Binaural Cue Reweighting Induced by Discrimination Training

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Work supported by Horizon Europe HORIZON-MSCA-2022-SE-01 grant N° 101129903 and APVV-23-0054, and SK-AT-23-0002

Motivation

- **Normal-hearing (NH)** listeners primarily use **ITDs** (Interaural time difference) at **low frequencies** and **ILDs** ((Interaural level difference) at **high frequencies** (Macpherson & Middlebrooks, 2002).
- However, the **weighting** is not always **optimal** (Ihlefeld & Shinn-Cunningham., 2011)., as many other factors influence binaural cue weighting (overall level of the sound, active manipulation of one of the cues vs. the cue, and room acoustics).
- **Hearing-impaired (HI)** listeners often use a **different weighting** (e.g., Cochlear Implants (CI) users only use ILD at all frequencies).
- Therefore, **if it is possible to train people to use the best weighting under specific conditions, that might improve spatial hearing in both NH and HI listeners.**

Previous studies of binaural reweighting produced mixed results:

- No reweighting effect in discrimination around 0 values of ITD/ILD (Jeffress & McFadden, 1971)
- ILD (but not ITD) weights increased during task performance with no feedback (Kumpik et al., 2019)
- Reweighting induced in both directions by audiovisual (AV) training (Klingel et al., 2021)

Current Study

The current study has the main goal:

- **Introduce an adaptive left/right discrimination training protocol (originally proposed by Klingel et al., 2020)** that overcomes several **disadvantages** of the AV training of Klingel et al., (2021) such as**:**

  1) **no need** for any **sophisticated equipment** (AV/VR headset)
  2) **doesn't** expected to result in **compression of space**

ADDITIONAL GOALS:

1. Evaluate the **training** for both **increasing ITD** and **ILD.**
2. Propose a **Signal Detection Theory-**based model (using the 2I-2AFC model of Durlach., 1968) that provides a robust estimate of the relative binaural cue weight related to the trading ratio.
3. Perform **analysis of the training-session** data to examine the time course of training within and between training sessions and its dependence on training parameters

Experimental Procedure

Three subject groups:

- **ITD target group:** Trained to increase ITD weight (14 subjects)
- **ILD target group:** Trained to increase ILD weight (11 subjects)
- **Control group:** No training (11 subjects)

Design: Day 1: **Pretest** (all groups) + **1st Training Session** (training groups only)

Day 2: **2nd Training Session** (training groups only)

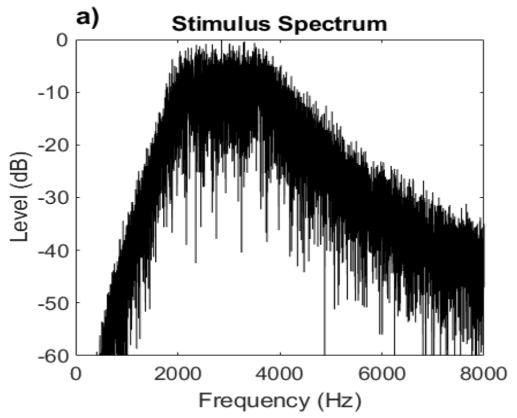
Day 3: **3rd Training Session** (training groups only) + **Posttest** (all groups)

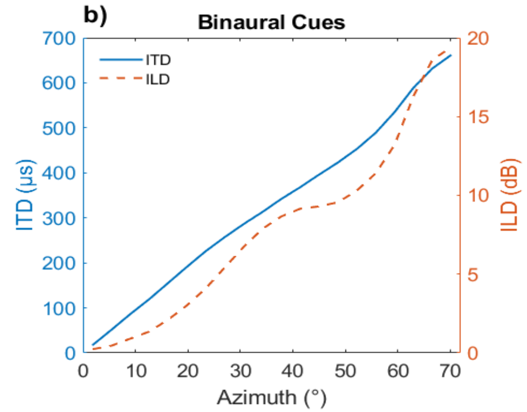
Stimuli: 500-ms narrow-band noise bursts (2-4 kHz; F_C = 2.8 kHz)

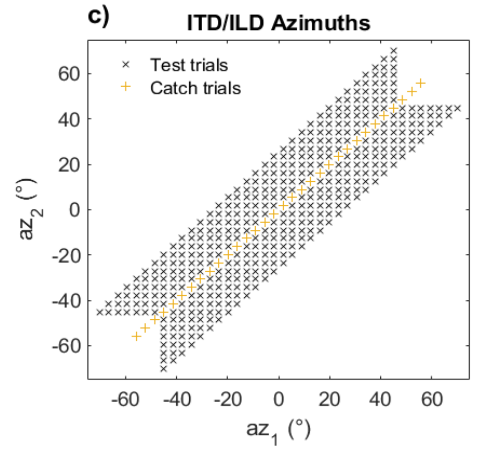
Each stimulus consisted of two noise bursts, separated by a 0-ms gap

Each burst had a different incongruent combination of ITD and ILD, corresponding to two azimuths az_1 and az_2.

