Discrimination Training and Reweighting of Interaural Level vs. Time Difference Cues

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Background

- Normal-hearing (NH) listeners rely on two binaural cues for sound localization in horizontal plane:

- Interaural Time Difference (ITD)
  - results from difference in the travel time from a sound source to the ears.
  - dominant at low frequencies (up to 1.5 kHz).
- Interaural Level Difference (ILD)
  - results from head-shadowing and difference in distance from sources to the two ears.
  - dominant at high frequencies (above 1.5 kHz).

Backgraound

- NH listeners weigh binaural localization cues based on the sound's frequency (Macpherson & Middlebrooks, 2002)
- Other factors influence binaural cue weighting (a.k.a. trading ratio):
  - Overall Level (Deatherage & Hirsh, 1959)
  - Active manipulation of one of the cues / attention (Lang &Buchner, 2008)
  - Room Acoustics (Rakerd &Hartmann, 2010)
- Studies attempting to induce a change in binaural cue weighting produced mixed results:
  - No reweighting effect (Jeffress & McFaddeen, 1971)
  - ILD weights increased, but ITD weights did not (Kumpik et al, 2019)
  - Reweighting induced in both directions, using AV training in virtual environment (Klingle et all, 2021)

Aim

Propose a simpler training protocol to induce reweighting without requiring sophisticated AV/VR equipment (e.g., that could be run as a cell-phone-based training game):

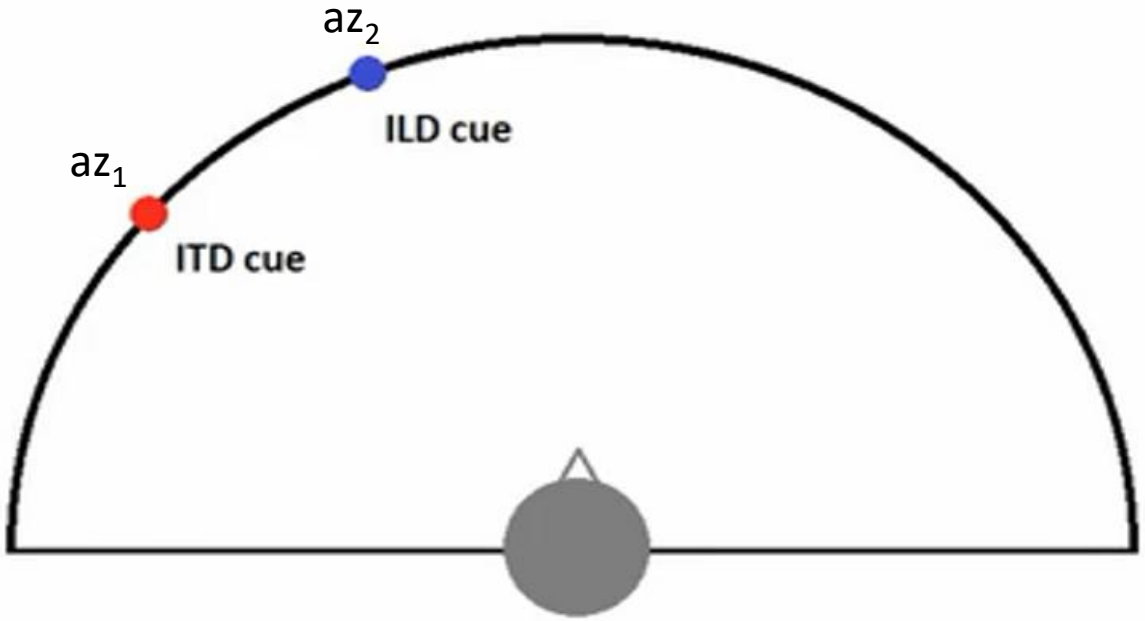
Adaptive training using left/right discrimination task with feedback.

Methods

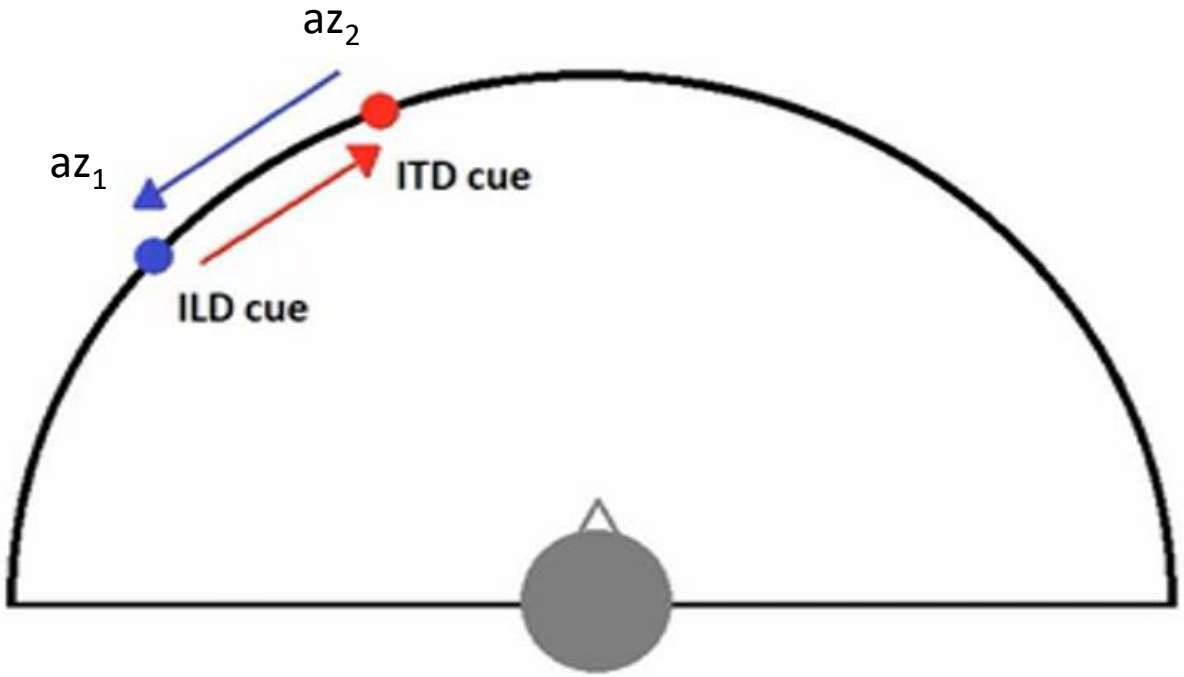
- Three groups:
  - ILD group (n = 11): Feedback congruent with ILDs (Klingel et al., 2020)
  - ITD group (n = 14): Feedback congruent with ITDs
  - Control group (n = 11): no training (Klingel et al., 2020)
- Auditory stimuli:
  - Narrow-band noise bursts (2-4 kHz) presented over headphones
  - Incongruent combinations of ITDs and ILDs
  - Catch trials with congruent cues, to monitor participants' performance
- Experiment performed on 3 consecutive days:
  - Day1: Pretest (all groups) + 1st training session (training groups only)
  - Day 2: 2nd training session (training groups only)
  - Day 3: 3rd training session (training groups only) + Posttest (all groups)
- Two-interval, 2AFC left/right discrimination task
  - Pre/Posttest: Constant Stimuli
  - Training: 2-down-1-up adaptive staircase procedure

One trial – Pre/Posttest weight estimation

1st stimulus

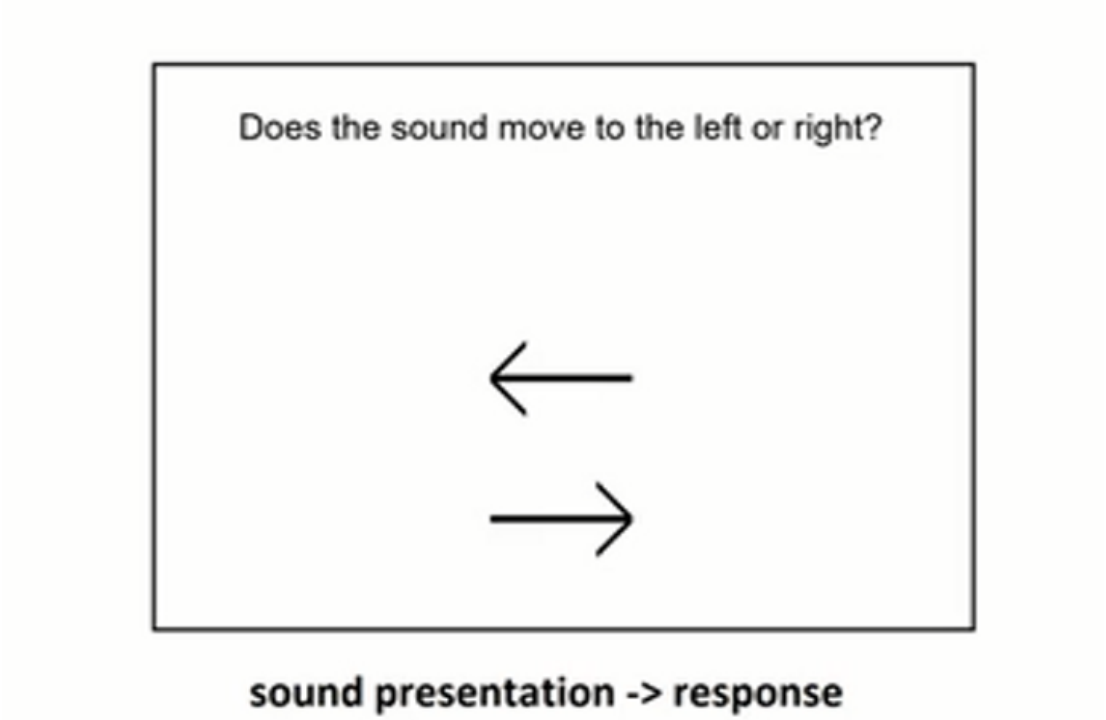


2nd stimulus



az_1 and az_2 varied from -70 to 70°, az disparity of up to 25.2°.

