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Plasticity in Spatial Hearing: Re-Weighting of Binaural Auditory Localization Cues Based on Visual Feedback

30.01.2018, AABBA Meeting, Vienna

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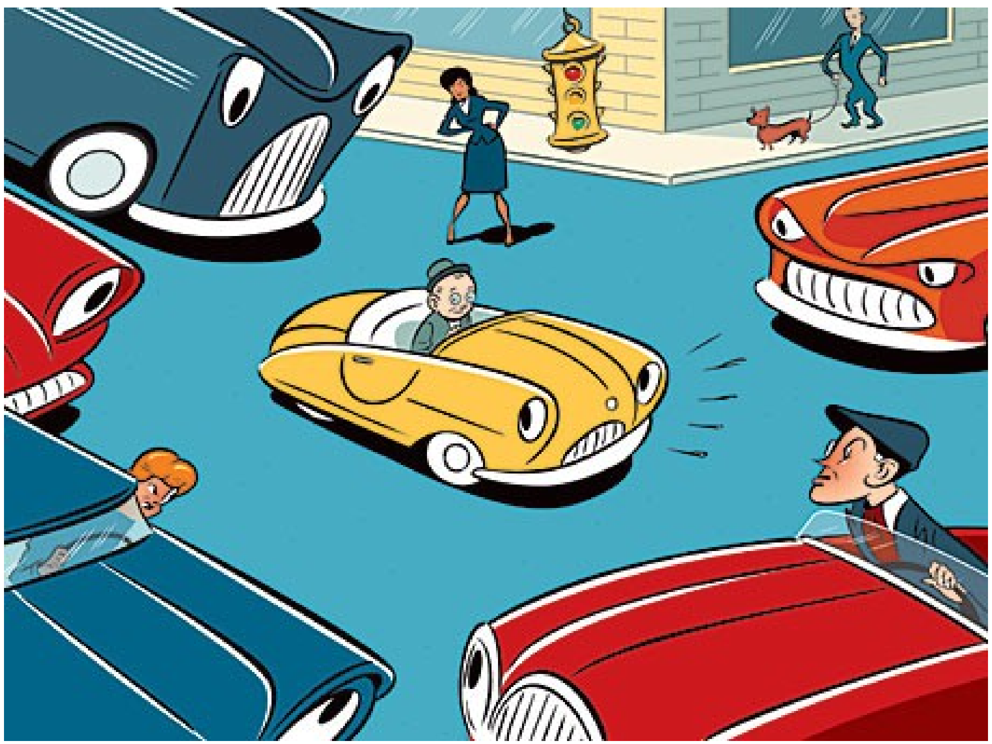
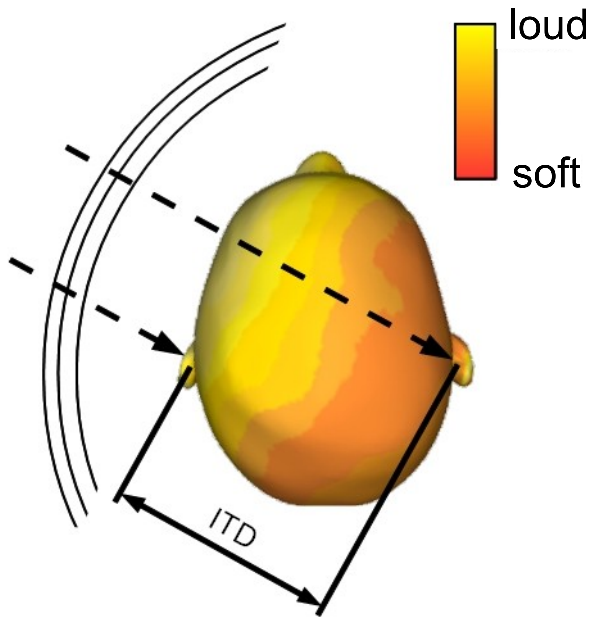
Spatial Hearing

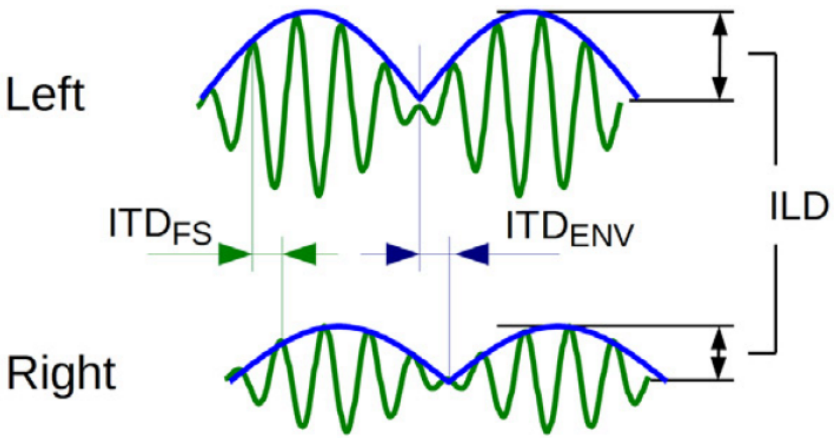
Sound Source Localization



Selective Attention to Sound Sources of Interest

Main Cues for Azimuthal Sound Localization





Interaural level difference (ILD)

Interaural time difference (ITD):

- Fine-structure-ITD (ITD_{FS})
- Envelope (ITD_{ENV})

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)

Examples of Binaural Cue Plasticity

- 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 after effect)* (Recanzone, 1998)
- Listeners adapt to new mapping of binaural cues to visual locations within one week (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)
  - Random carrier (pulse) ITD
- 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

