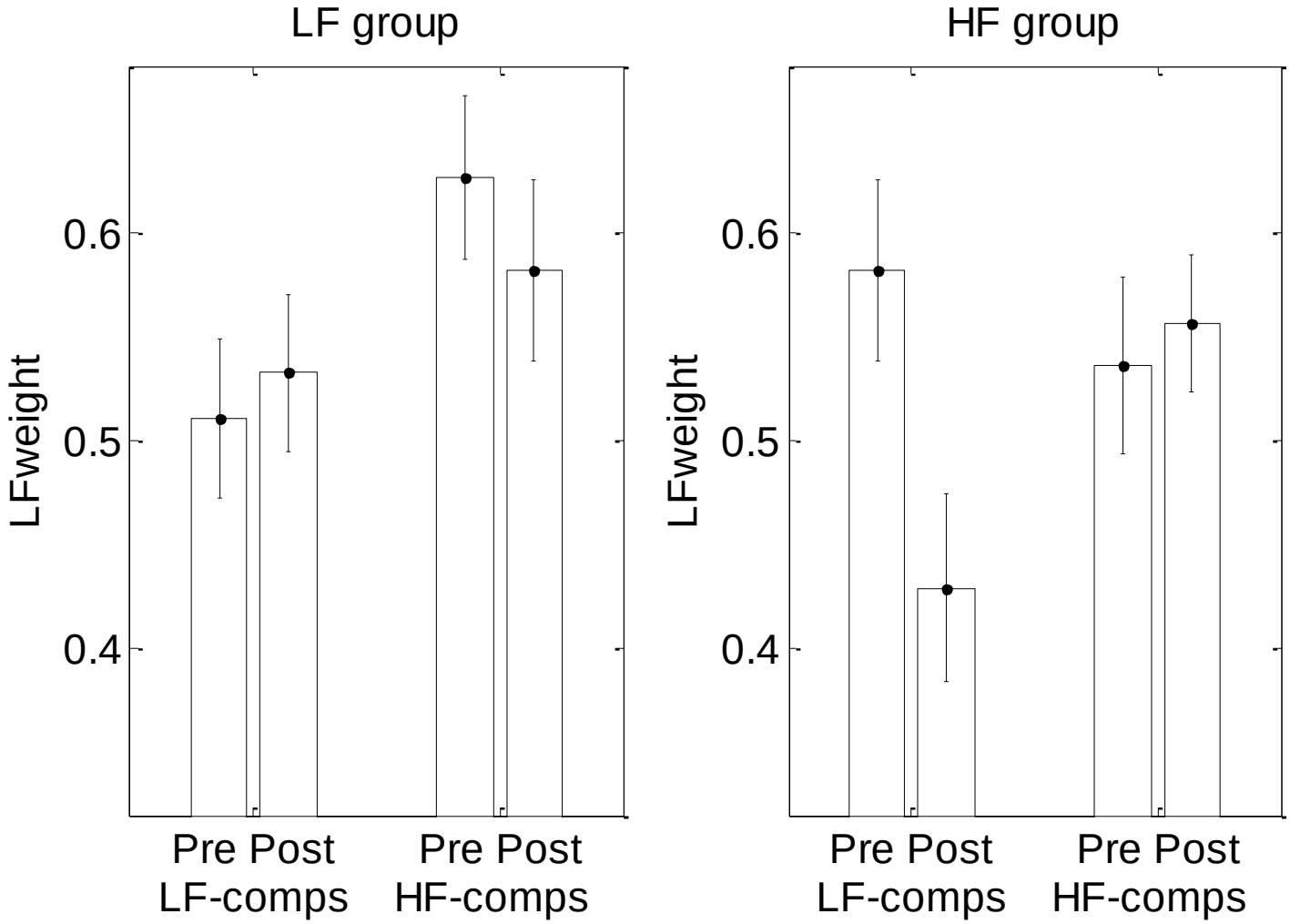




LF: adaptation mostly in center

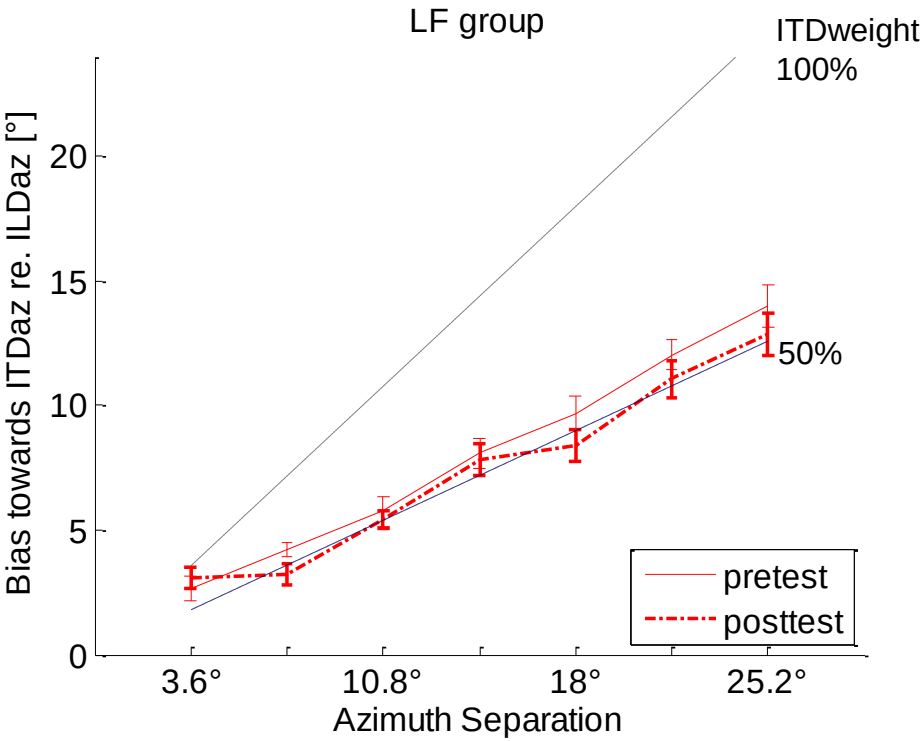
HF: adaptation mostly in periphery

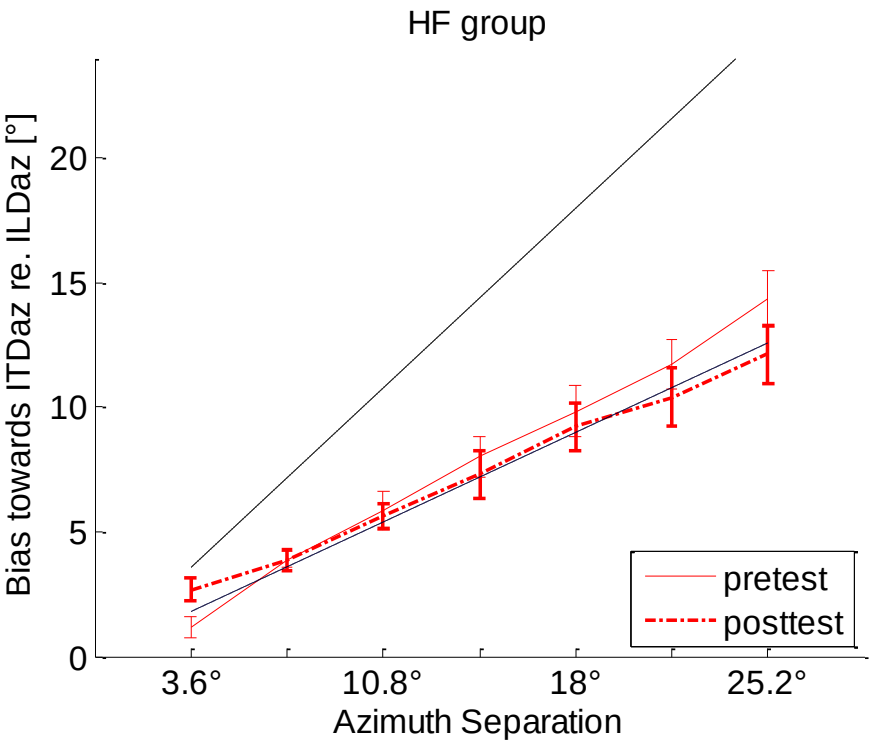
Generalization to Untrained Frequency



HF training generalizes to sounds consisting of trained frequencies and a new 2.8-kHz component, but only for trained **low-frequency** components (.35-.7kHz).

Exp 2: Generalization to Oculus ITD/ILD test





Difference between groups not significant (while post-pre difference significant).

Spectral reweighting does **not generalize** to **ITD/ILD reweighting** in Oculus environment.