One trial – Pre/Posttest

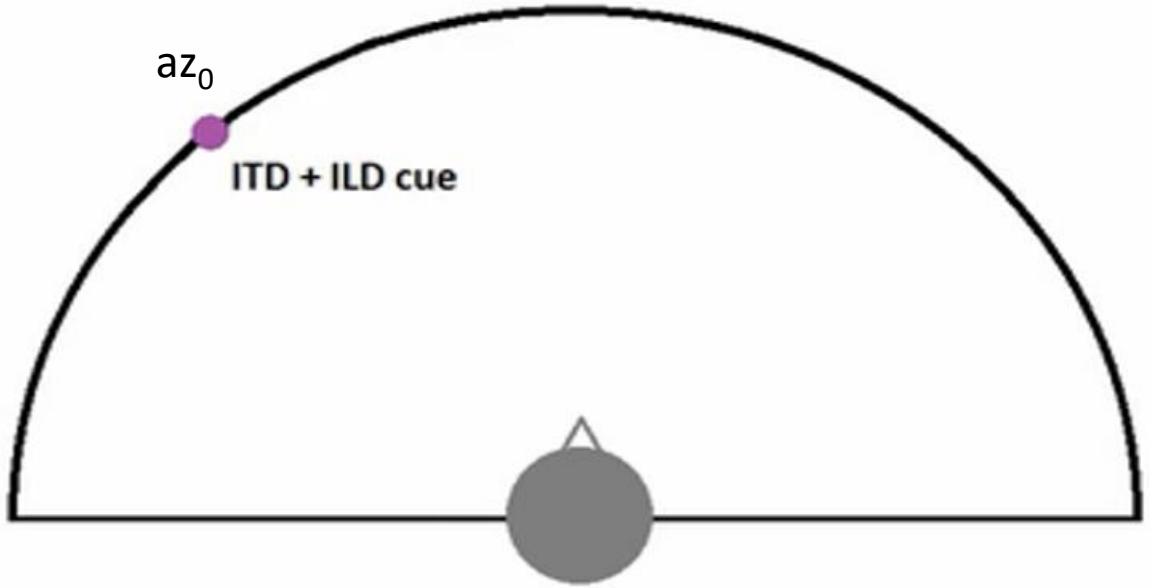


sound presentation -> response

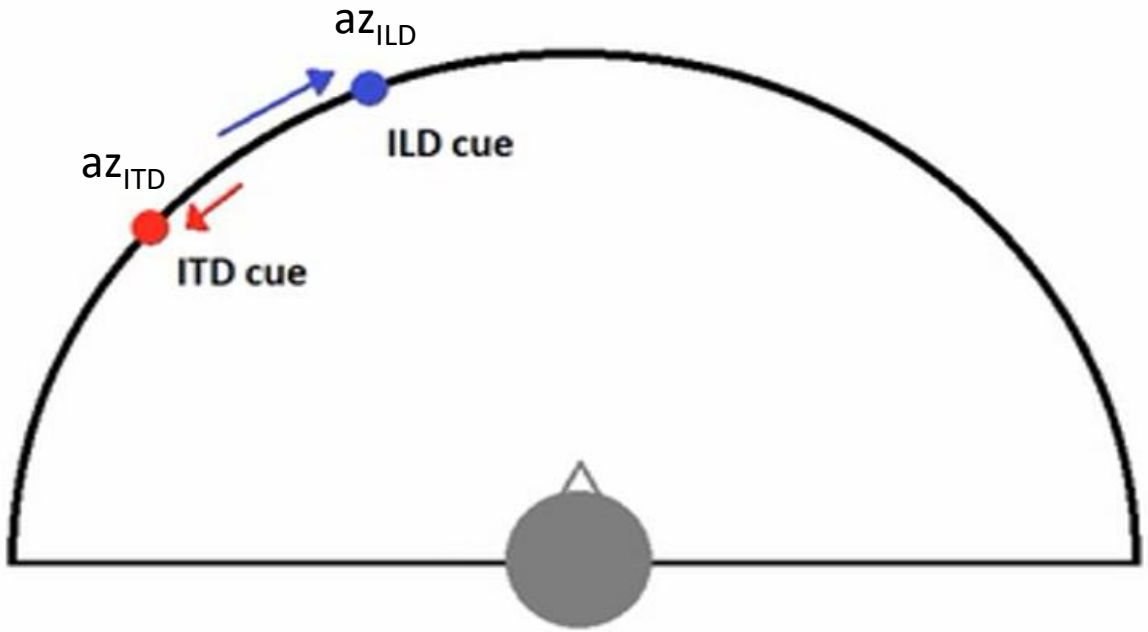
ILD weight estimated as proportion of trials in which responses were consistent with ILD motion direction ($w_{ITD} = 1 - w_{ILD}$).

One trial - Training

1st stimulus



2nd stimulus

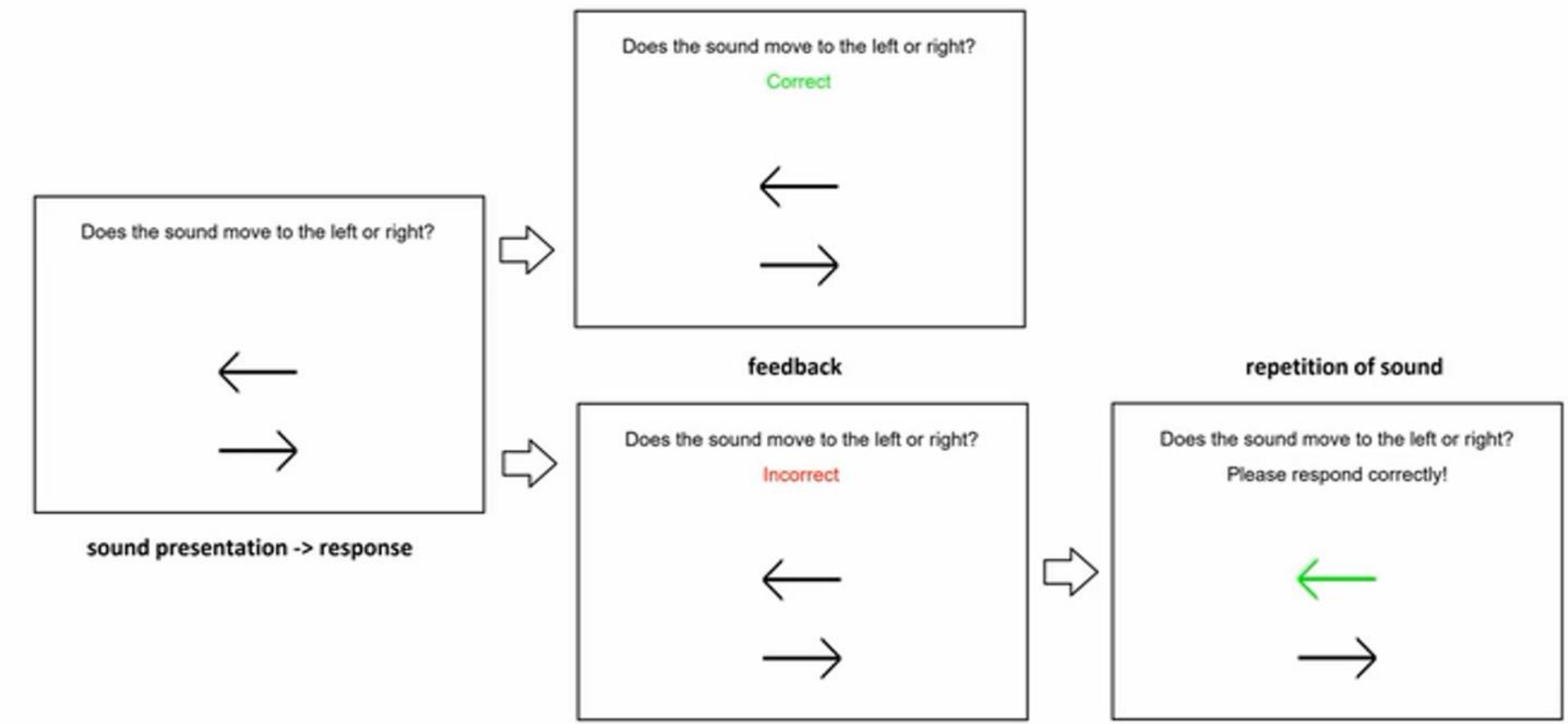


Az of trained cue (eg az_{ITD}) varied adaptively.

az_{ILD}-az_{ITD} constant in adaptive track.