General (Normal-Hearing) Hypothesis

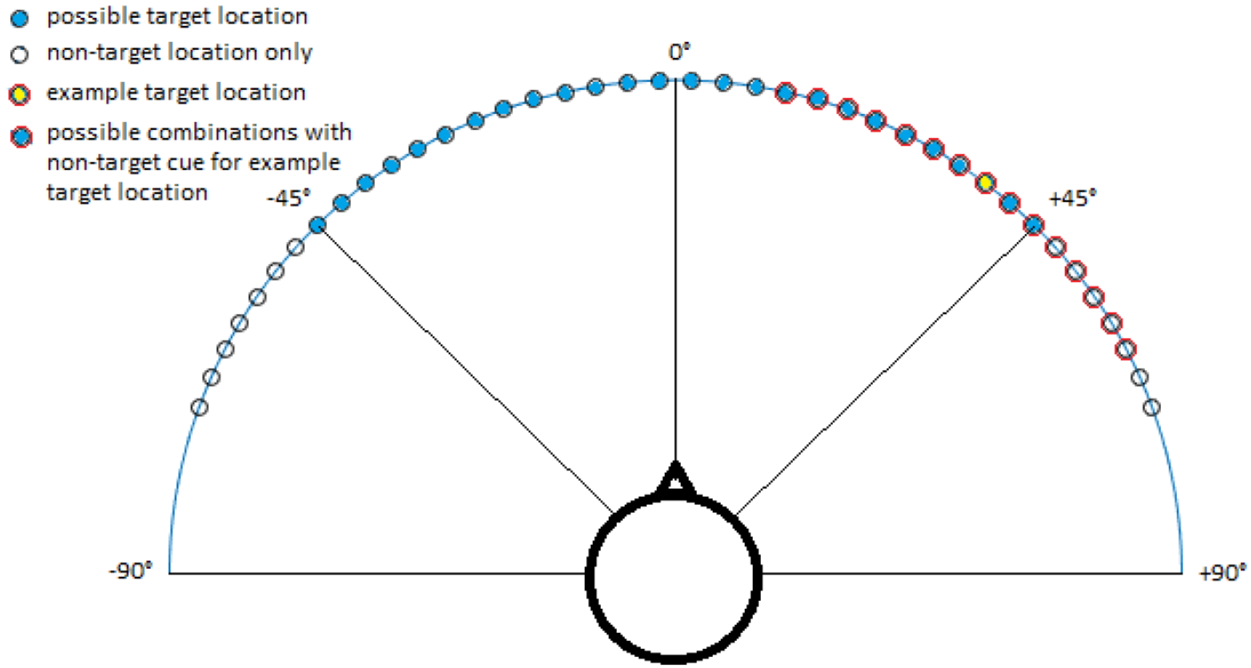
- Perceptual training using stimuli with *inconsistent* binaural cues - reinforcing one binaural cue but not the other cue - increases perceptual weight of reinforced cue
- Lack of re-weighting in Jeffress and McFadden (1971) due to the “abstractness” of their training scheme

General Approach

- 20 normal-hearing listeners
- Presentation of auditory stimuli with inconsistent binaural cues and visual stimuli
- Two test groups:
  - *ITD target* group: visual stimulus consistent with (reinforces) ITD cues (n=10)
  - *ILD target* group: visual stimulus consistent with ILD cues (n=10)
- Seven-day multisensory learning phase involving:
  - Visual feedback
  - Active sensorimotor feedback
- Minimizing conscious (strategic) learning:
  - Many spatial positions
  - Symmetric binaural cue inconsistencies
  - Limited cue inconsistencies to avoid perception of double images

Stimuli

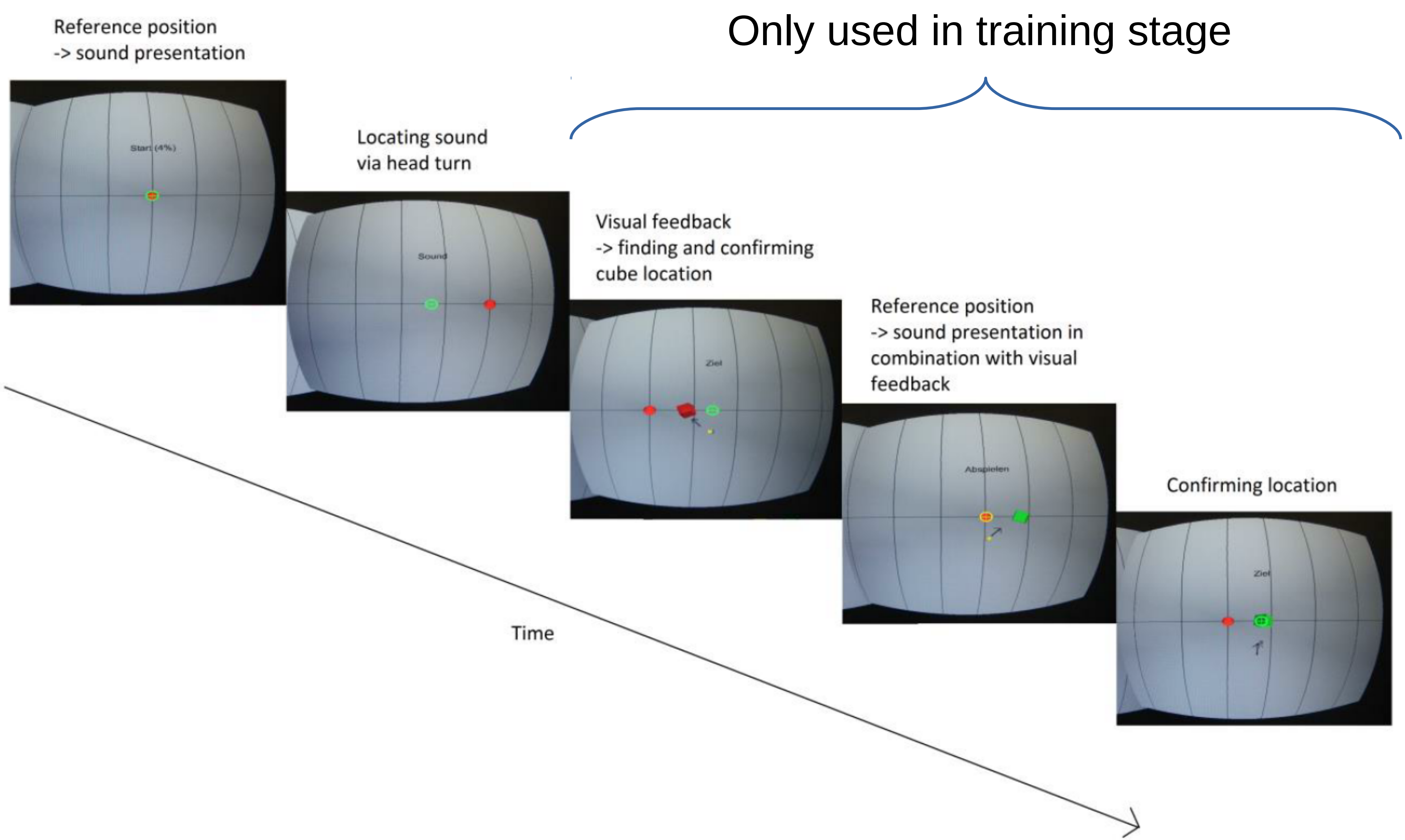
- Bandpass-filtered noise (1 octave, centered at 2.8 kHz)
  - Provides salient ILD and ITD cues
- 26 target locations between -45° (left) and +45° (right)
  - ILD and ITDs derived from *Kemar* HRTFs (Xie, 2013)
  - Covering field of view of visual display (in reference position)
- *Inconsistent* binaural cues: uniformly distributed locations +/- 25.2° around locations of *consistent* cues



