Changing the Frequency-dependent Weighting of the Localization Cues

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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

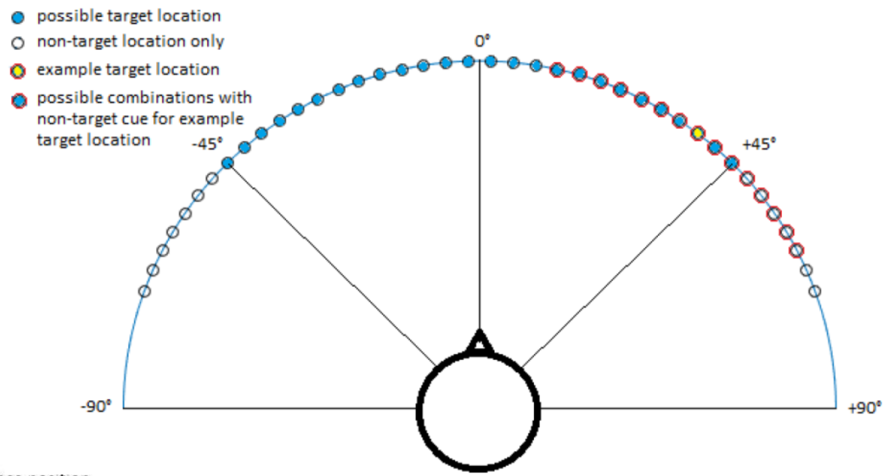
- Sensitivity to single cue (ITD or ILD) improves with feedback training (e.g., Wright, 2001)
- Auditory localization recalibrates fast to spatially disparate visual stimuli (*ventriloquism aftereffect)* (Recanzone, 1998, Kopčo et al, 2009)
- Listeners adapt to new mapping of binaural cues using visual feedback (Shinn-Cunningham et al., 1998)

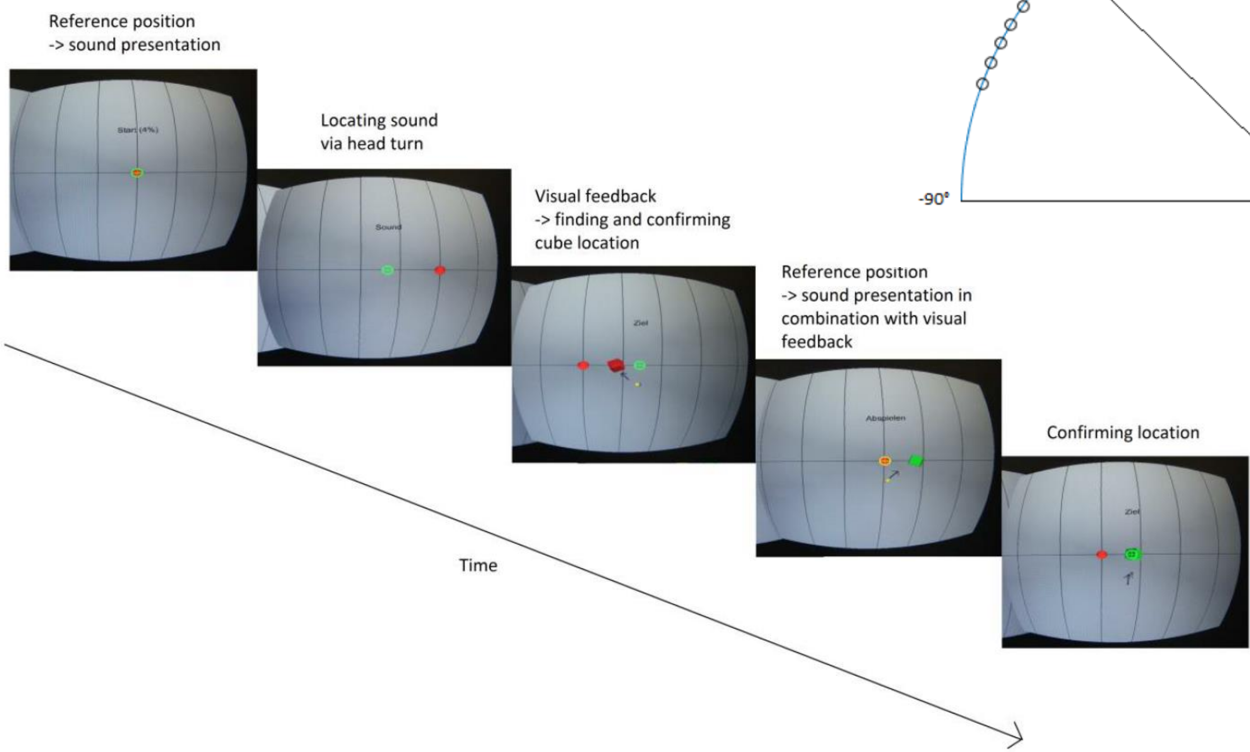
Asymmetry in Binaural Cue Use with Cochlear Implants (CI)