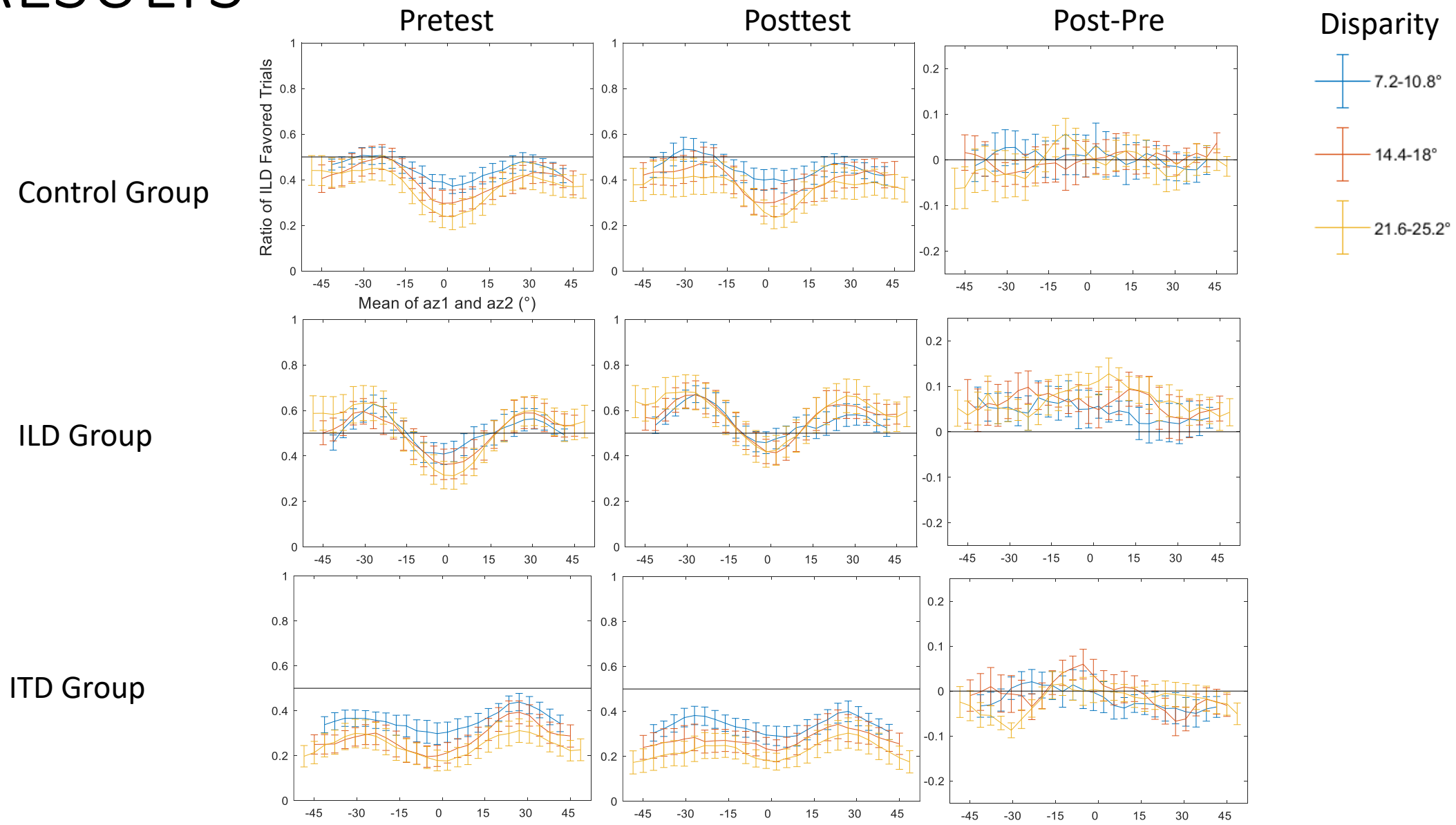
3 adaptive tracks run in parallel (with az_{ILD}-az_{ITD} of 18, 21.6 and 25.2°)

One trial - Training



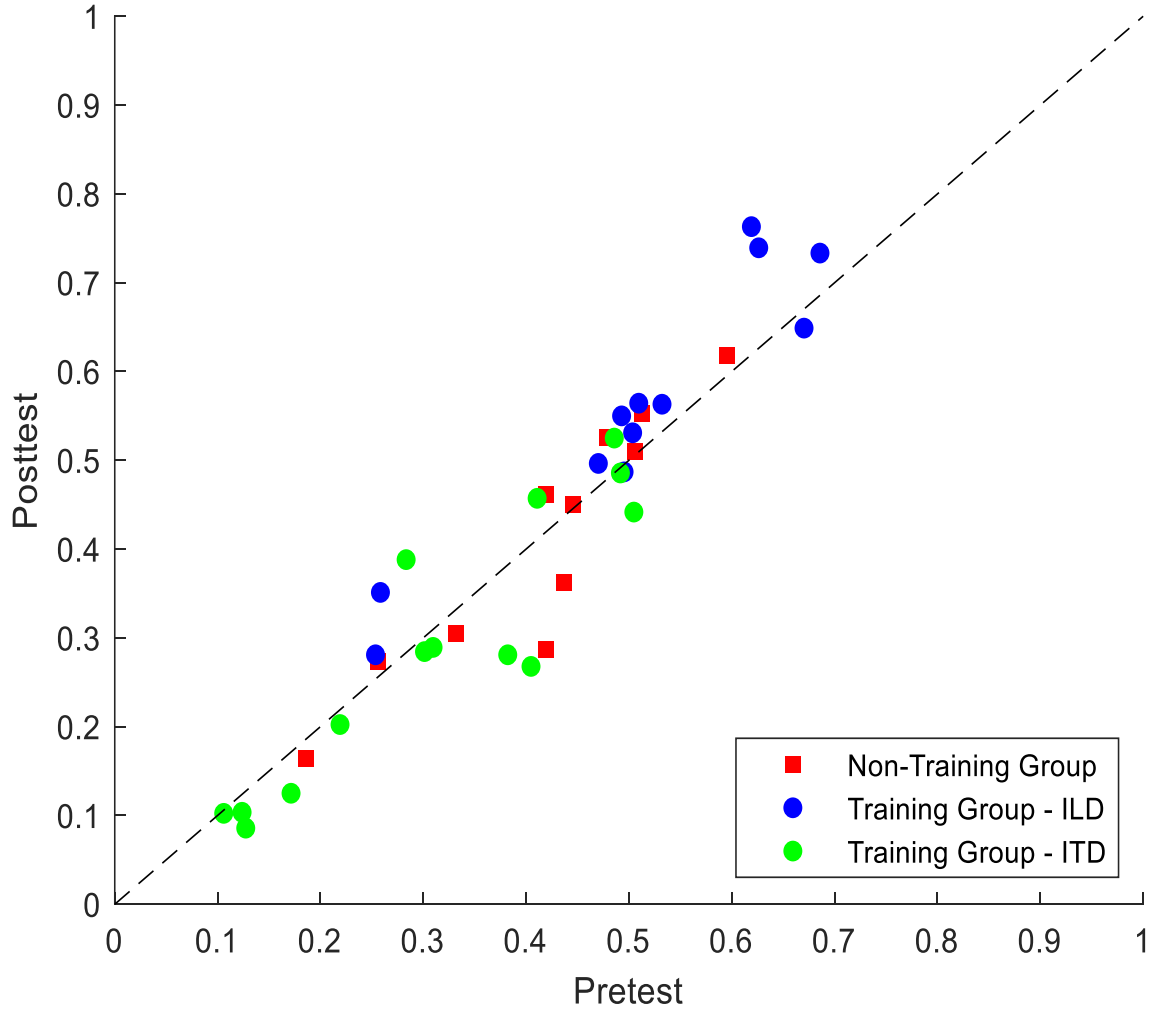
On incorrect trial, subject asked to listen to sound again and imagine the sound moving in correct direction and respond accordingly.