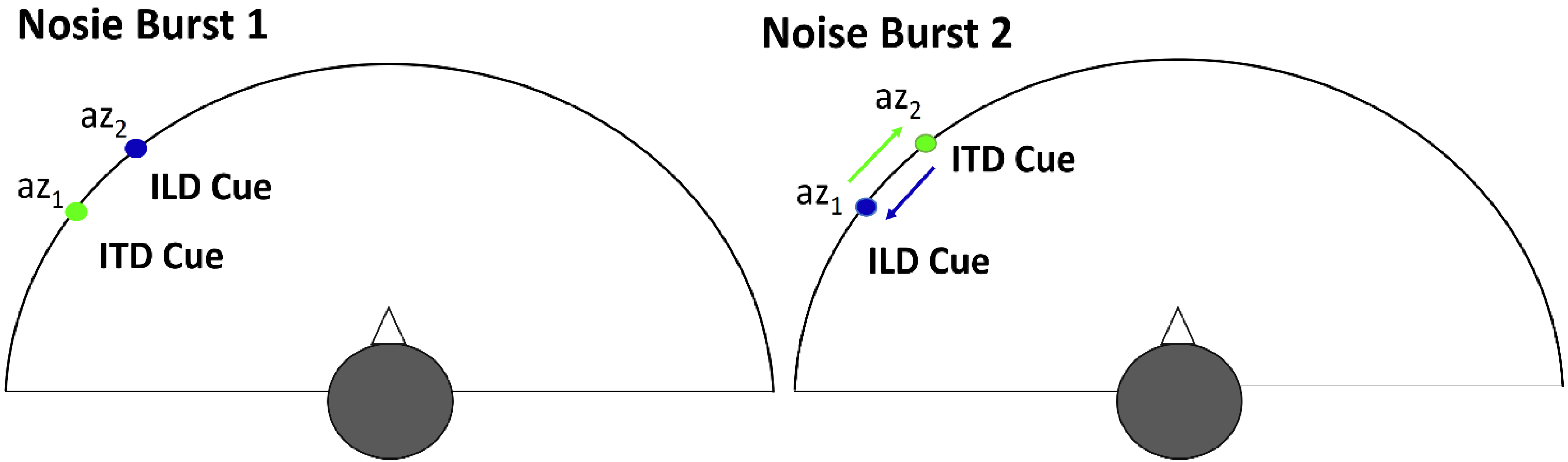
Test trials: az_1 and az_2 were randomly selected (range ±70.2°, az disparity of up to 25.2°)





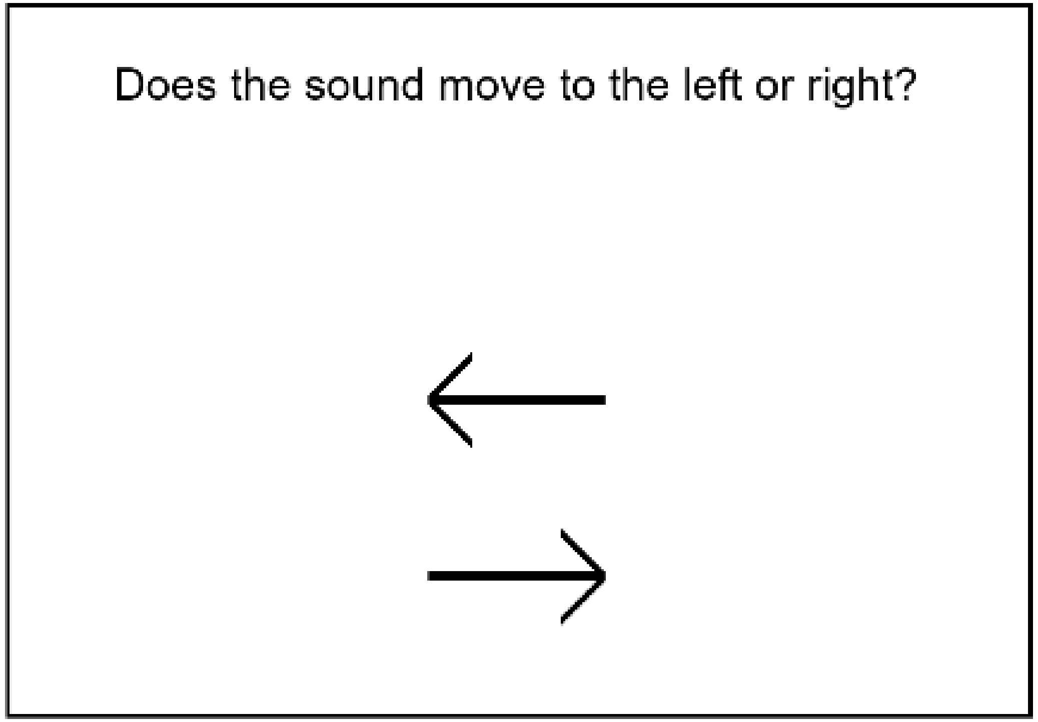


One trial – Test: Stimulus consisting of 2 noise bursts



Design of the stimulus in a pre-/posttest trial. Each stimulus consisted of 2 consecutive noise bursts, one containing ITD corresponding to az_1 and ILD to az_2 (or vice versa) and the other one with the cue azimuths reversed.

