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

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BACKGROUND

- For spatial hearing in the horizontal plane, humans rely on the binaural cues: interaural time difference (ITD) and interaural level difference (ILD).
- Normal-hearing (NH) listeners apply frequency-dependent weights when combining these cues to determine the perceived azimuth of a sound source. (Macpherson & Middlebrooks, 2002)
- Multiple 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 reverberation (Rakerd & Hartmann, 2010)
- Several previous 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 audio-visual training in virtual environment (Klingel et al., 2021)

CURRENT STUDY

- Propose a simpler training protocol than Klingel et al. (2021) 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.

- Perform an experiment to test **whether the training will change the weights NH listeners apply when combining ITD and ILD into a spatial percept, if one of the cues is reinforced selectively.**
- Method shown to work for ILD training vs control group (Klingel et al., 2020). Here, adding ITD training.

METHODS

- 3 experimental groups:

  ITD target group: Trained on ITD (ITD = target cue, ILD = non-target cue)

  ILD target group: Trained on ILD (ILD = target cue, ITD = non-target cue)

  Control group : No Training

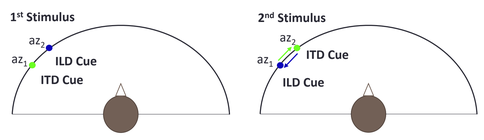
- **Design:** Day 1: **Pretest** (all groups) + **1st Training Session** (Training groups only)

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

  Day 3: 3rd Training Session (Training groups only) + **Posttest** (all groups)
- **Participants:** 36 subjects; Audiometrically normal-hearing
- **Apparatus:** Sound card (RME Fireface 400), headphones (Sennheiser HD 800 S)
- **Stimuli:** Narrow-band noise bursts (2-4 kHz) presented over headphones
  Incongruent combinations of ITDs and ILDs
  Catch trials with congruent cues, to monitor subjects' performance
- **Task** : Two-interval, 2AFC left/right discrimination task
  - Pre/Posttest: Constant Stimuli
  - Training: 2-down-1-up adaptive staircase procedure

Testing Procedure – one trial:

Figure 1: Design of a Pre/Posttest trial. az_1 and az_2 varied from -70 to 70 °, az disparity of up to 25.2°. Subject indicated perceived change in location: *Does the sound move to the left or right?*

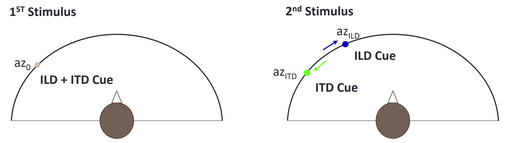


METHODS (CONT'D)

Pre/posttest: Subject indicates perceived direction (Fig. 3, left panel).
ILD weight w_{ILD} estimated as proportion of trials in which responses were consistent with ILD motion direction ($w_{ITD} = 1 - w_{ILD}$).

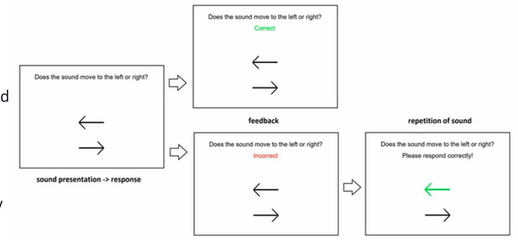
Training Procedure – one trial:

Figure 2: In 1st Stimulus, ILD and ITD corresponding to the same azimuth.
In 2nd stimulus, ILD shifted to right and ILD shifted to left.



Az of trained cue (e.g., 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°).

Figure 3: On-screen response during training trial. On incorrect trial, subject asked to listen to sound again and imagine the sound moving in correct direction and respond accordingly. (During test trials, only the first screen appeared.)



RESULTS: CATCH TRIALS

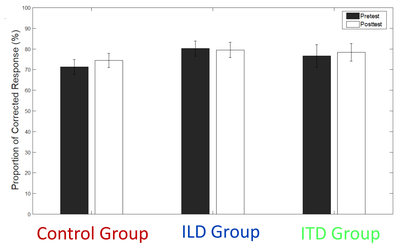


Figure 4: Proportion of correct responses on catch trials.