RESULTS



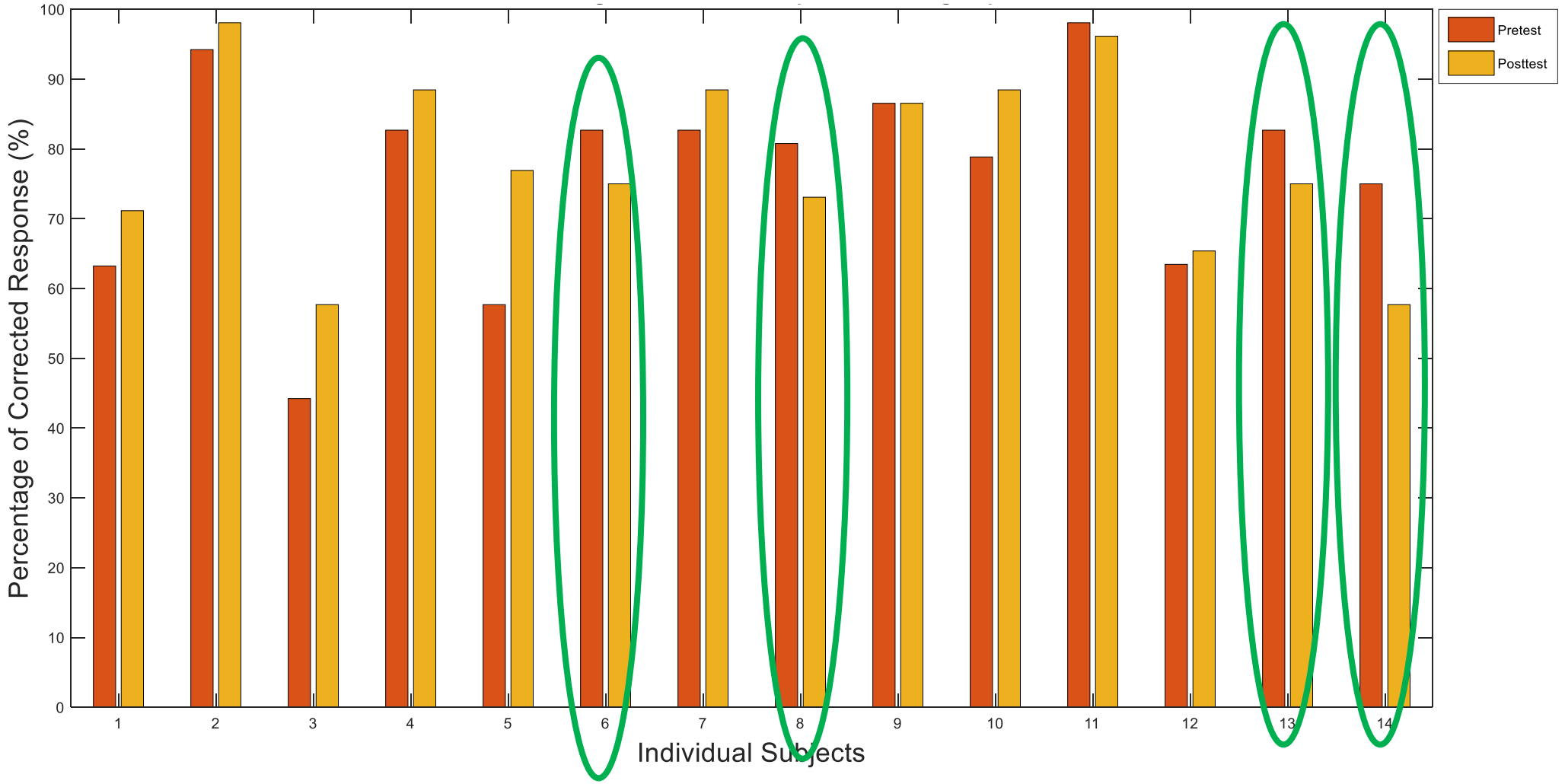
Training works for ILD group, but appears not to work for ITD group

RESULTS: individual ILD weights in pre/posttest



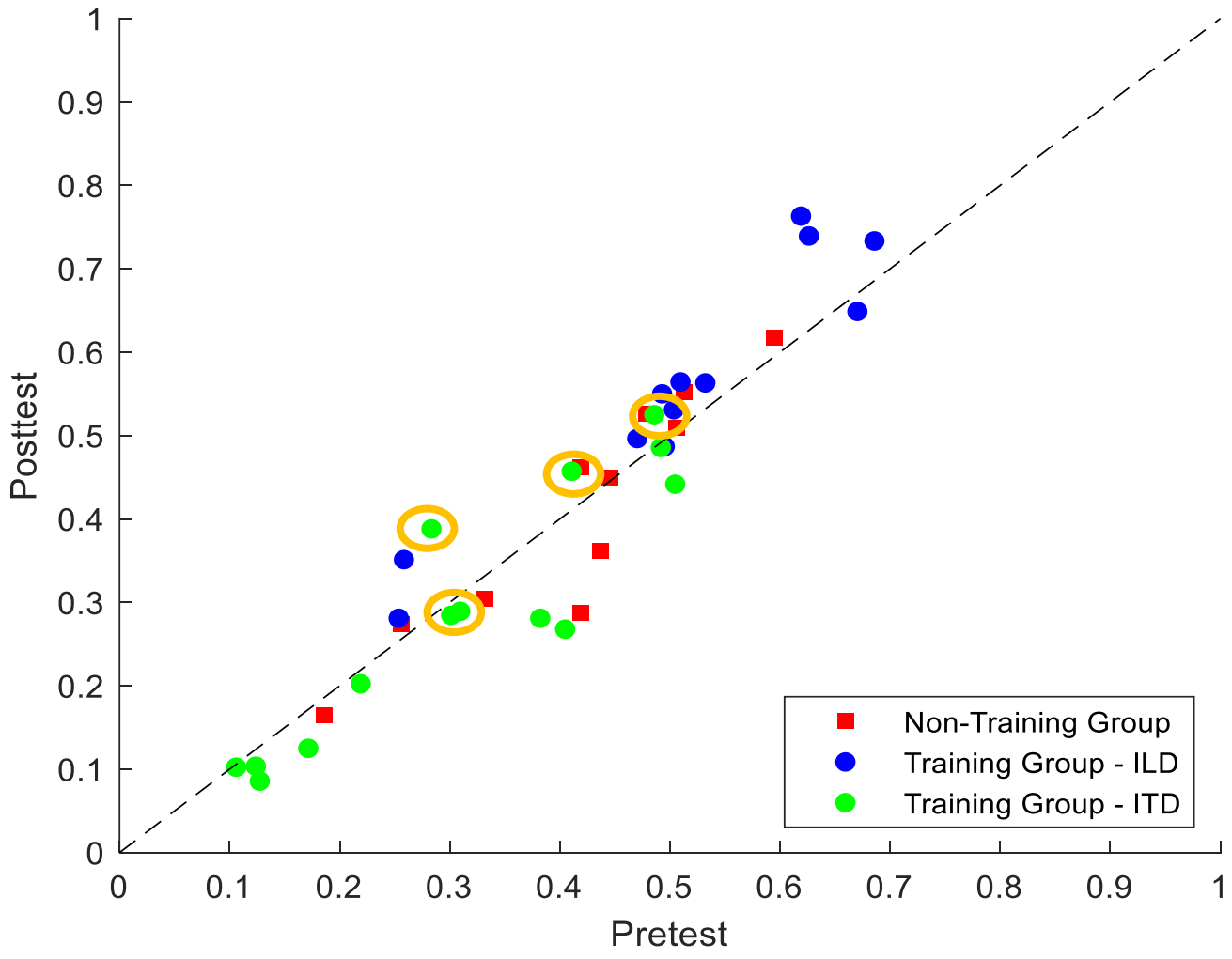
In ITD group, 3 subjects changed their weights in direction opposite to training.