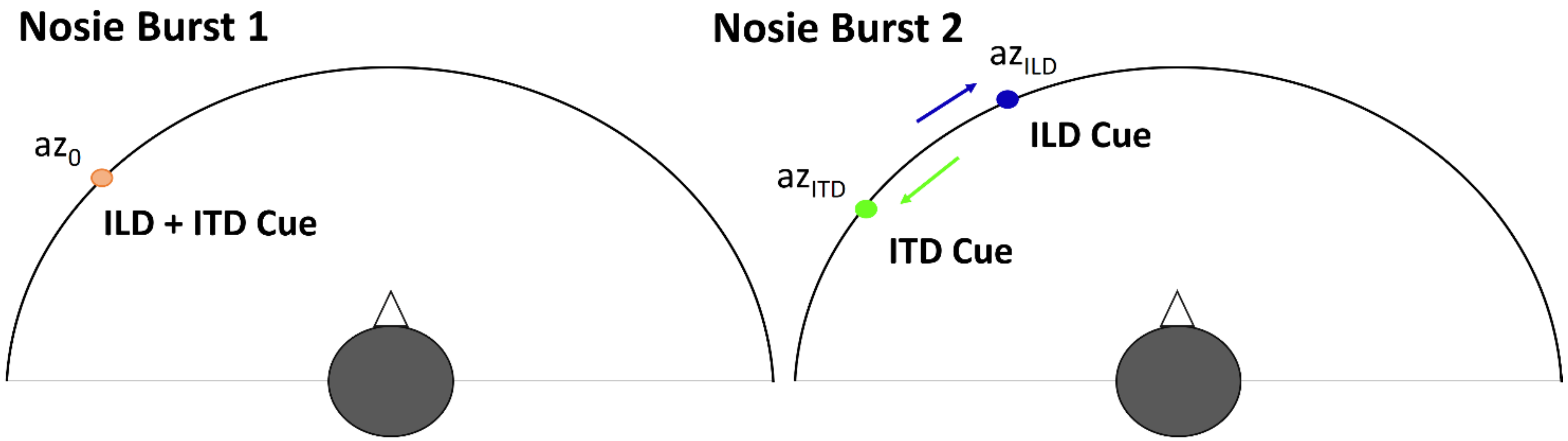
Visual interface during Testing



sound presentation -> response

On-screen prompts during testing trials

One trial – Training: Stimulus consisting of 2 noise bursts

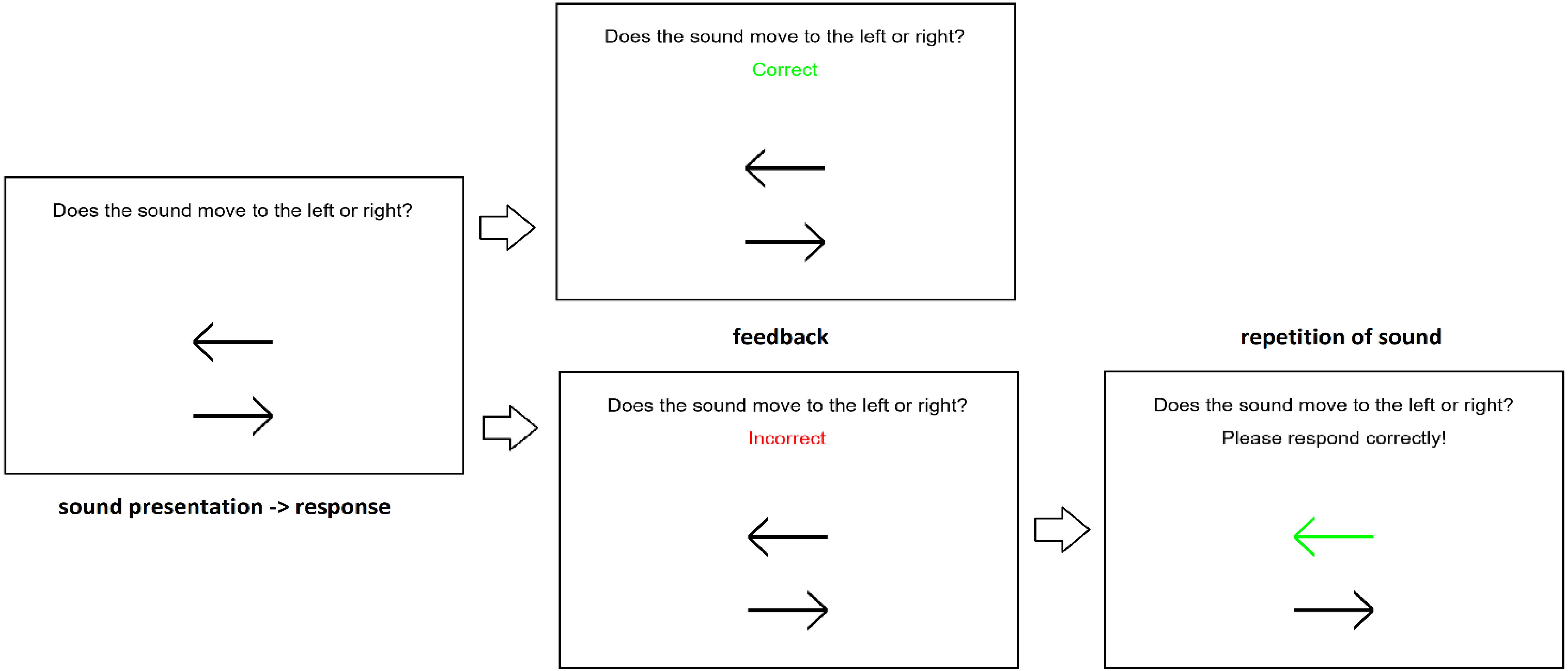