- 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

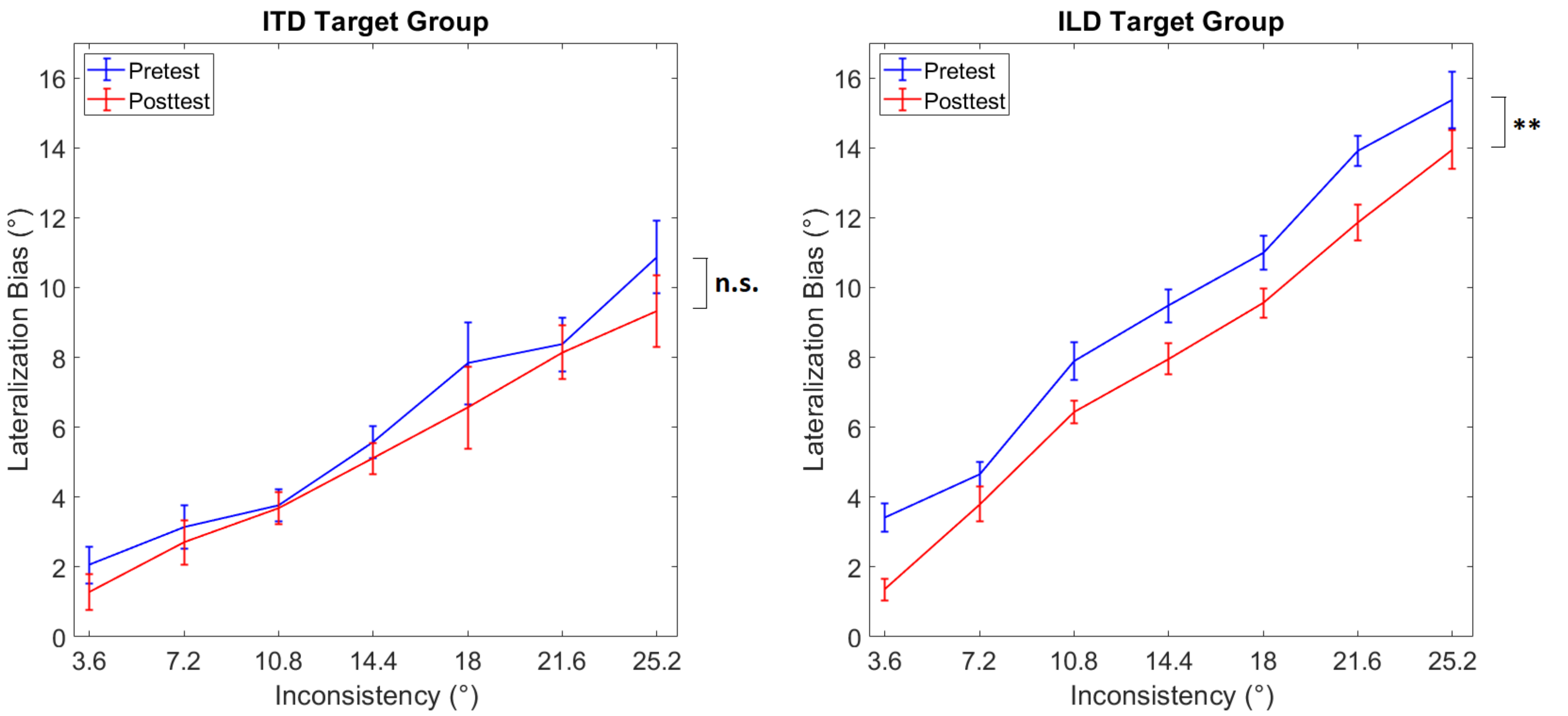
Exp1: Approach

- Stimuli (1-octave noise, Fc=2.8kH) presented with ITD/ILD location inconsistency of up to 25.2° over a range of target locations.
- Provide VR visual feedback consistent with ITD or ILD.
- 7 days of 1.5-hr training