RESULTS: ITD Group Performance on Catch Trials



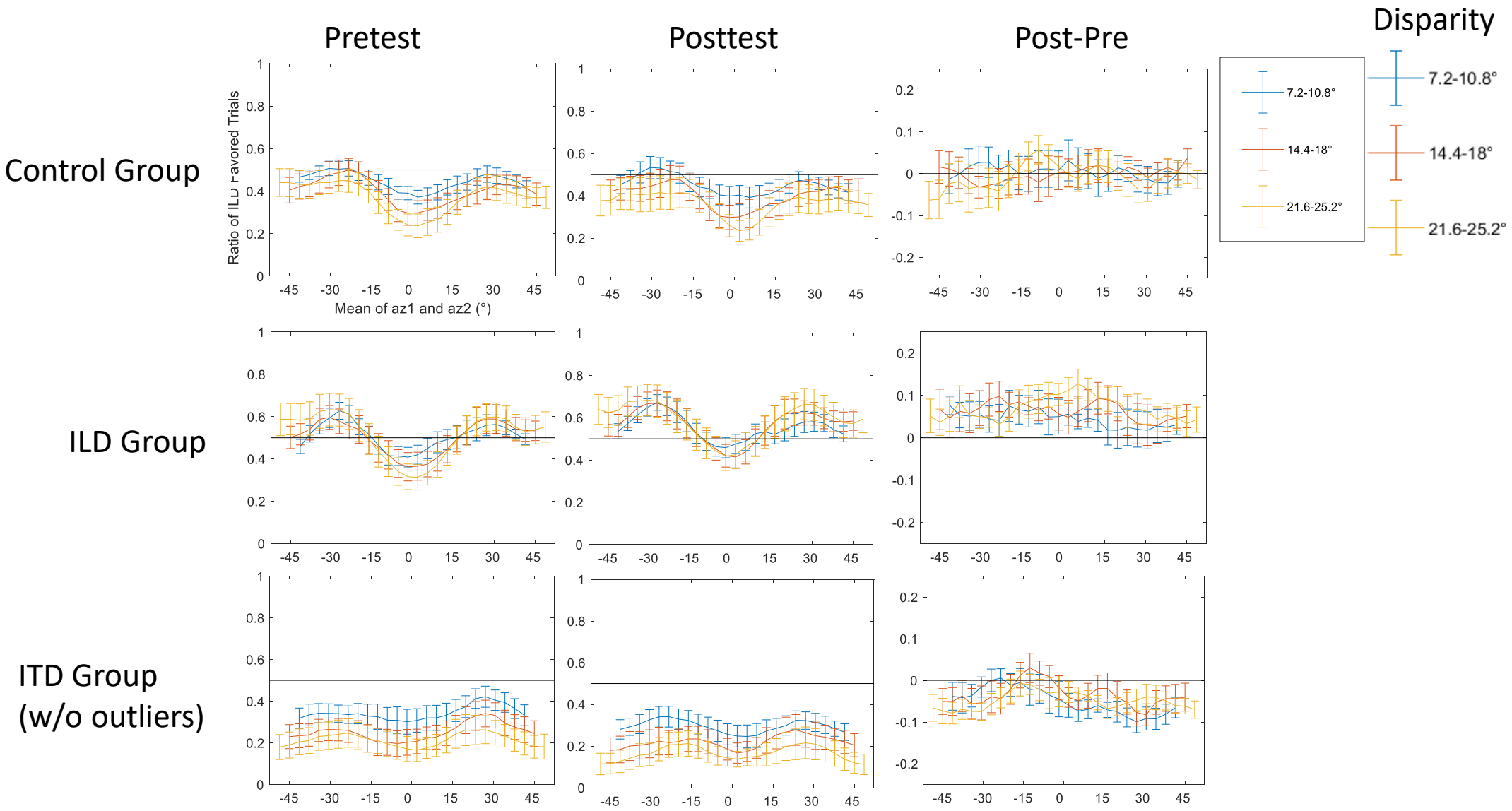
All but 4 subjects improved catch-trial performance form pre to posttest.

RESULTS: individual ILD weights in pre/posttest



When catch-trial outliers excluded, training works for ITD group.

RESULTS w/o ITD outliers



When catch-trial outliers excluded, training works for ITD group.

Summary and future directions

- Responses followed the ILD azimuth significantly more often in the posttest than in the pretest for the ILD training group (Klingel et al., 2020).
- After removing outliers, the training effect also observed for ITD group.
- **Binaural reweighting can be induced in both directions by simple adaptive discrimination training without visual signals.**
- **Training not expected to result in compression of space as in visually guided training (Klingel et al., 2021)**
- **Training individualized (visually-guided training was not).**

- While the weight estimates varied with target azimuth and spatial disparity, the weight change was approximately independent of these spatial factors.
- Next step: Investigate why weighting changes with azimuth using a decision theory model which provides a weight estimate independent of disparity.
- Integrate into existing auditory brain training game “Listen” (from UCR Brain Game Center).
- Test whether training works for HI subjects (e.g., ITD training for CI users).

Modeling the reference frame of the ventriloquism aftereffect

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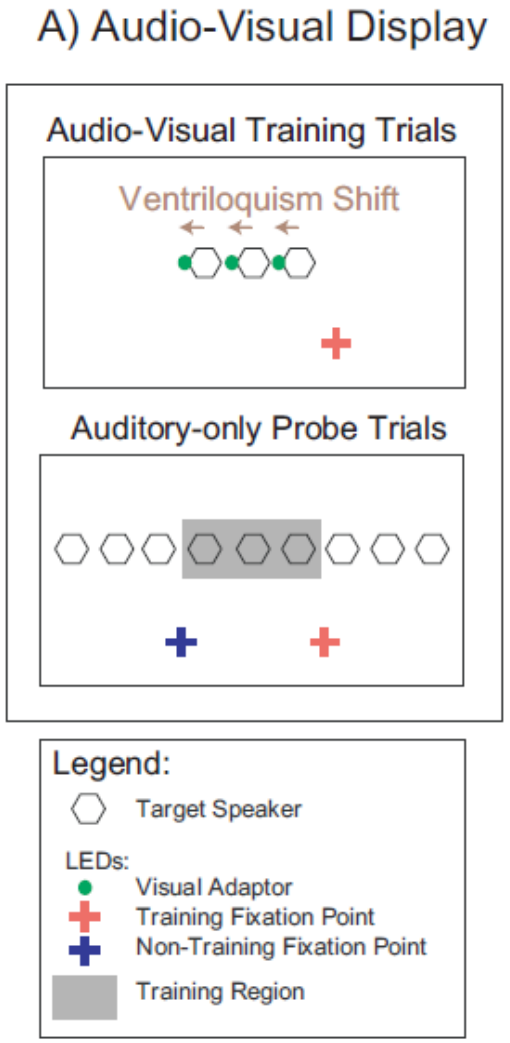
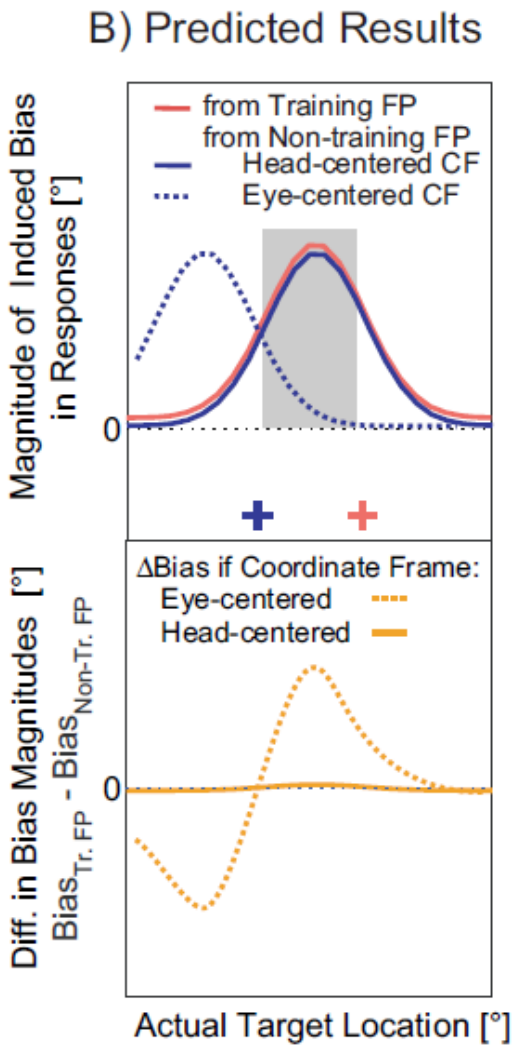
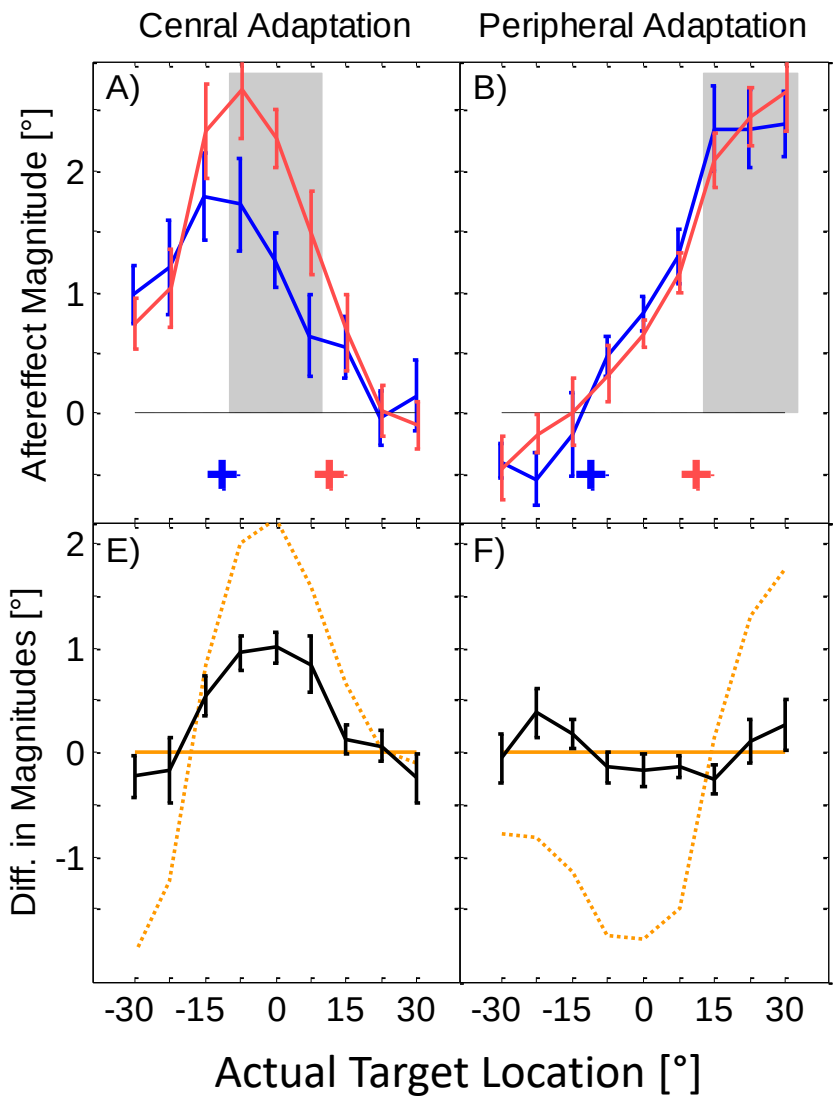
Results of Experiments: Ref. Frame of VAE