az of trained cue (e.g. az_{ITD}) varied adaptively using (2- interval, 2 – Alternate Force Choice)

az_{ILD}- az_{ITD} constant in adaptive track (2-down-1-up staircase procedure)

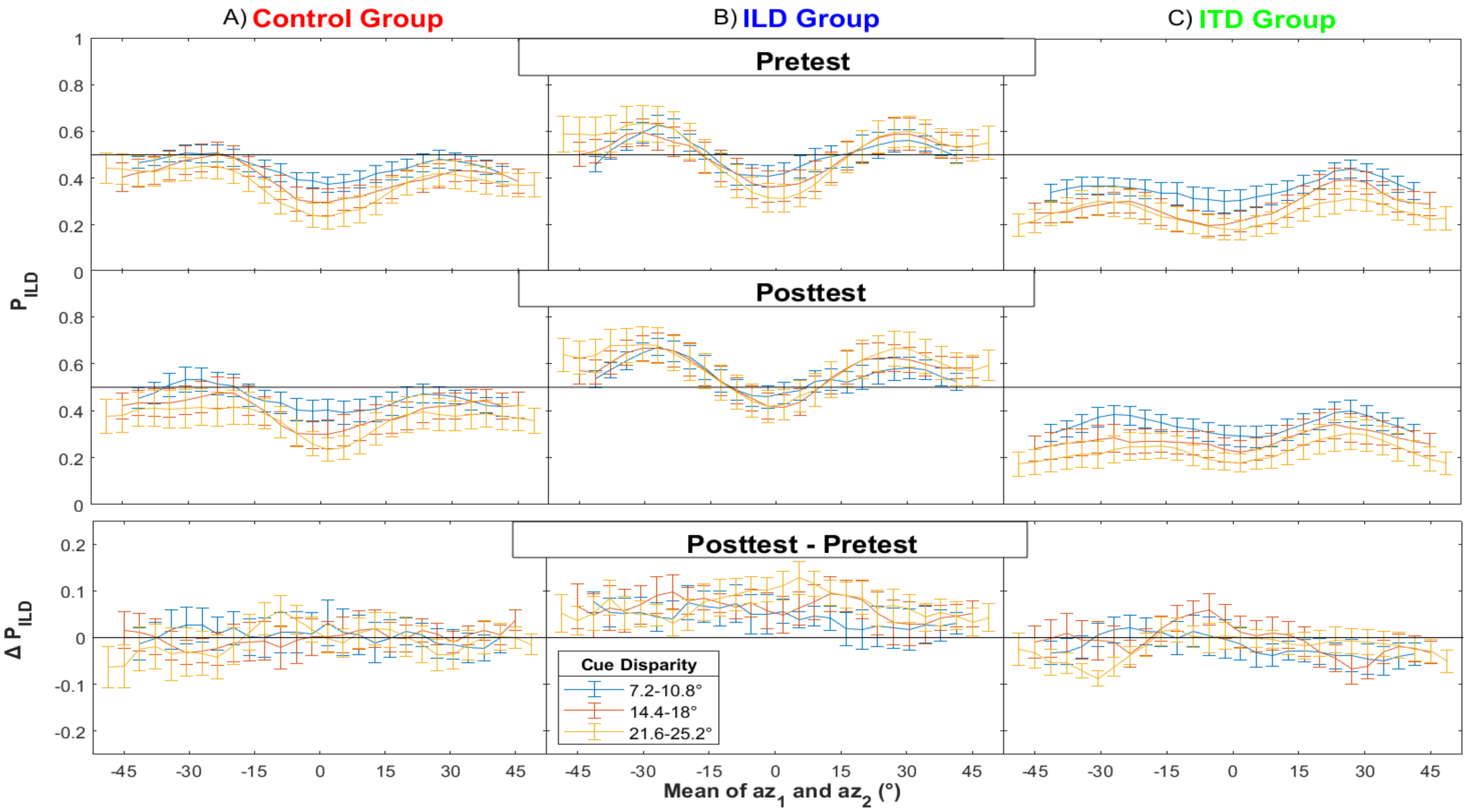
3 adaptive tracks run in parallel (with az_{ILD}- az_{ITD} of 18, 21.6 and 25.2°)