Exp 3: Headphones / Adaptive Game training

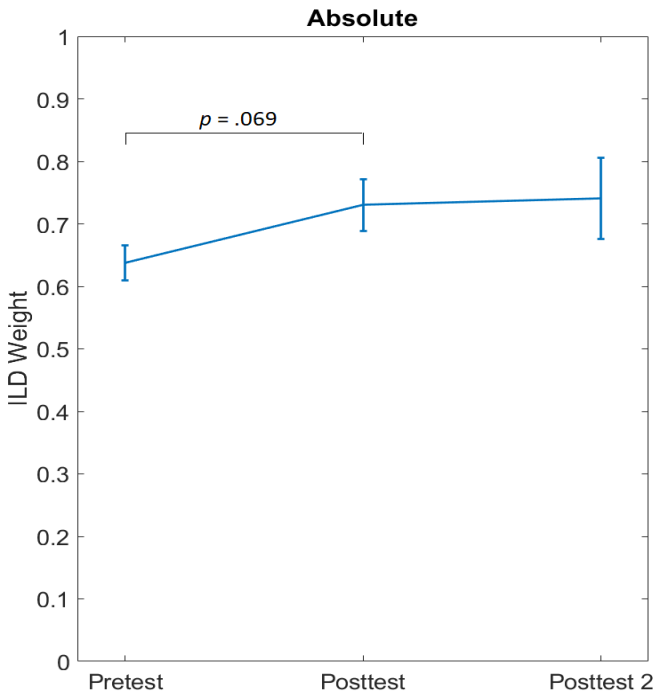
Idea:

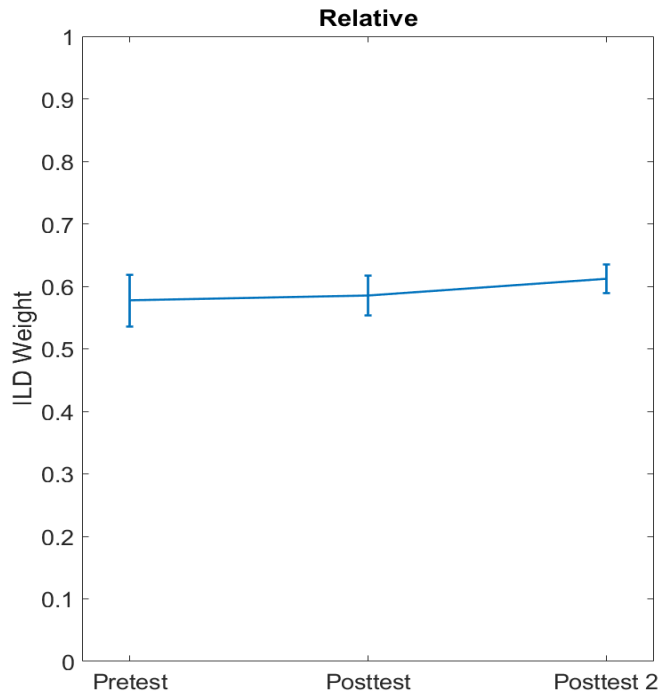
- Based on the Oculus VR training, train subjects using adaptive procedure and a simple left-right discrimination task to increase ILD weight:
  - in absolute discrimination: left vs. right from middle,
  - in relative discrimination task: left vs. right from reference.
- Test which procedure is more effective, and whether it generalizes to ITD/ILD reweighting (using VR, Exp 1).

Experiment 3:

- stimuli like in Exp 1,
- fix ITD-ILD mismatch angle at 1 of 3 values (10.8, 18, or 25.2°),
- adaptively vary ILD while ITD is always contralateral (at given mismatch),
- 3 adaptive tracks interleaved (for the 3 mismatches),
- present just one stimulus (absolute task) or stimulus pair (relative task).