Set-up

- Auditory stimuli:
  - Presented via headphones
- Visual stimuli:
  - Virtual environment presented via head-mounted display (*Oculus rift*)
  - Rendered in real-time in horizontal dimension
- Response:
  - Subjects indicate perceived source position by head turn

Procedure

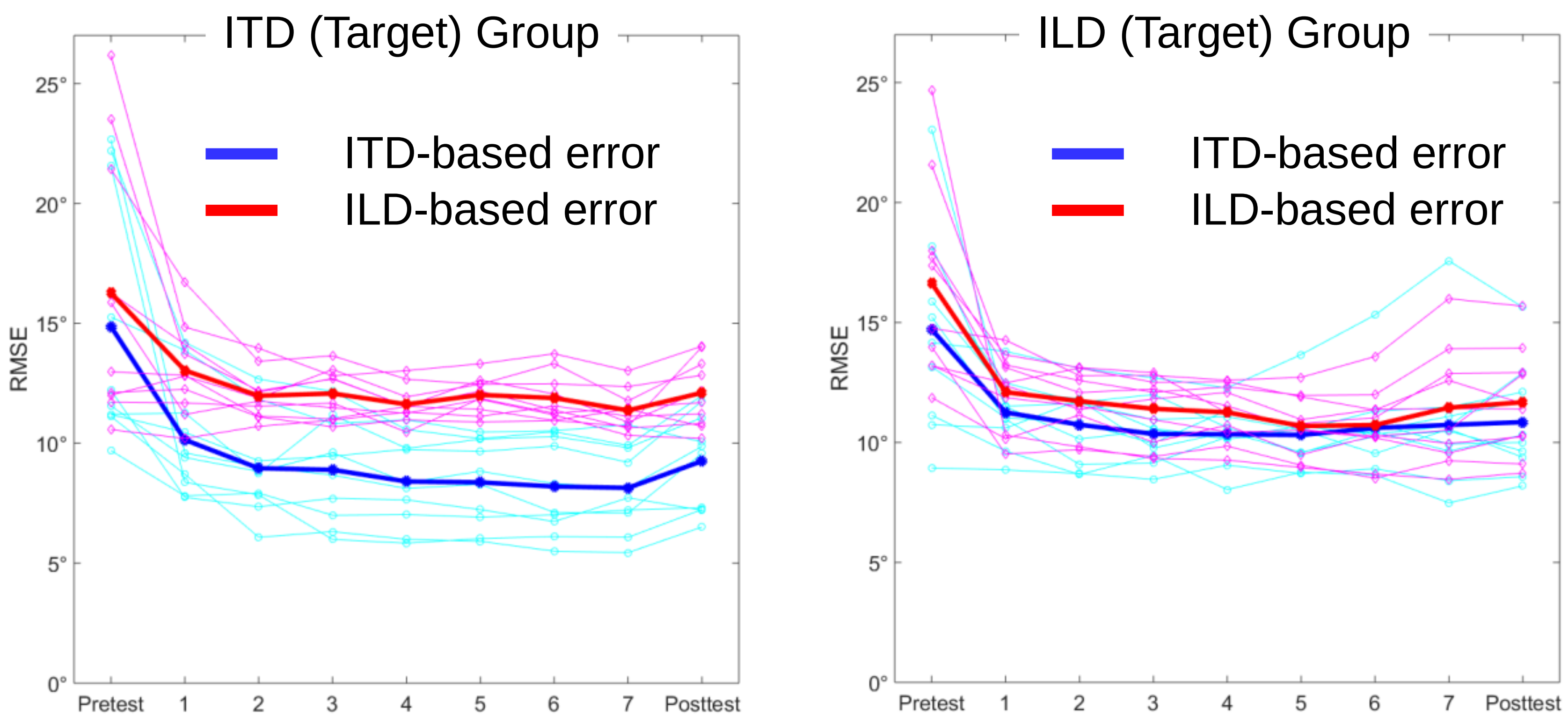

Only used in training stage
Reference position
-> sound presentation
Start (4%)
Locating sound
via head turn
Sound
Visual feedback
-> finding and confirming
cube location
Ziel
Reference position
-> sound presentation in
combination with visual
feedback
Abspielen
Confirming location
Ziel
Time

Stages

- Lateralization pre-training:
  - Procedural learning using consistent ITD/ILD combinations only
  - Visual & proprioceptive feedback (due to head turn)
- Pretest:
  - 446 items (26 target positions x 15 non-target cues)
  - No feedback
  - Identical for both groups
- Training
  - Seven days within two weeks
  - Visual & proprioceptive feedback according to target cue in each group
- Posttest:
  - Identical to pretest

Overall RMS Errors:

Larger Improvement for *consistent* cue



- Reduction of RMS error, mainly within first training session
- Improvement larger for *consistent* (visually reinforced) binaural cue:
  - Significant interaction between time (pre- vs. posttest) and cue type (ITD vs ILD) in both groups ($p \leq .034$)
- Indication for re-weighting, but RMS error may include procedural learning effects