Visual interface during Training



On-screen prompts during training trials. On incorrect trial, subject asked to listen to sound again and imagine the sound moving in correct direction and respond accordingly.

Results



Training worked for ILD Group. For ITD group, training seems weaker and less clear.

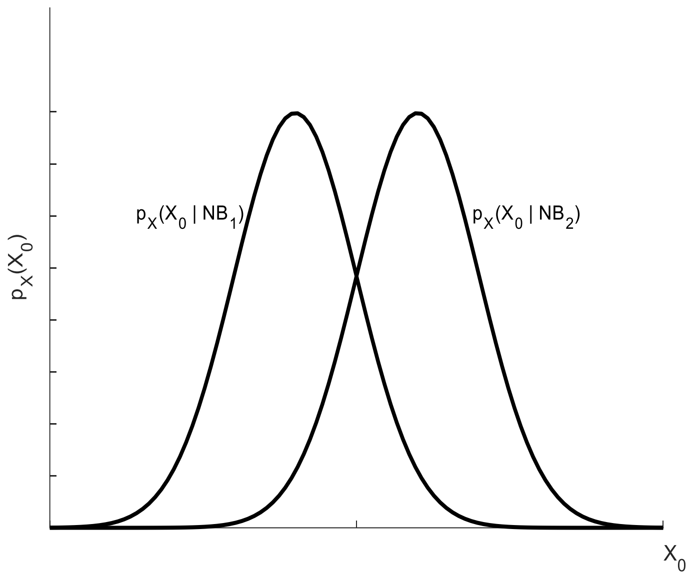
Proportion of responses that followed the ILD, P_{ILD}, as a function of azimuth (mean of az_1 and az_2)

*P_{ILD} = 1 (subjects only used ILD)

Why Modeling??

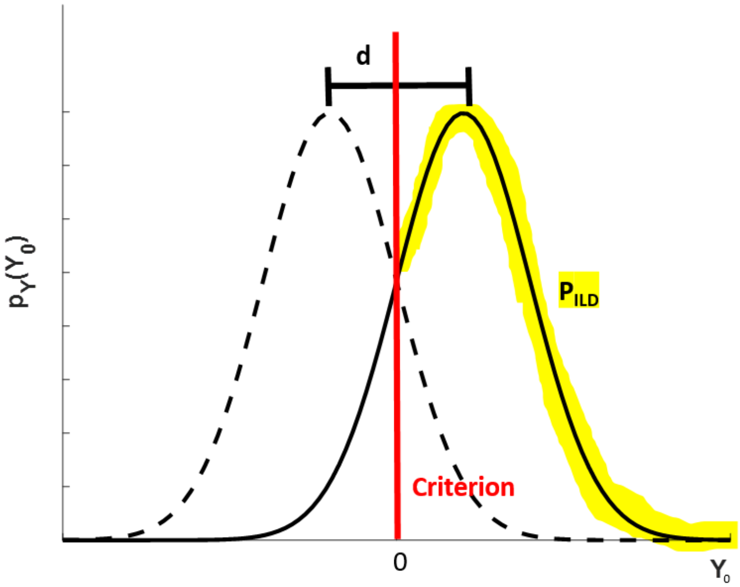
Why P_{ILD} measure is problematic?

- it depends on the stimulus azimuth and disparity
- its susceptibility to noise grows with decreasing disparity, reducing the reliability of the estimated P_{ILD}, and
- it is difficult to use it to derive one generalizable measure of relative the ITD/ILD weight, like the trading ratio.