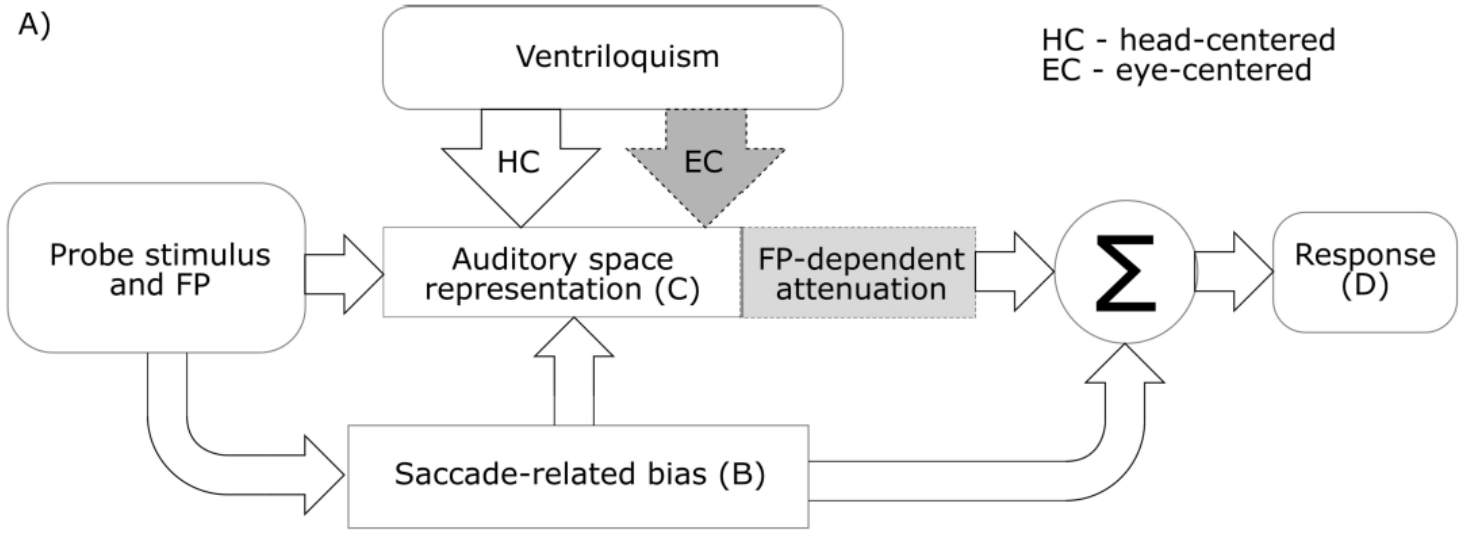


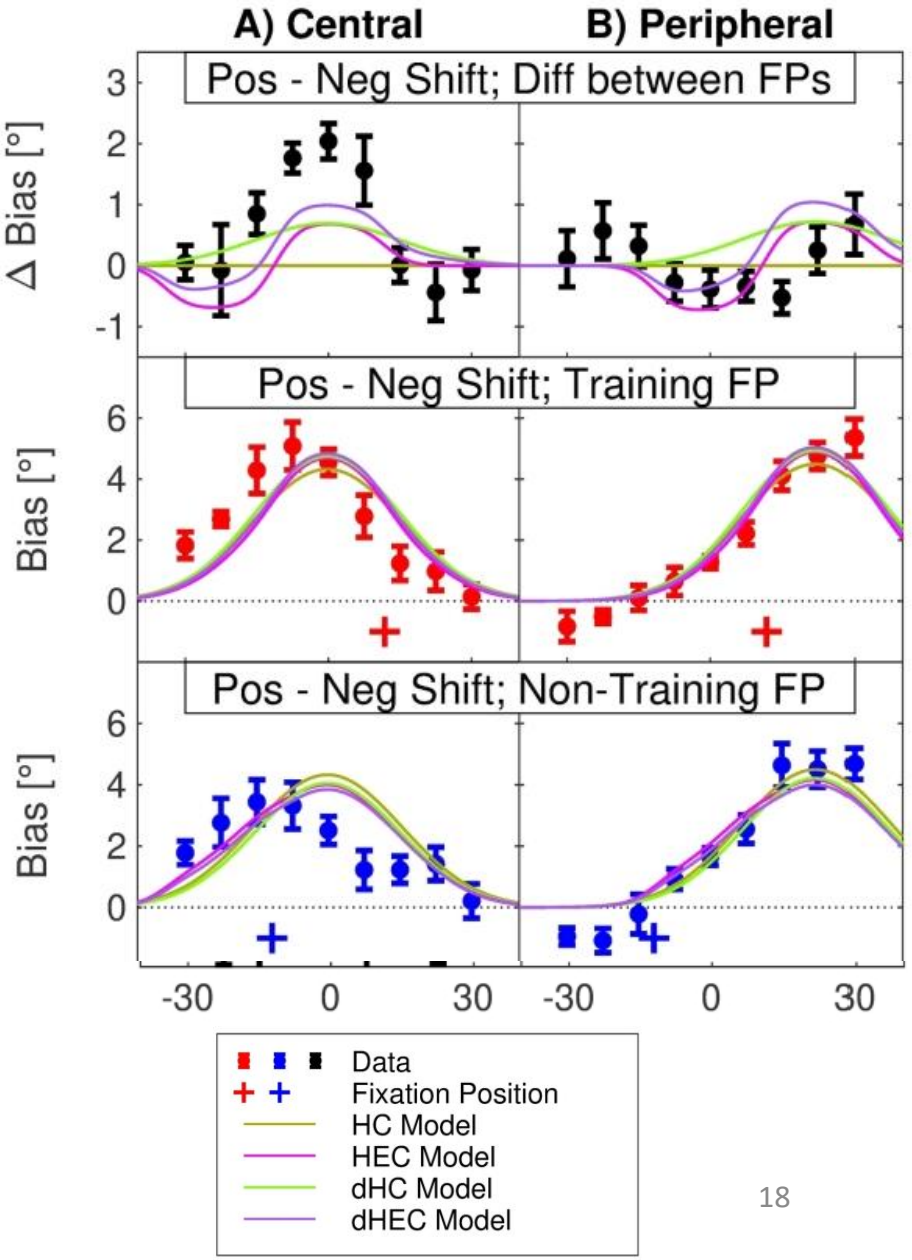


RFs differ for central vs. peripheral experiments (7 subjects):

- Central – mixed RF
- Peripheral – mostly head-centered RF

Previous model and its performance

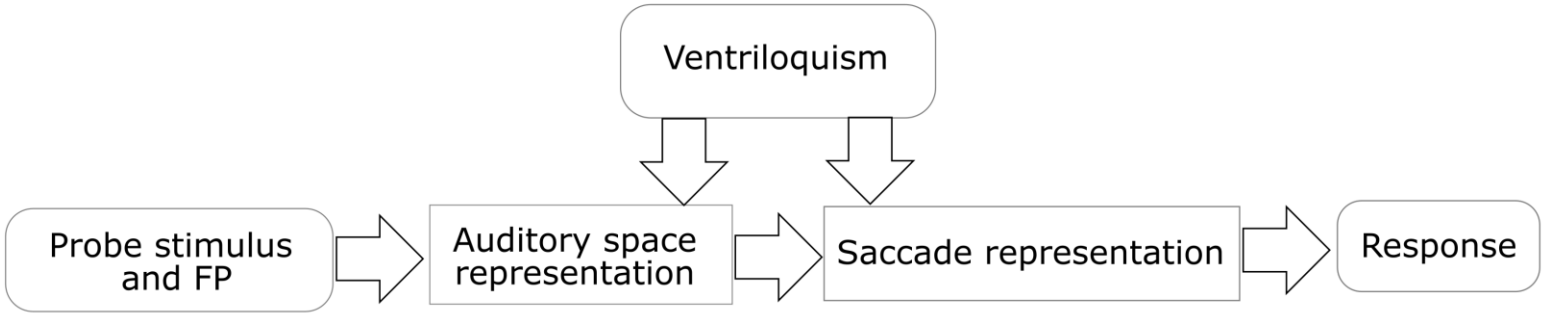




Loksa & Kopco (2022) model:

- can predict the central and peripheral data separately, but not simultaneously.
- even for the central data, predictions are better when "FP-attenuation" mechanism considered, not EC-referenced ventriloquism signals.