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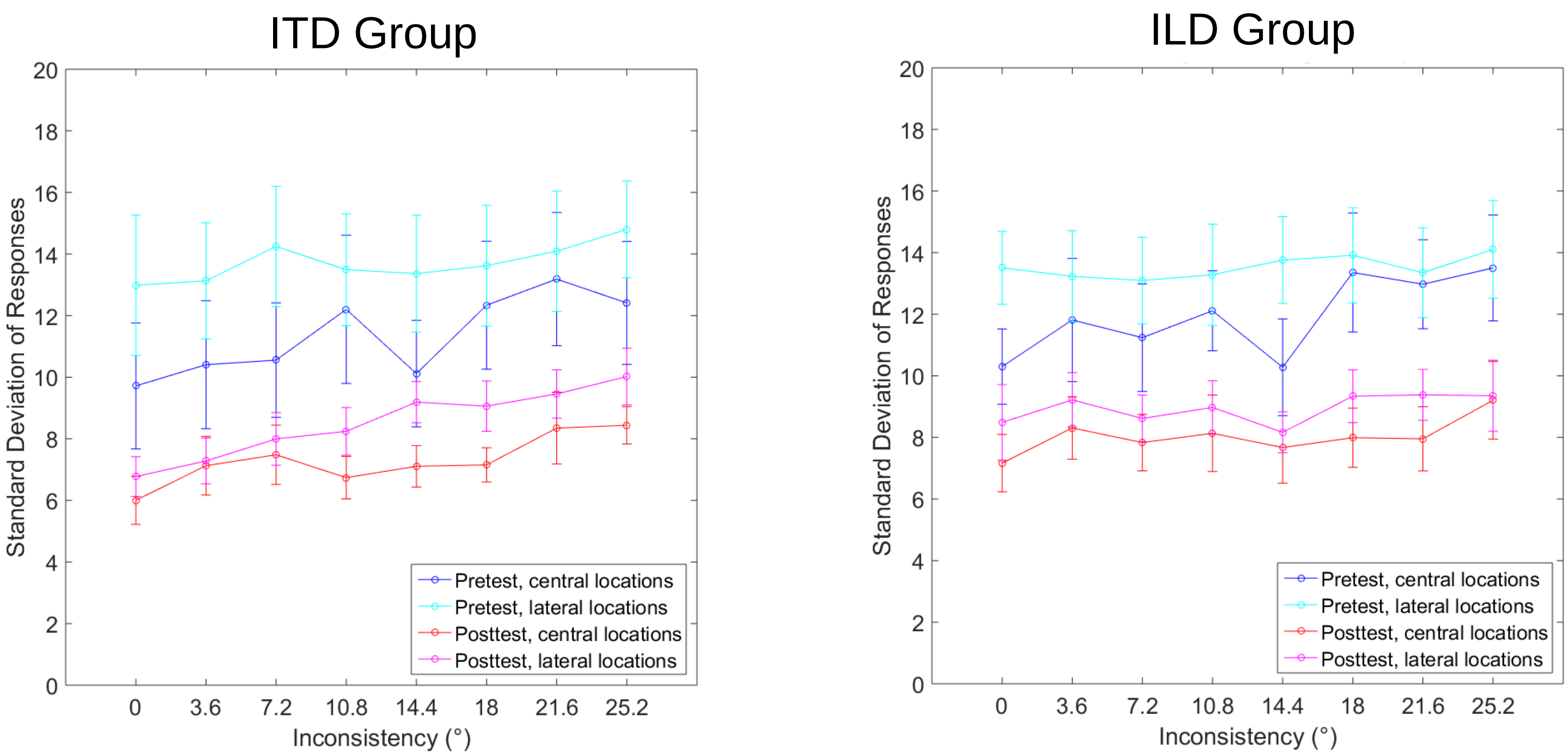
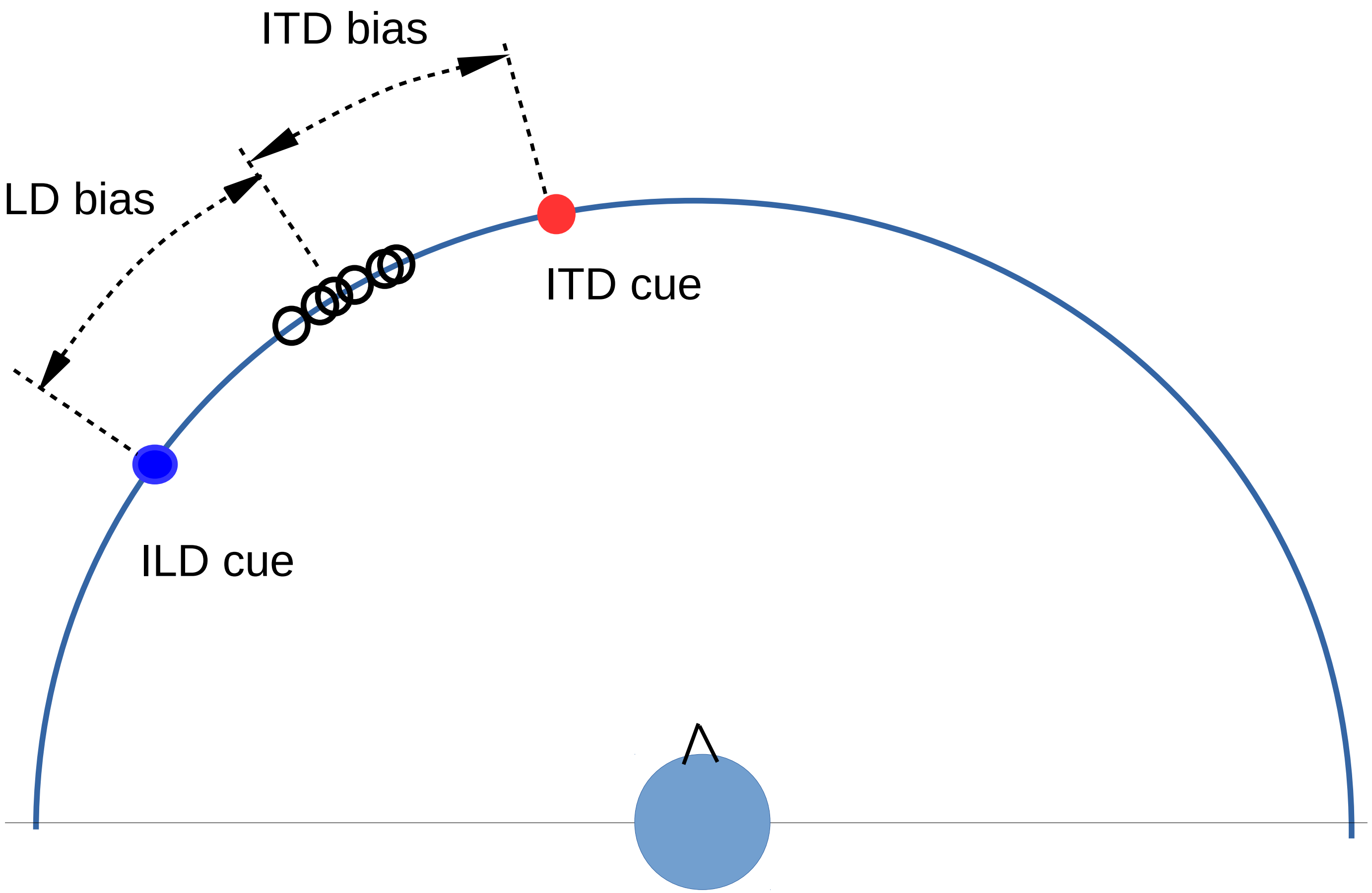
Response Variability as Function of Binaural Cue Inconsistency