Catch-trial performance similar in pre/posttest for all 3 groups.
In ITD Group, performance decreased for subjects who didn't show training effect.

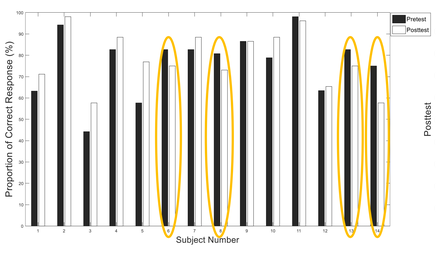


Figure 5 : Individual subject performance on catch Trials in ITD group. Orange ovals indicate outliers with a 5+% performance decrease in posttest.

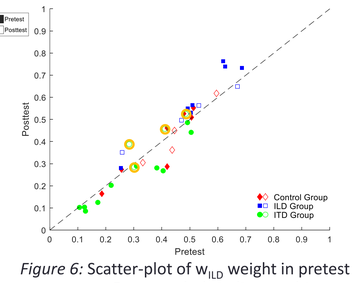


Figure 6: Scatter-plot of w_{ILD} weight in pretest vs. posttest. Open symbols indicate subjects with a 5+% performance drop in posttest. Orange circles indicate outliers from Fig. 5.

RESULTS: BINAURAL REWEIGHTING

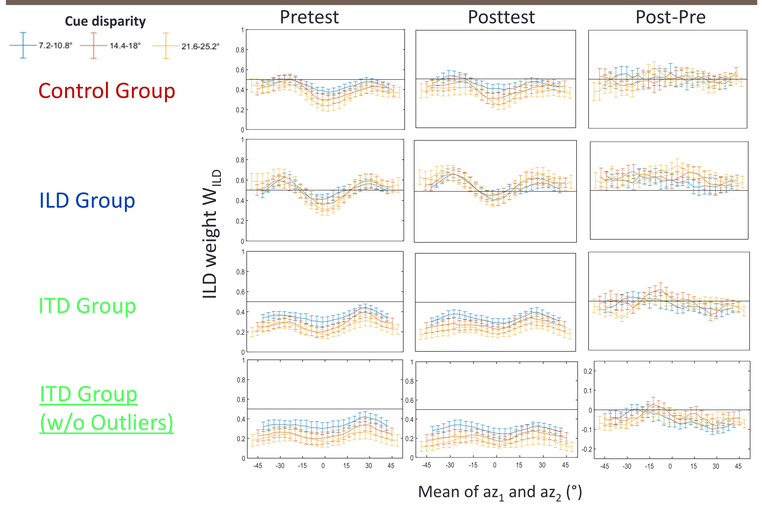


Figure 7: Ratio of trails in which responses followed the azimuth as a function of the mean of az1 and az2 plotted separately for different az_1-az_2 cue disparities. The error bars shows the standard of the mean. Results for ITD group shown separately with and without the outliers from Fig. 6.

Training works for ILD Group. For ITD group, training works when catch-trial-based outliers excluded.

CONCLUSIONS

- 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 is also observed for ITD group.
- **Binaural reweighting can be induced in both directions by simple adaptive discrimination training without visual signals.**
- **This training is not expected to result in compression of space as in visually guided training of Klingel et al. (2021)**
- **Also, this training is individualized (the visually-guided training was not).**

FUTURE WORK

- While the weight estimates varied with target azimuth and spatial disparity, the weight change was approximately independent of these spatial factors. We plan to
  - investigate why weighting changes with azimuth using a decision theory model which provides a weight estimate independent of azimuthal disparity,
  - integrate it into an existing brain training game "Listen" (from UCR/NEU Brain Game Center),
  - test whether it works for HI subjects (e.g., ITD training for CI users).

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Acknowledgement: [Work supported by grant ASH (Adaptability in Spatial Hearing), WTZ #MULT 07/2020, APVV DS-FR-19-0025 and VEGA 1/0350/22]