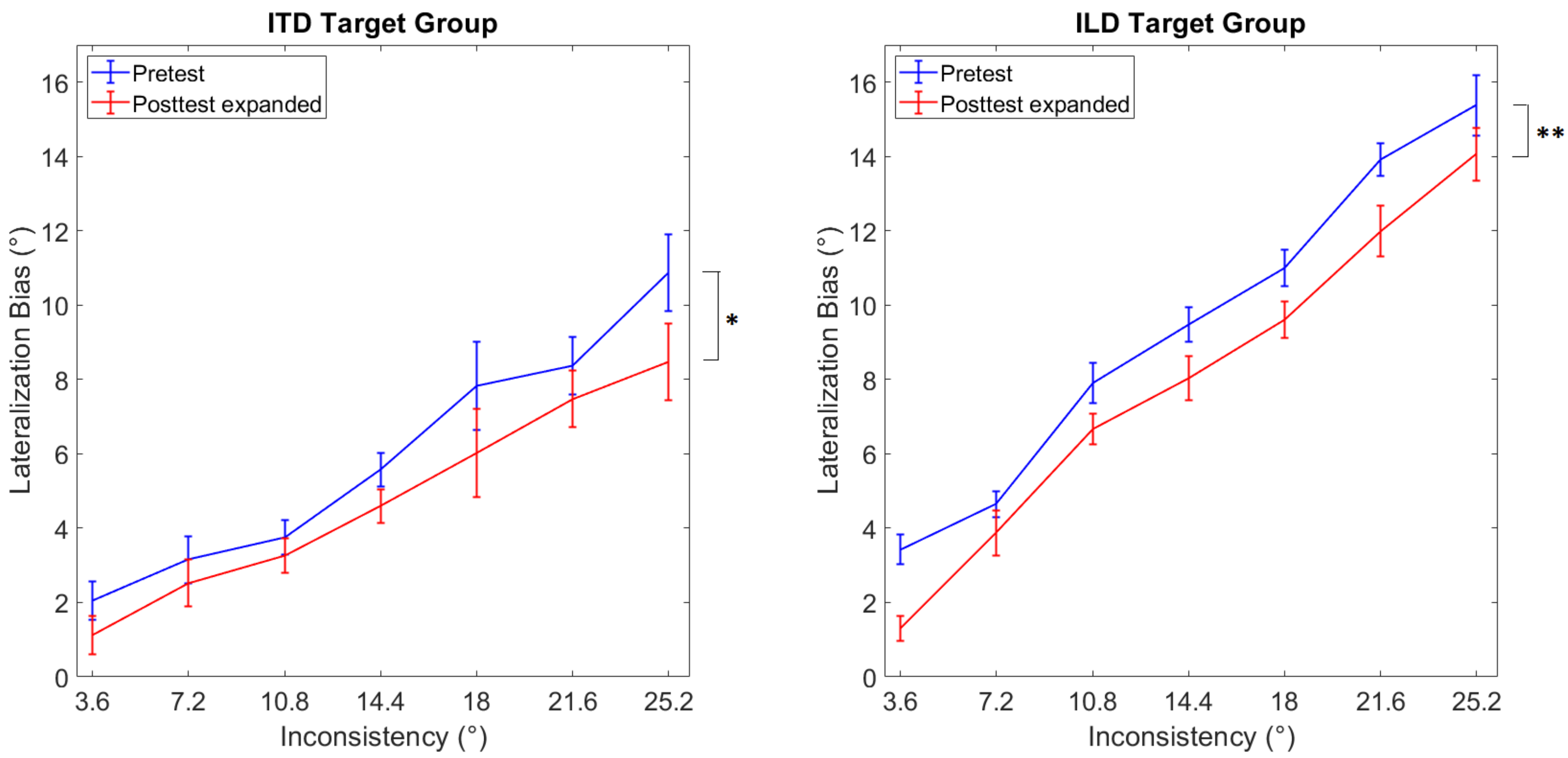


Exp1 Results: Binaural Cue Weights



- Significant re-weighting only in ILD target group (bias re. target-cue decreases from pre- to post-test)
- However, post-test data compressed (biased towards middle of response range, especially for the ITD target group)

Exp1 Results: Binaural Cue Weights after expansion