- Significant decrease of variability from pre- to post-test ($p < .001$)
  → Procedural learning
- Significant increase of variability with increasing inconsistency ($p < .001$)
  → Auditory image widening
- Trend for larger variability for more lateral positions ($p = .068$)
  → Consistent with localization literature

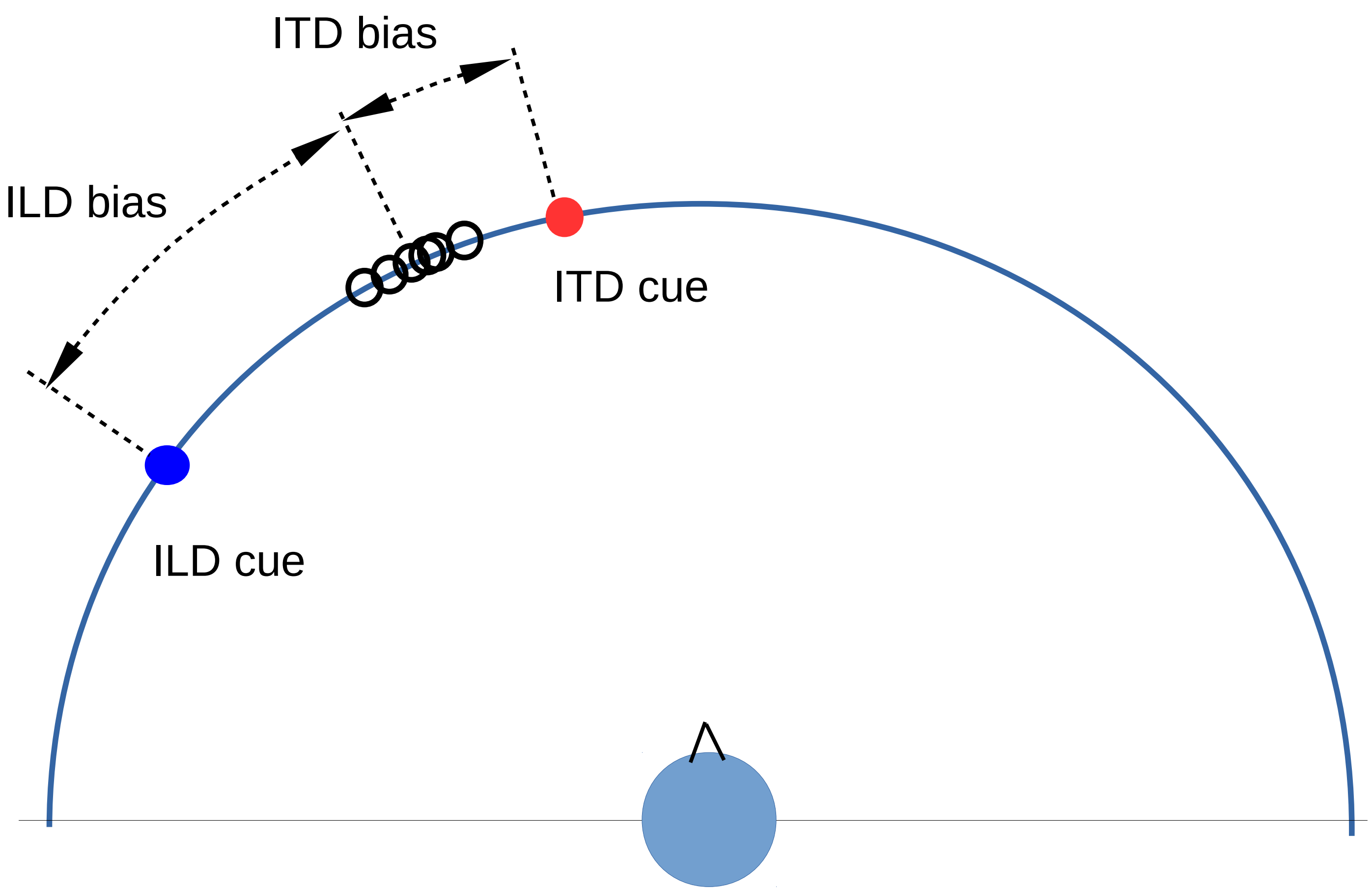
Response Bias

- Not susceptible to procedural learning effects!