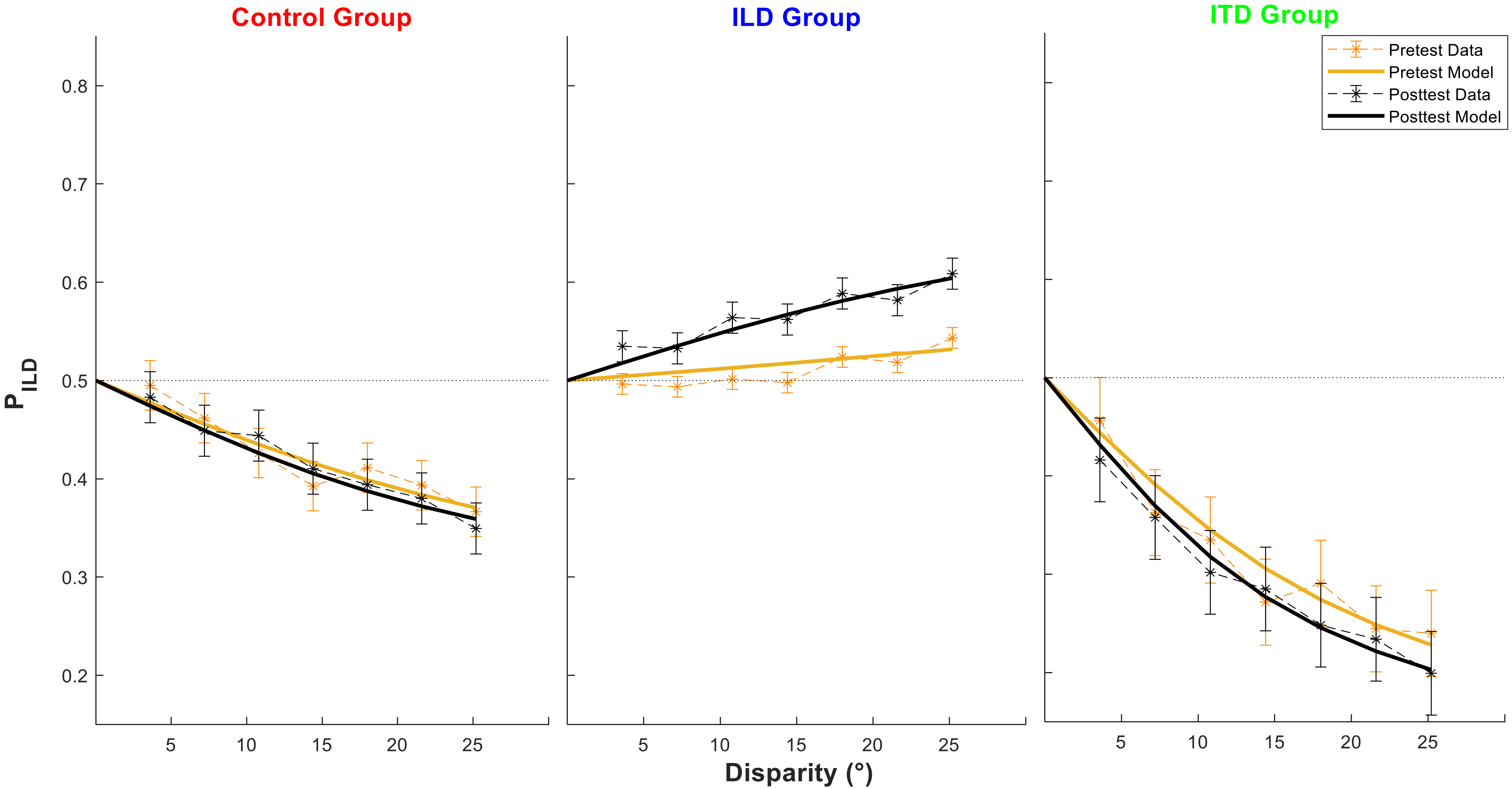
- Using the assumptions similar in *Kopčo et al. (2012)*, the proposed model predicts P_{ILD} as a function of w_{LT}, the estimated relative weight of the ILD vs. ITD cues, using the equation:

$$P_{ILD} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{d}{2}} e^{\frac{-t^2}{2}}\, dt, \text{ where } d = w_{LT}|az_2 - az_1|$$



d is a d' measure that represents the sensitivity to ILD vs. ITD
w_{LT} is a relative ILD/ITD weight for azimuthal disparity