Exp 3: Test results

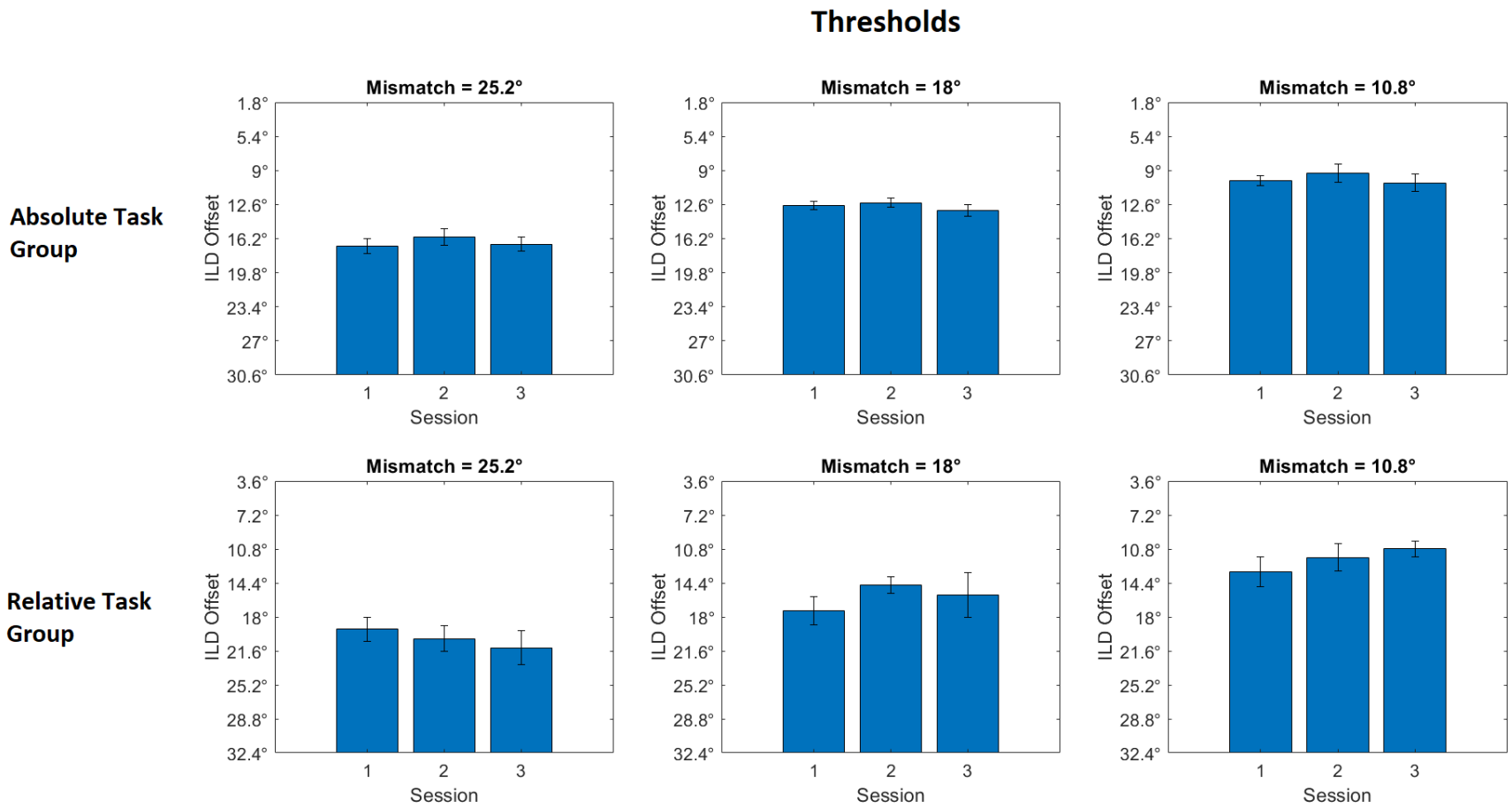




Subjects 1, 2, 11, 12, and 14 excluded

Better performance with Absolute task, but improvement not significant.

Exp 3: Training Thresholds



Relative task group tended to improve over sessions (for smaller mismatches).

Summary

Exp 1 – **Oculus-VR** (Ferber et al, 2018): Reweighting of binaural cues
- can be achieved in **VR virtual environment**,
- is more stable for ILD-training than ITD-training,
- has not been tested on other reweighting tasks, or for generalization.

Exp 2 – **Real environment**: Reweighting of spectral cues
HF training
- results in relative increase in HF components weighting,
- the increase generalizes to stimuli containing a new frequency (2.8kHz), but only when combined with LF components → relative HF weight increase is likely caused by absolute LF weight decrease.

LF training
- no effect, except where LF weight initially very low (25%),
- could work if more such locations used (eg, only for central locations)

Summary (cont.)

Exp 2 – **Real environment**: Generalization of HF reweighting to ITD/ILD:
- no generalization observed in current 2.8kHz VR-Oculus testing,
- but, significant pre – post change suggest a lot of ?procedural? training → lower sensitivity,
- testing on LF stimuli might be more effective (based on the 2.8kHz generalization results).

Exp 3 – **Adaptive Game ILD training**
- so far, not effective,
- absolute task is simpler, but does not result in improvement over time,
- relative task is more complex, shows improvement over time → more training might be effective.

Overall, in NH listeners, training works better for ILD/HF increase. Good news or bad news for CI listeners (for which ITD weighting needs to increase)?

Acknowledgment:
Danube Partnership Slovakia-Austria-Czech Rep. APVV DS-2016-0026
European Union H2020-MSCA-RISE-2015 #691229