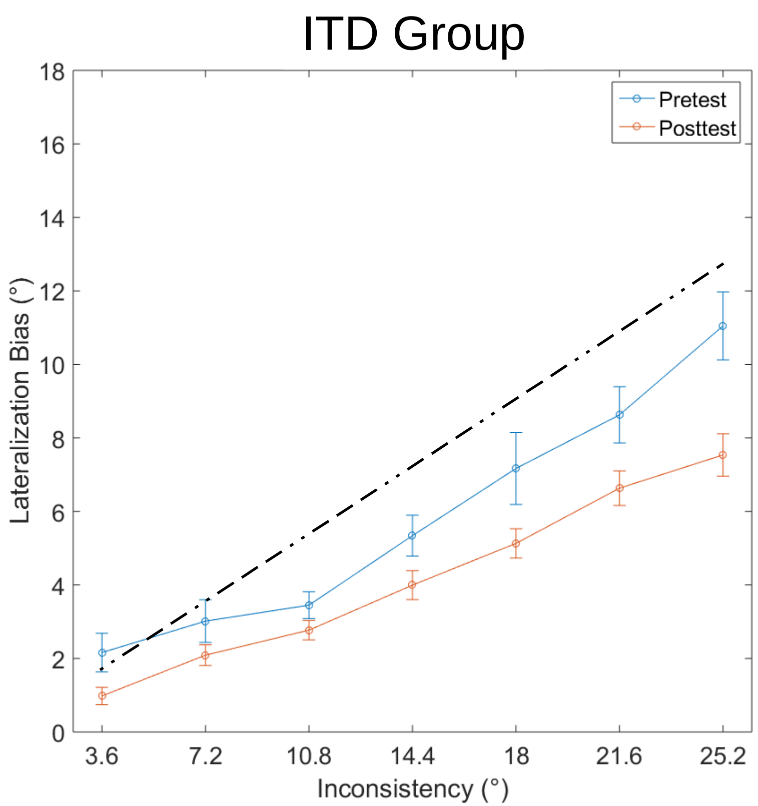
Response Bias

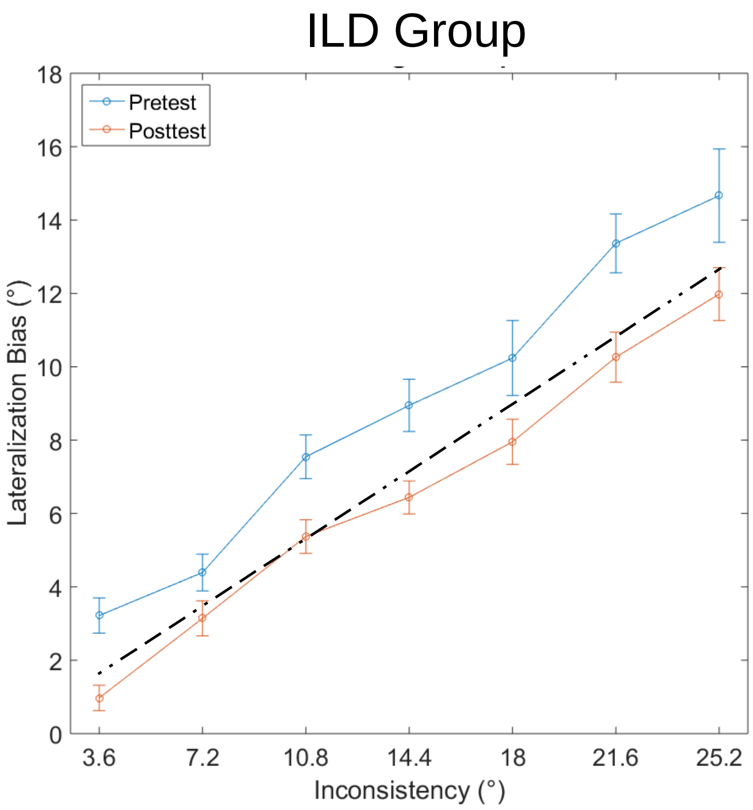
- Reduction of consistent-cue bias (in this case ITD)



Bias as Function of Binaural Cue Inconsistency:

Mean across all azimuths < 45°

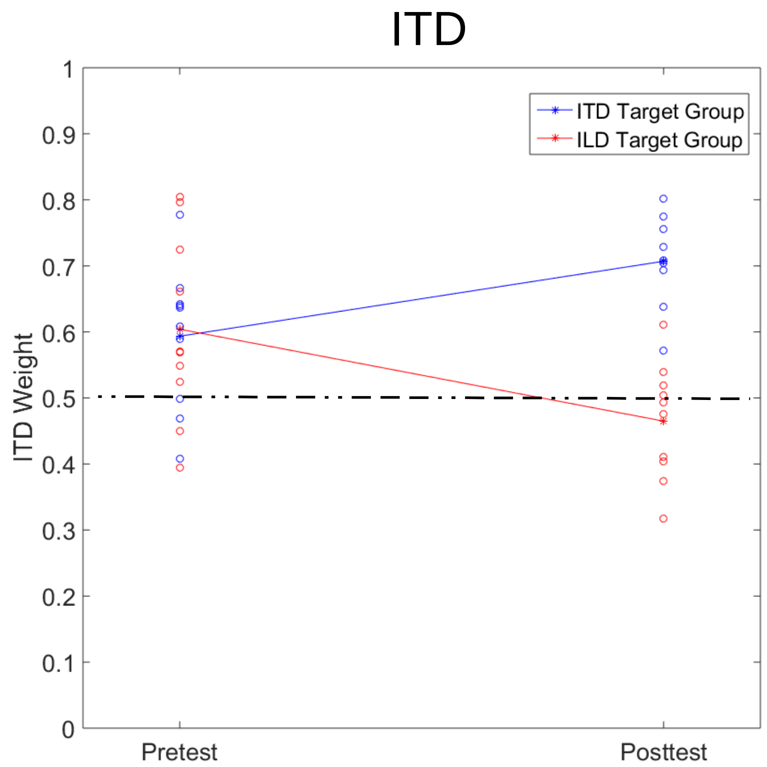


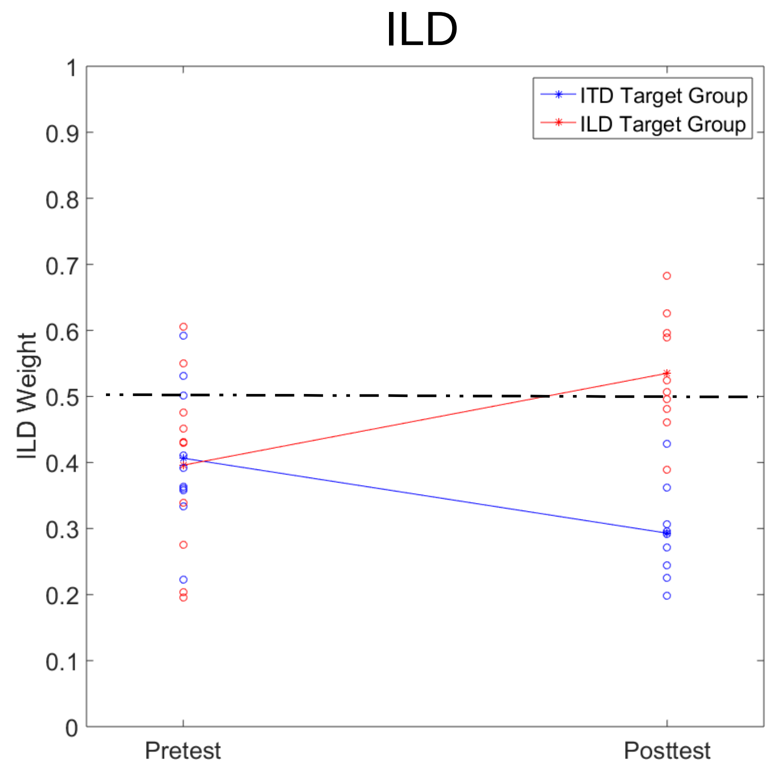


- Re-weighting in both groups: target-cue bias decreases significantly from pre- to post-test ($p \leq .010$)
- Amount of re-weighting proportional to degree of inconsistency