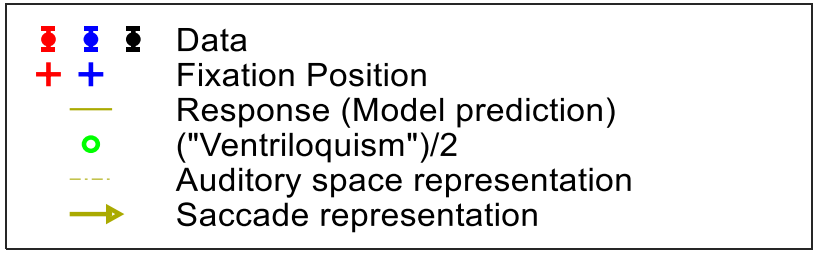
New model and its performance

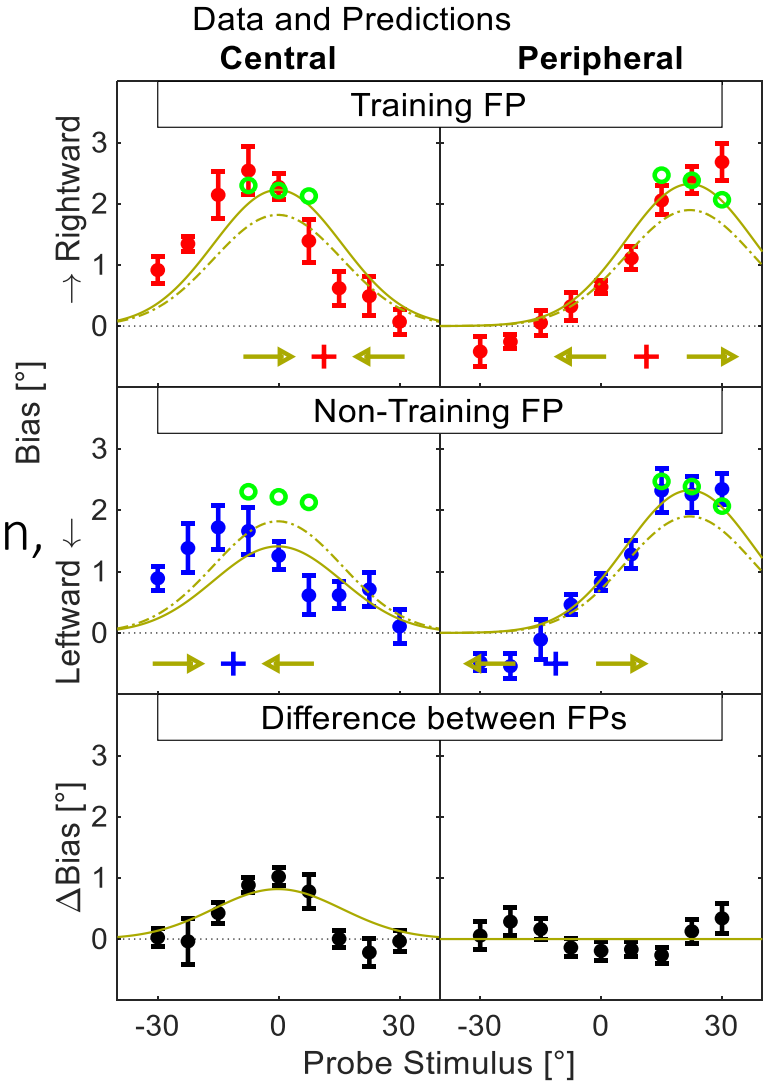


New model:

- Only assumes
- a **HC-referenced ventriloquism effect on auditory space** representation, and **adaptation in auditory saccades** by ventriloquism.
- Can predict both central and peripheral data.

→ **Reference frame of ventriloquism aftereffect only head-centered**





Neuronal correlates of auditory distance perception

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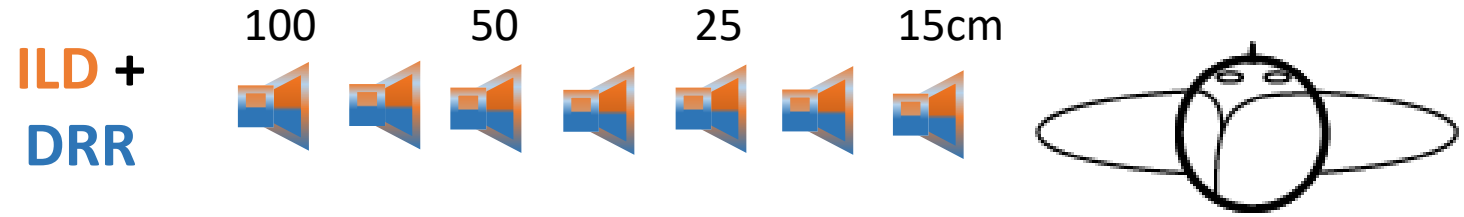
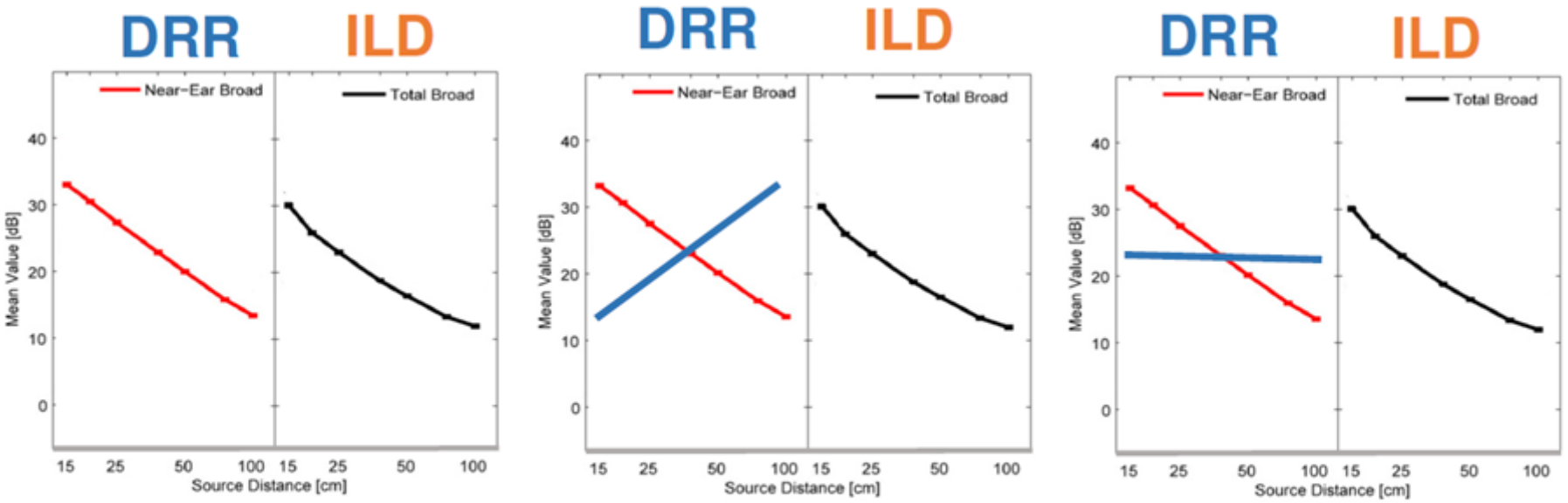
Distance perception: level-independent cues

Goal: test whether previously identified distance brain areas encode distance cues or percept.





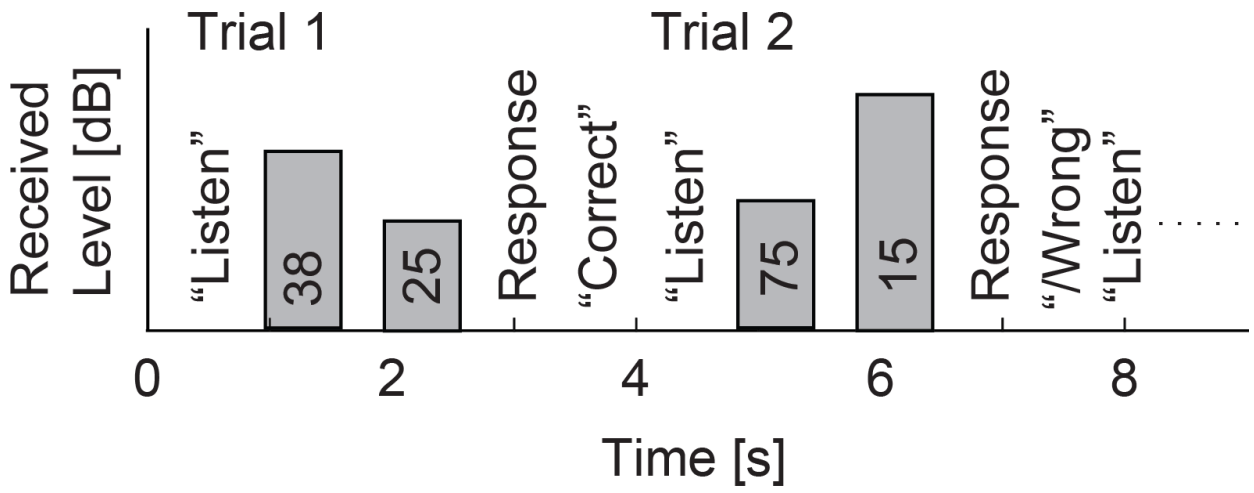
Congruent condition Incongruent condition ILD-only condition