- After correcting for compression in post-test, re-weighting visible in both groups

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: VR pretest, speaker pretest, training session 1

Day 2: Training session 2

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

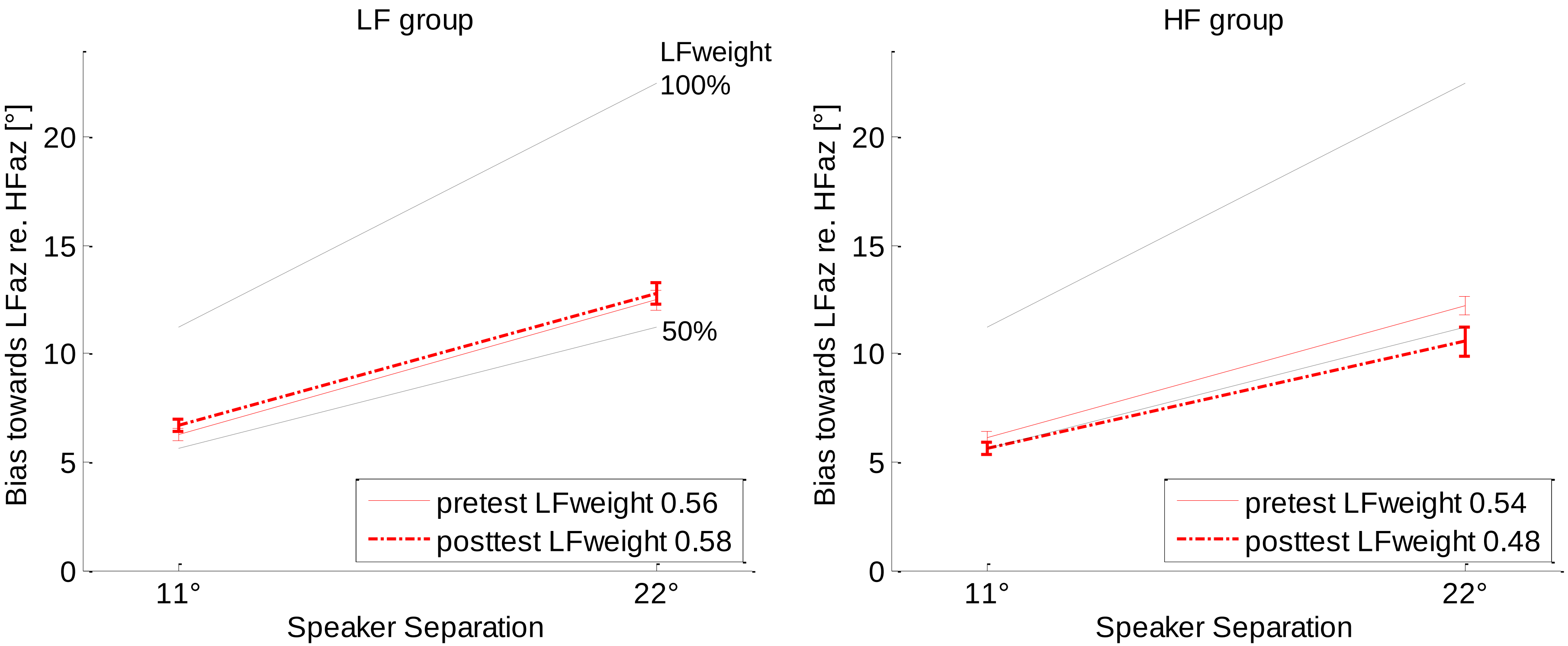
Results analyzed as:

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

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

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

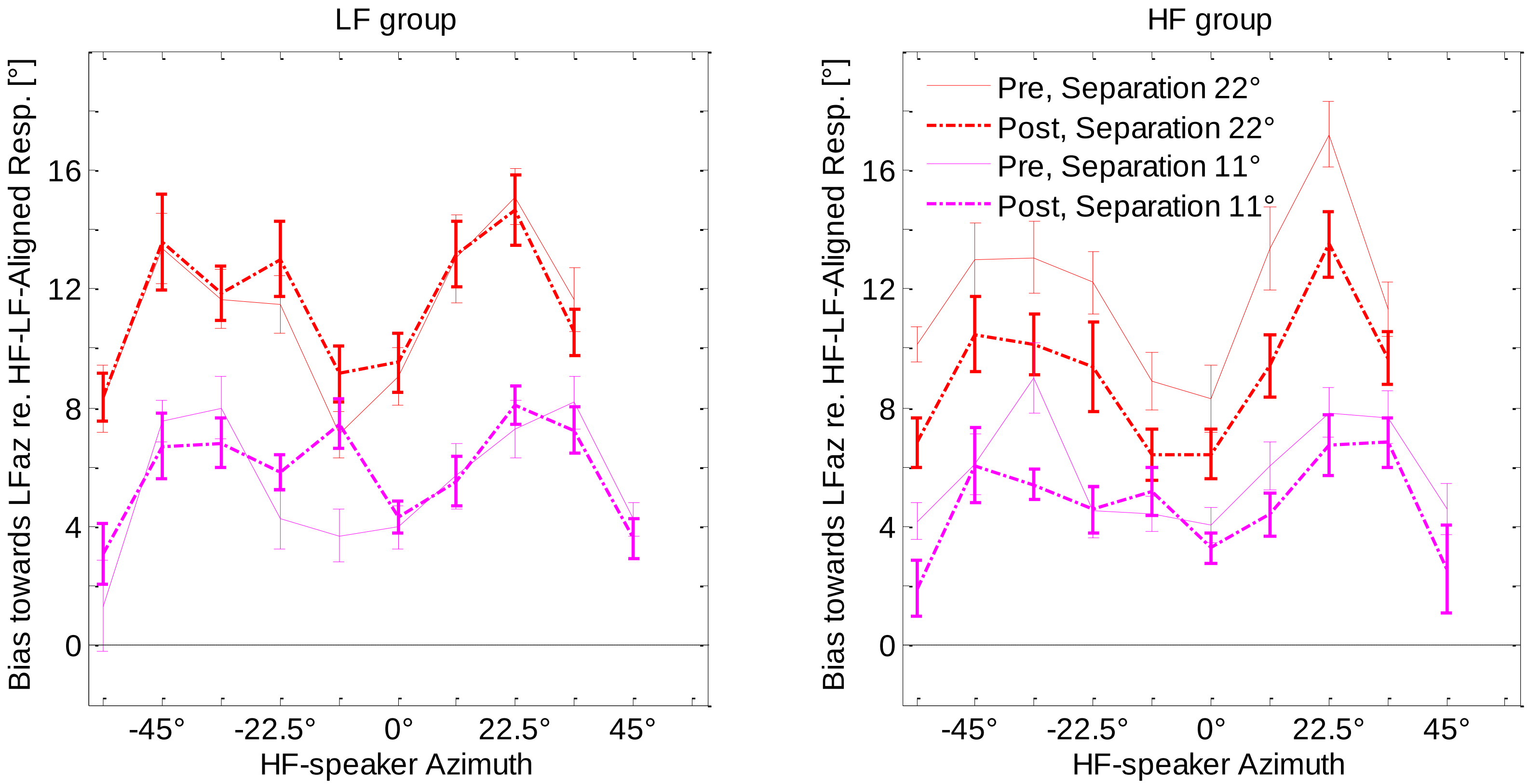
Exp 2: Results – response bias avgd x-target location