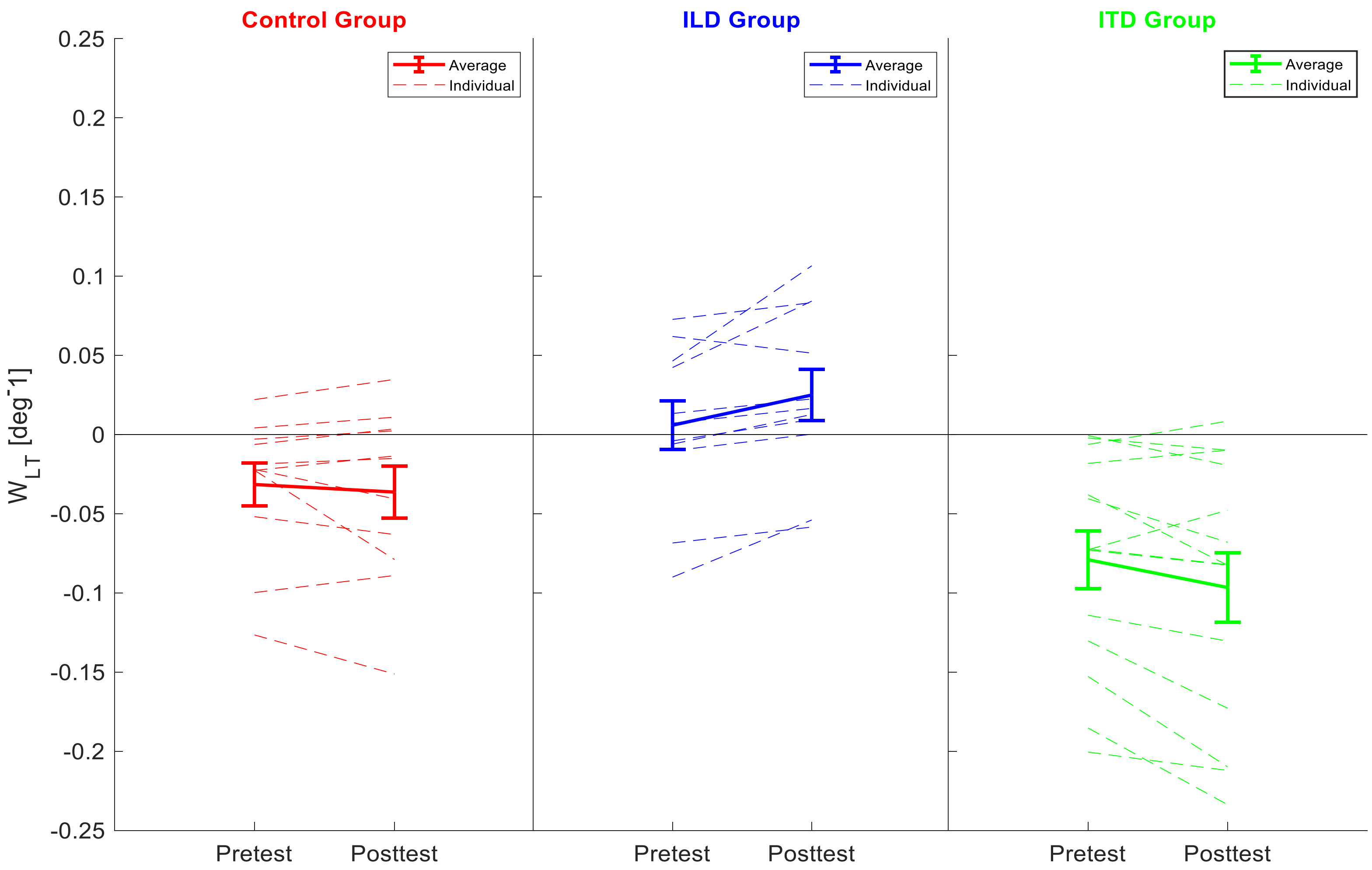
Results



The **model fits** are **very accurate** (across-subject average coefficient of determination of the individual fits, ***r*²**, is **.379**).

Across-subject average P_{ILD} as a function of cue disparity (collapsed across azimuths; dashed lines) along with the across-subject average of the model fits to each individual (solid lines).