Dimensionless Binaural Cue Weights

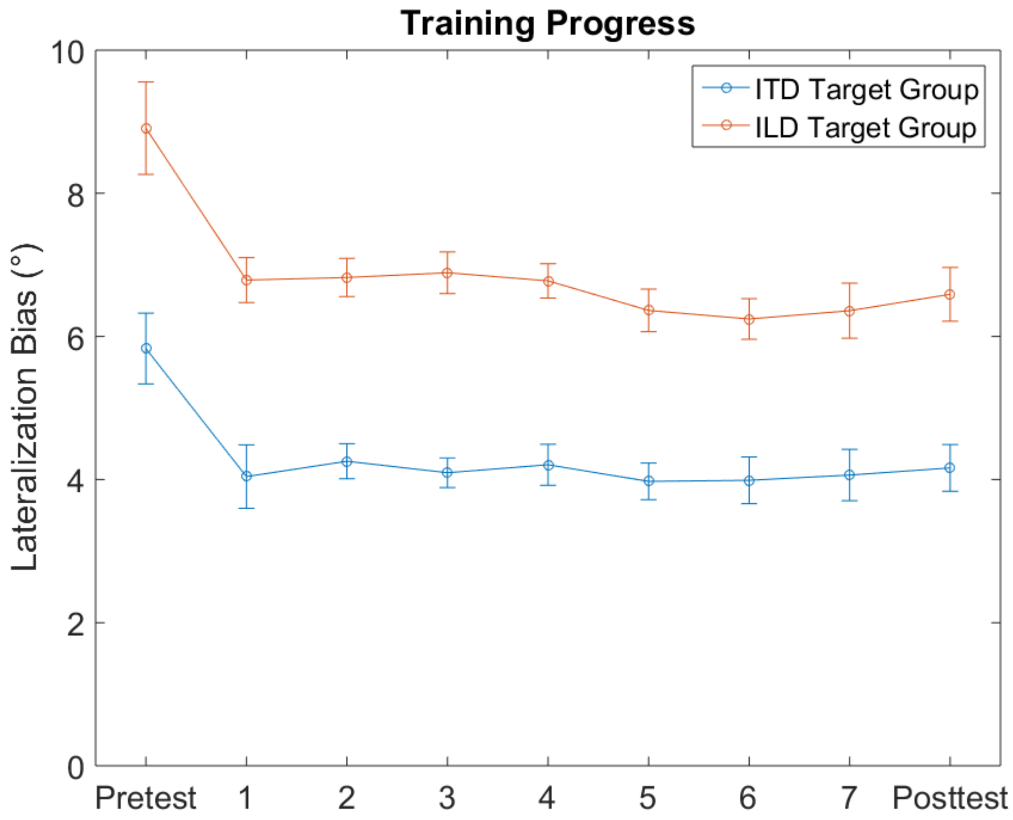
(similar to Macpherson and Middlebrooks, 2002)





- Cue weight: given by slope of linear regression of function “cue bias” vs. “cue inconsistency”
- Pretest: for both groups, ITD is weighted more than ILD
- For both groups, target-cue weight increases significantly from pre- to post-test ($p \leq .020$)

Target-Cue Bias Across Training Sessions



- Training effect mainly within first training session
- Little effect thereafter, particularly for ITD Group

Conclusions

- When confronted with inconsistent binaural cues, NH listeners enhance the perceptual weight of the visually reinforced cue
- Indication for flexible, plausibility-based use of binaural cues
- Re-weighting appears to be relatively fast (within a few hundreds of items)
- Auditory image width appears to slightly increase with cue inconsistency, but:

  … no indication for double images (ITD vs ILD), as sometimes reported in literature

  … this provides no useful information for conscious or strategic re-weighting
- Future steps:
  - Current results are promising for re-weighting ITD cues in CI listeners
  - More realistic (broadband) stimuli
  - Effects of re-weighting on ITD-based spatial release from speech masking
  - Determine neural site of re-weighting