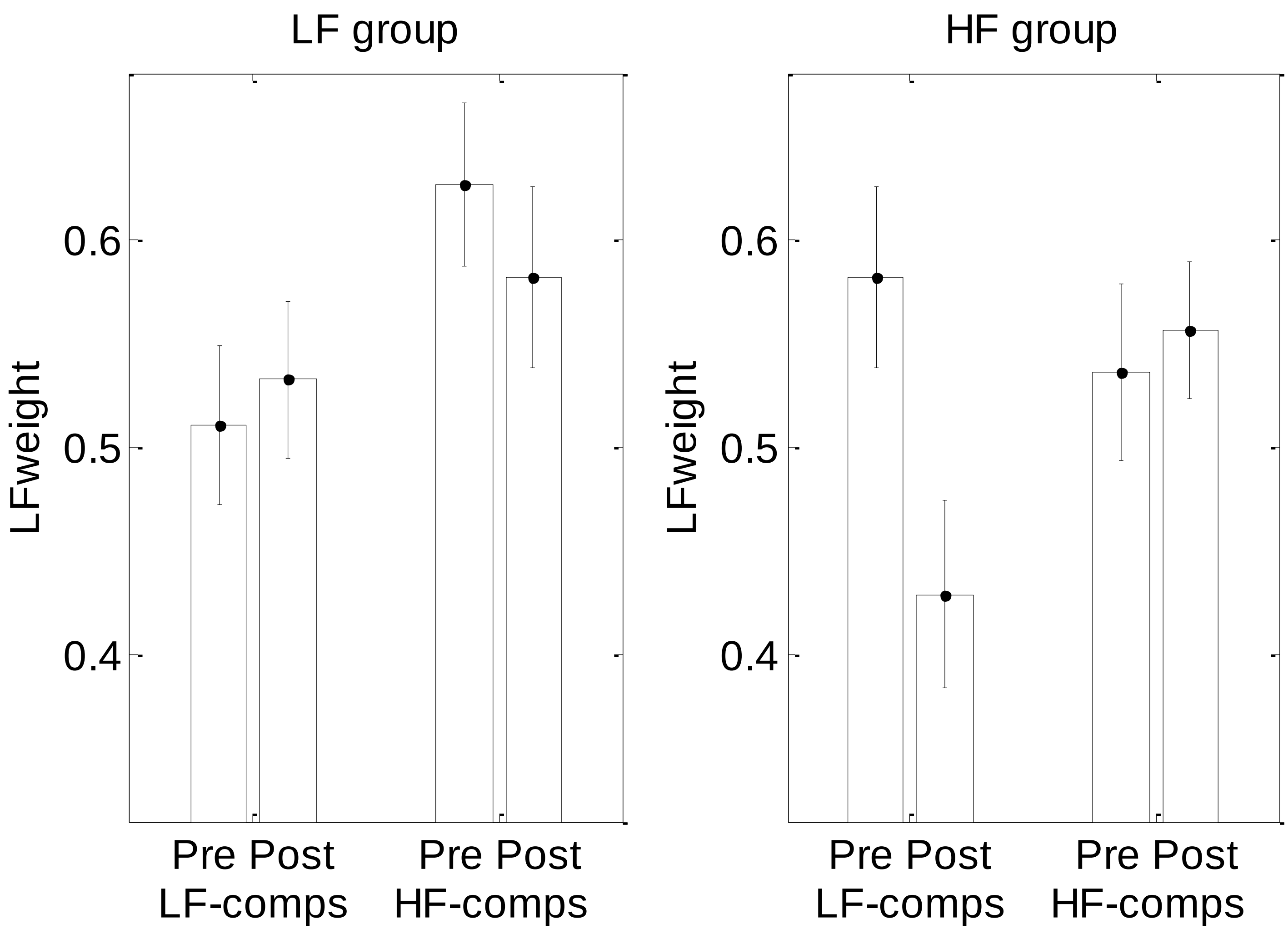
LF group: no significant effect

HF: decrease in LF weighting

Exp 2: Results – Response bias re. HF location

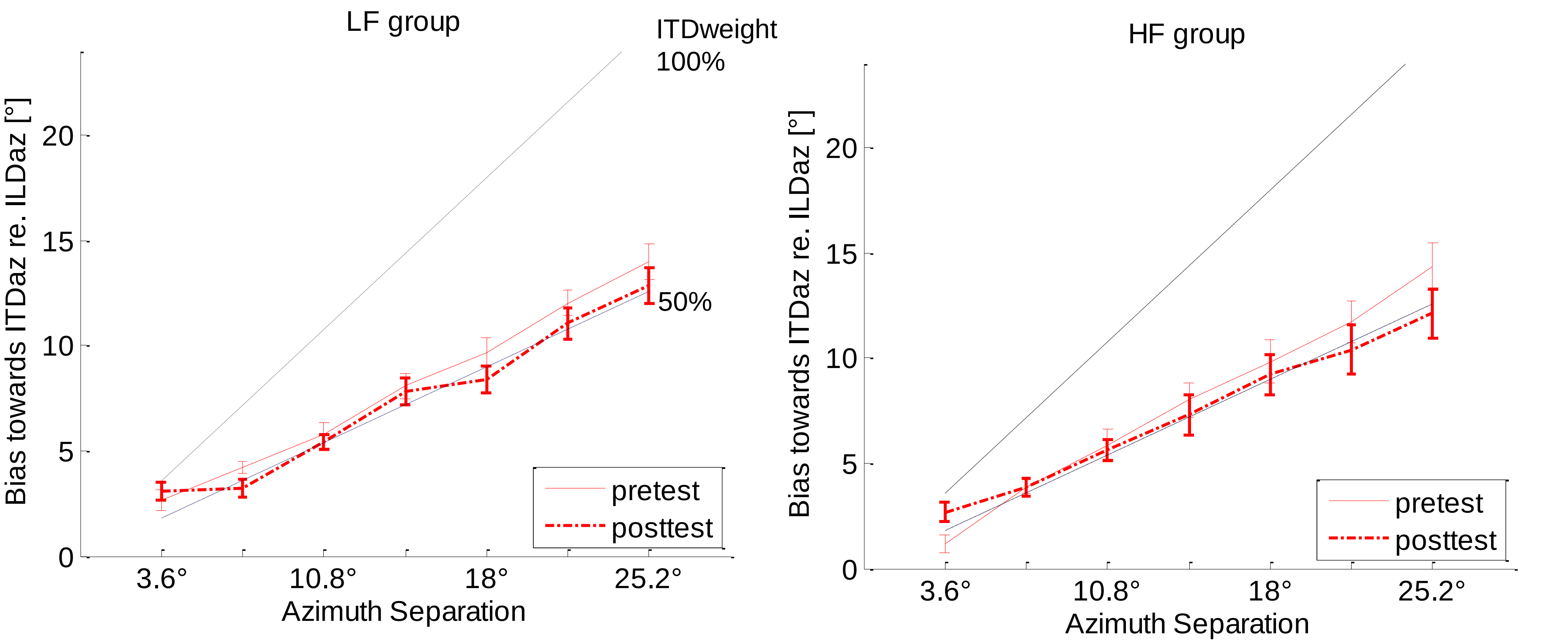


Generalization to Untrained Frequency



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 VR 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.

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 yet 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 (central locations),
- could work if more such locations used

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 suggests ?procedural? effects (potentially masking re-weighting effects)
- testing on LF stimuli might be more effective (based on the 2.8kHz generalization results).

Overall, in NH listeners, effects are more robust for ILD/HF increase. Good news or bad news for CI listeners (for which ITD weighting needs to increase)?

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