Results

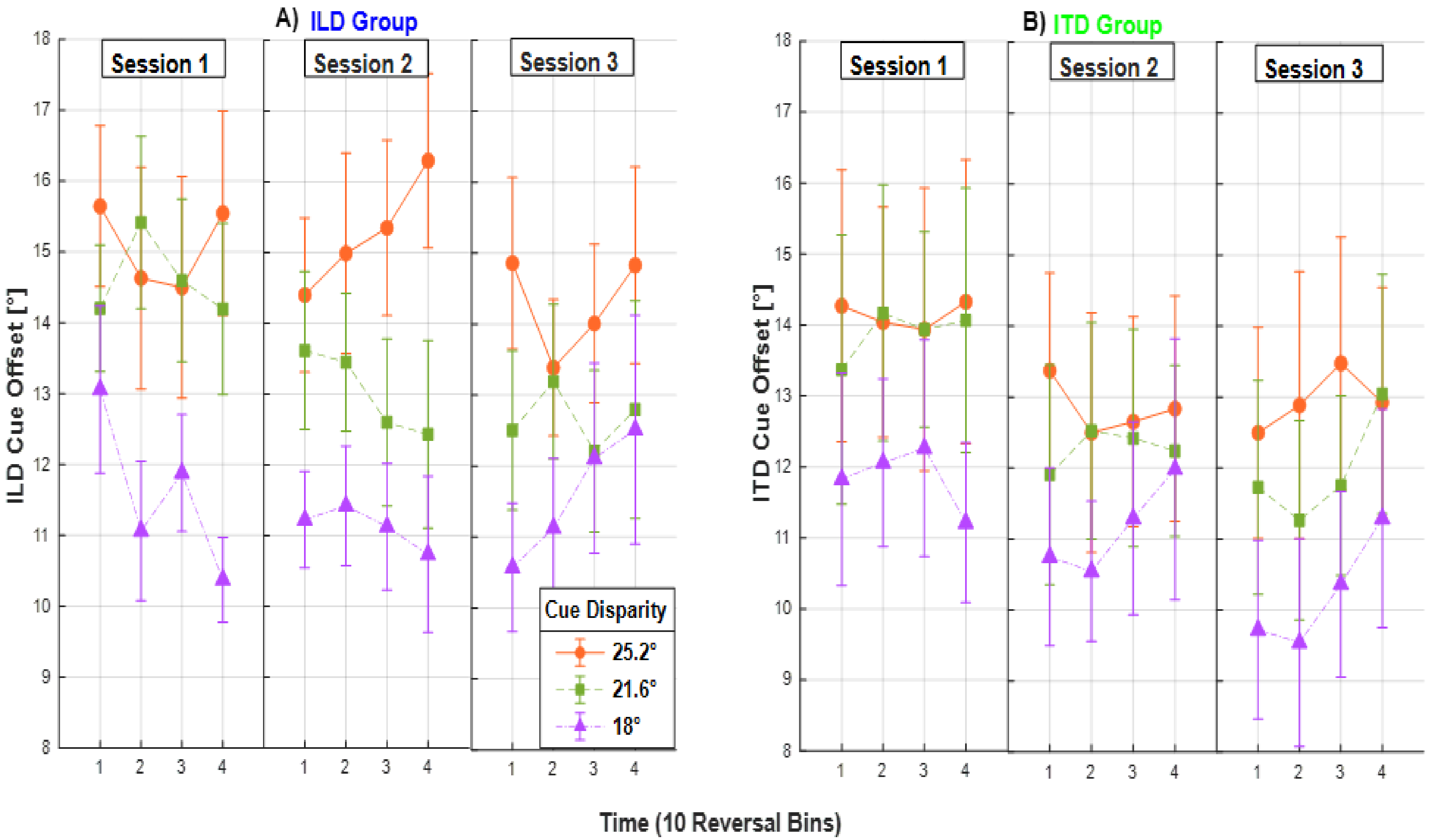


Pretest and Posttest weights w_{LT} estimated for individual participants and average within groups

- RM ANOVA with factors of group and time found a significant interaction time ($F(2,33) = 8.54$, $p = .001$)
- Post-hoc t-tests performed separately on both groups were significant (**ILD**: $p = 0.009$; **ITD**: $p = 0.019$)
- The average difference in weights were 0.020 deg^{-1} for **ILD** group and -0.018 deg^{-1} for **ITD** group

Using model-based estimates of pretest vs. posttest weights, the training worked for both **ILD** and **ITD** groups with similar strength.

Training Sessions



- RM ANOVA found significant main **effects of session** ($F_{2,46}$ = 8.5, p = 0.0007) and **disparity** ($F_{2,46}$ = 44.7, p < 0.0001) .
- **No** significant **effect of group**, suggesting a similar learning trajectory in the ILD and ITD group.
- **No pattern** was observed **within sessions**, but there was an improvement **across sessions.**

Trained-cue offsets in 10-reversal bins during the adaptive training runs, plotted separately for each session (column) and cue-disparity adaptive track (color)

Summary

- **Binaural reweighting** can be induced in **both directions** by simple **adaptive discrimination** training without **visual signals**.
  1) it is **simple** (no AV virtual environment needed),
  2) it is **not expected** to result in **compression of space**
  3) it does **not depend** on the accuracy of **individualized spatial simulation.** Specifically, when **non-individualized HRTFs** are used to derive binaural cues corresponding to a specific azimuth.
  4) it is **individualized.** However, the **performance measure** used in those studies has several **disadvantages** and the **temporal profile** of the **training** has not been analyzed.
- With the **weight estimate (w_{LT}),** we observed the training effect was approximately equally effective for both **(**ILD and ITD**)** training groups.
- In both groups **(**ILD and ITD**)**, **training performance resulted in gradual** improvement **between the training sessions**. Thus**, further** training might have brought **stronger effects.**

FUTURE STEPS

- We will convert w_{LT} measure into standard ITD/ILD trading ratio to make the results comparable to other reweighting studies.
- Extend the model to make it applicable to the lateralization training results of (Klingel et al., 2021) and (Spisak 2021) which used absolute localization responses instead of discrimination in testing.
- Results of modeling will allow us to determine which training method is most effective.

THANK YOU!

Questions??