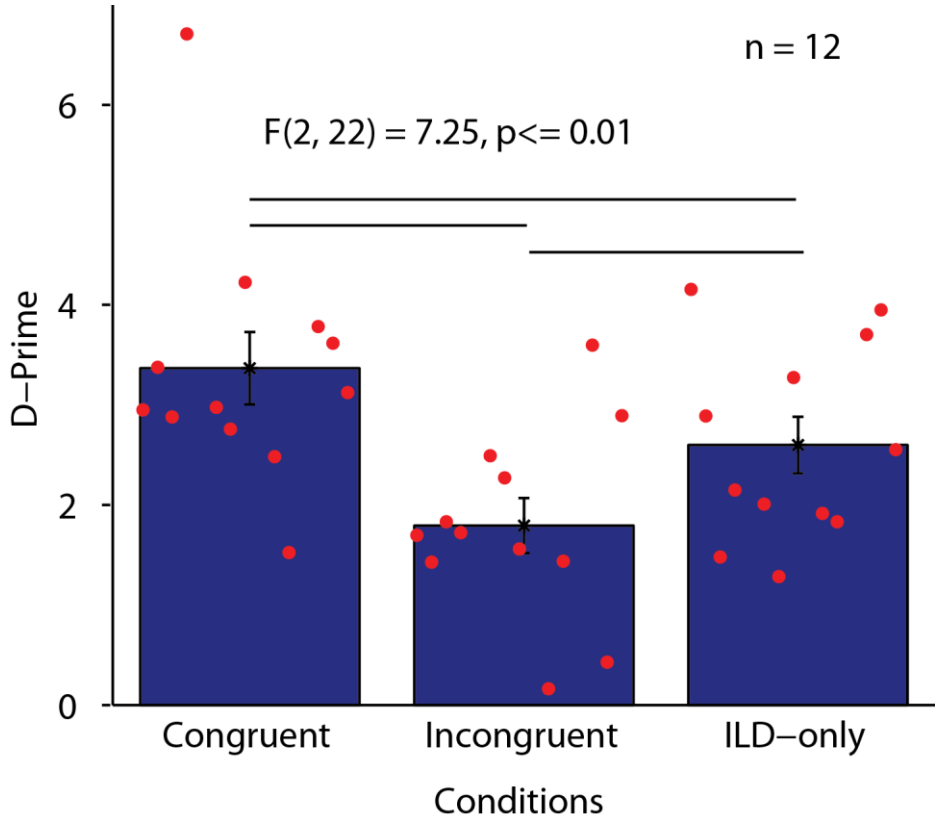
Behavioral experiments

Task:

Which of the sounds is closer to the listener?

*Subjects were instructed to ignore the intensity cue.

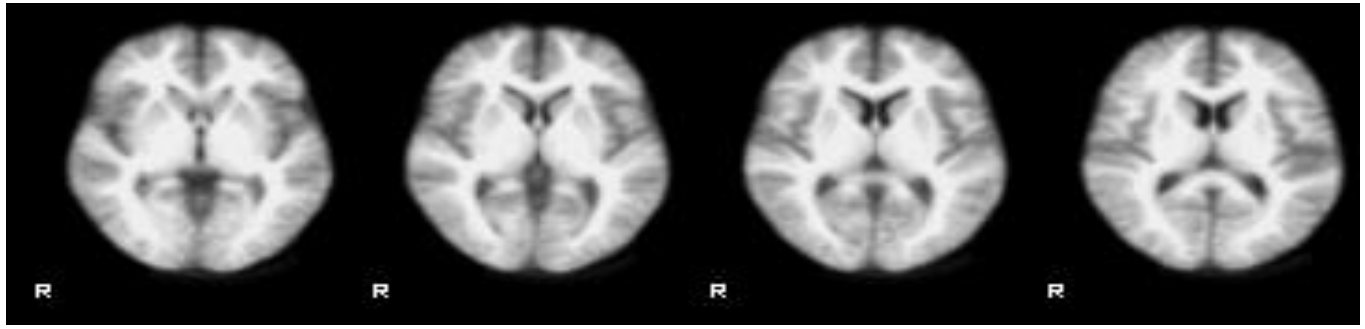




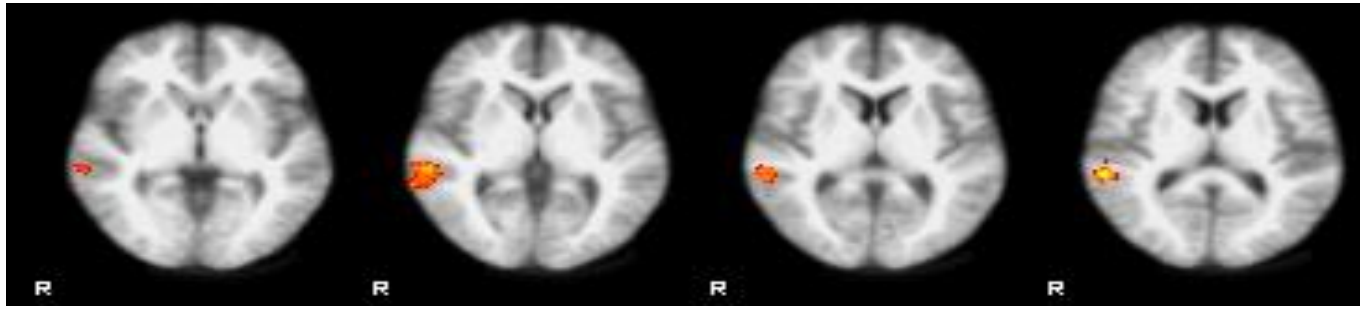
fMRI experiments – univariate analysis

Volume-based fMRI analysis Slices: 19-22

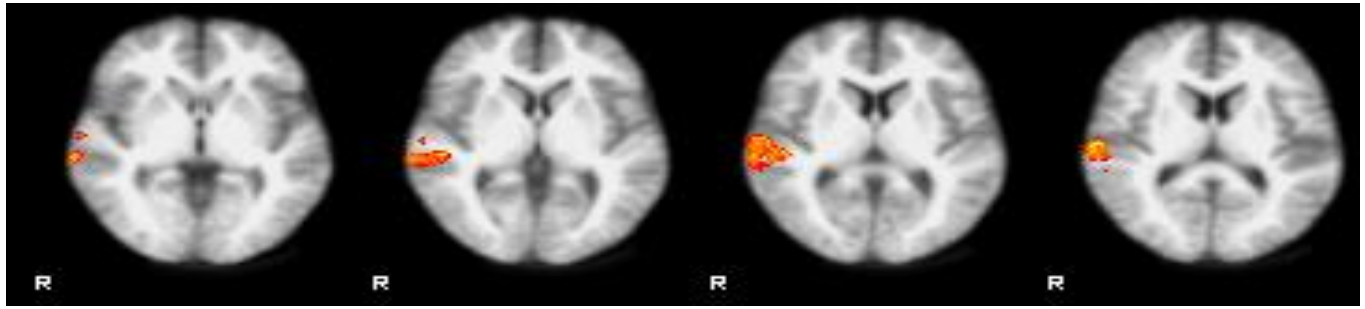
Congruent vs Incongruent



Congruent vs ILD only



Incongruent vs ILD only

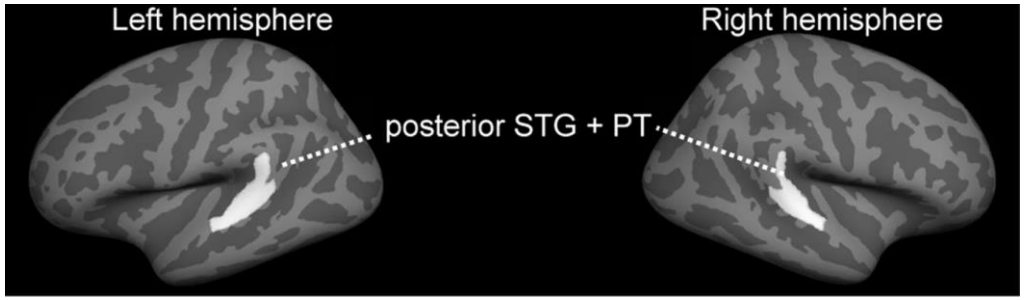


Differences in activation of single voxels in contralateral STG+PT consistent with units **sensitive to DRR**, **not** distance percept.

fMRI Multi-Variate Pattern Analysis (MVPA)

Not significant

Significant



	Left hemisphere	Right hemisphere	Hemispheres Combined
Congruent - Incongruent		p=0.02302	p=0.02414
Congruent- ILD only	p=0.02185		p=0.03390
InCongruent -ILD only			

An average difference in z-transformed correlations between same and different-condition split-half correlations in volume based fMRI analysis. (n= 13)

Distributed activation in contralateral STG+PT consistent with units **sensitive to distance percept**.