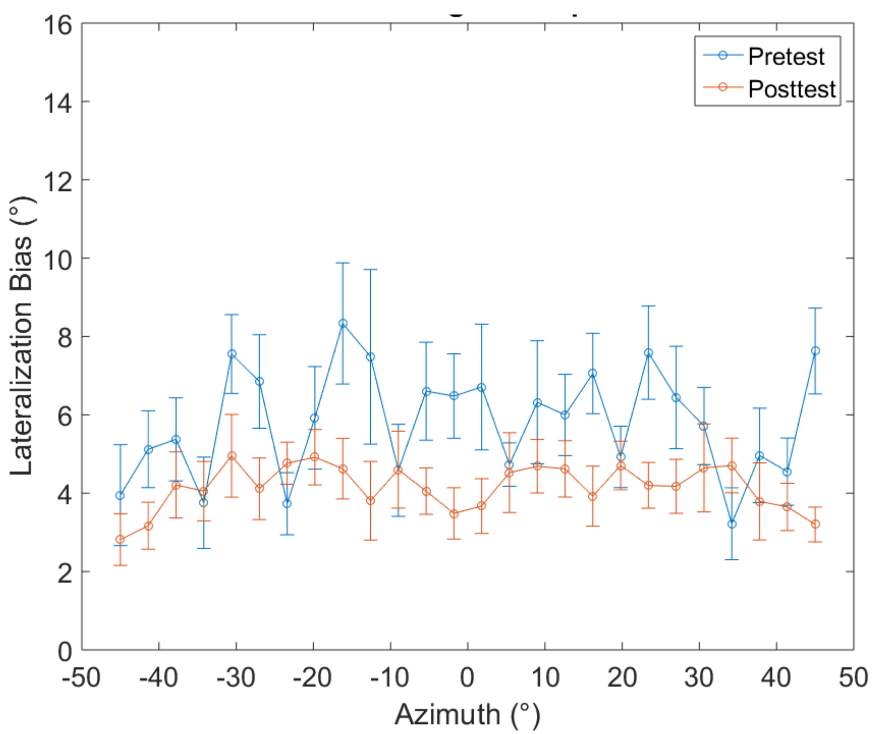
Funding

- OeAD project SpaCI (MULT_DR 11/2017)
- NIH Grant R01 DC 005775

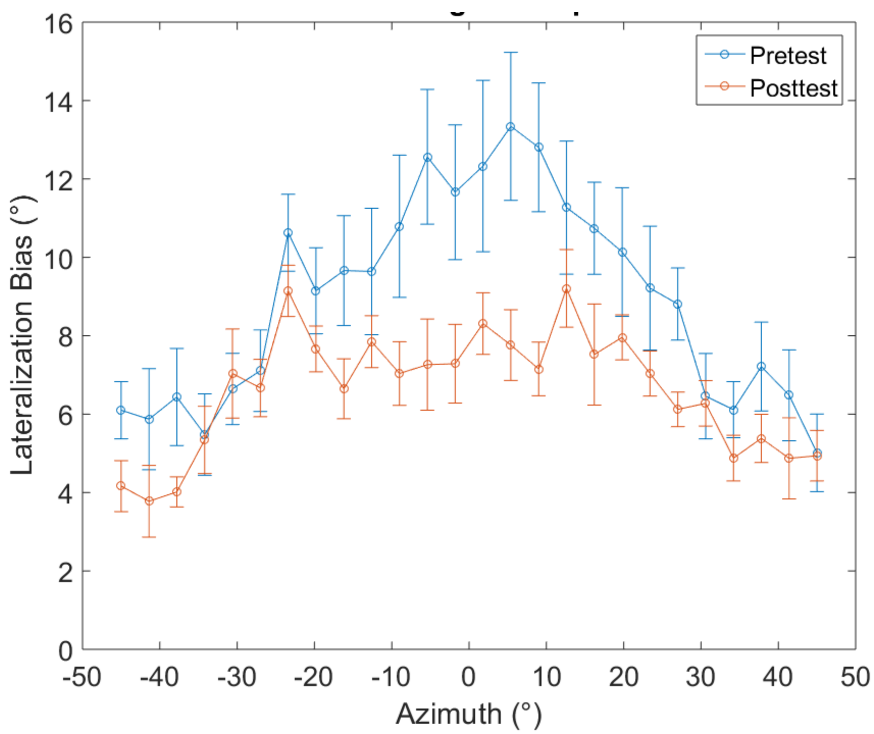
Response Bias as a Function of Target Azimuth

Mean across all binaural-cue inconsistencies > 0°

ITD Group



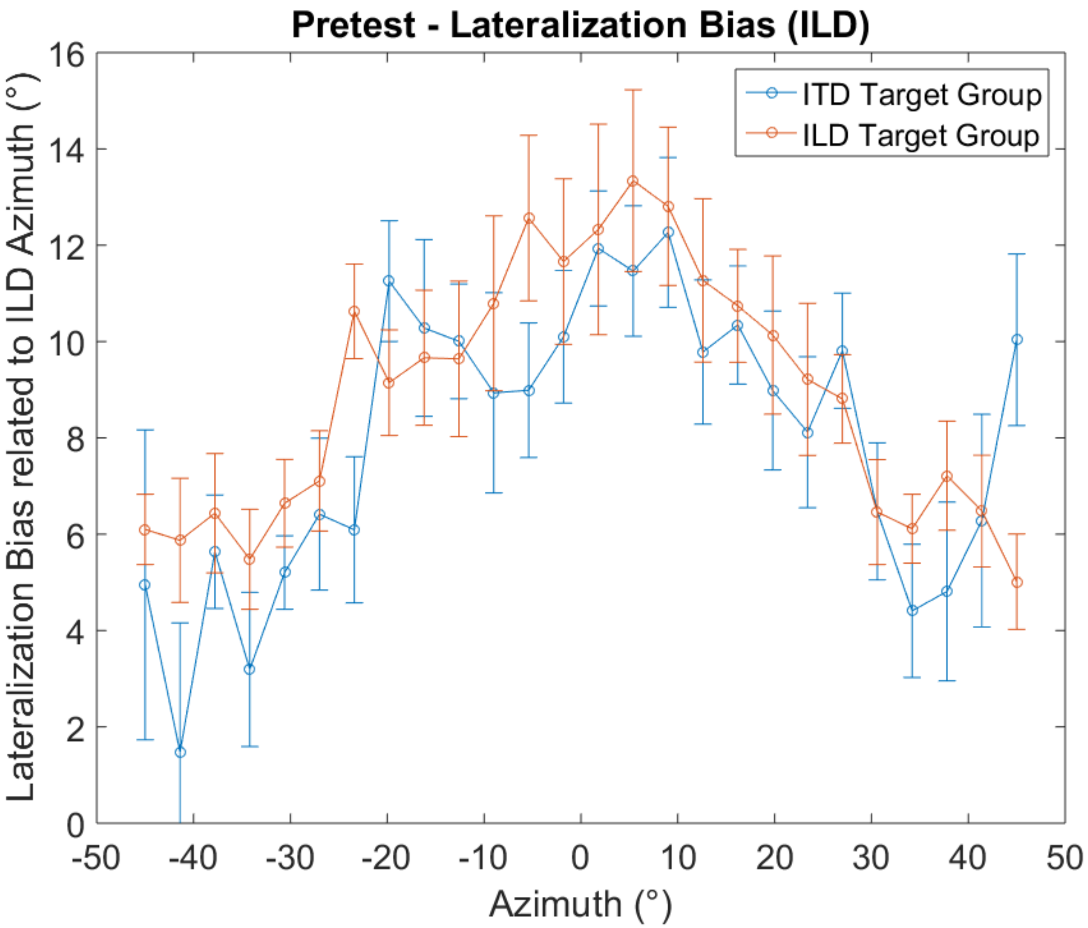
ILD Group



- Target-cue bias decreases significantly from pre- to post-test (ITD target group: $p = .003$; ILD target group: $p = .01$)
- ITD group: no effect of azimuth
- ILD group: significant effect of azimuth ($p = .001$)

BOTH Groups Show ILD-Bias Elevation for Central Azimuths

Mean across all binaural-cue inconsistencies > 0°



- ITD cues more dominant for central positions?