Binaural cue reweighting: Why does visually guided localization training in real environment always result in an increase of the ILD weighting?

Lucia Hucková[a] and Norbert Kopčo[a]

In collaboration with

Ondrej Spišák[a], Maike Klingel[b], Peter Lokša[a], René Šebeňa[a], Bernhard Laback[b]

[a] Perception and Cognition Lab, Institute of Computer Science
P. J. Šafárik University in Košice, Slovakia

[b] Institut für Schallforschung, ÖAW

[Work supported by Danube Partnership Grant DS-FR-19-0025, VEGA 1/0350/22, VEGA 1/0355/20]

Introduction

Weighting of binaural cues in sound localization

- is frequency-dependent (Strutt, 1907):
  - for low-frequency (LF) sounds ITD dominates,
  - for high-frequency (HF) sounds ILD dominates.
- has been typically measured as **trading ratios** using headphones (e.g., Colburn and Durlach, 1965), but also attempted using loudspeakers (Leakey and Cherry, 1957),
- can vary dynamically, e.g., in reverberation (Rakerd and Hartman, 2010), or due to attention (Lang & Buchner, 2008),
- can it be modified by training **(reweighting**), eg for CI listeners who use mainly ILDs?

Reweighting:

- has been achieved for **binaural cues** using audiovisual training **under headphones** (Klingel et al., 2021; Moore et al, 2020; Kumpik et al., 2019), but was not always successful (Jeffers and McFadden, 1971),
- has been achieved for increasing **monaural** vs. **binaural** cues by plugging one ear (Kumpik et al, 2010),
- occurs commonly for different **spectral components**, e.g., in speech perception (Stilp et al., 2016).

Original study (Bash 2021)

Goal: Propose a **training protocol in real environment** (with dynamic cues and no simulation quality/externalization/cross-modal binding issues) **to change binaural weights**.

Binaural cues can't be varied independently in real environment → **train spectral reweighting** and check **generalization to binaural**.

Results:

1. Found that **audiovisual training with dynamic cues** can be used to induce **spectral reweighting for horizontal localization** in real reverberant environment, both if increasing the weight of:
   - HF spectral components, or
   - LF spectral components.
2. Tested whether such spectral reweighting **generalizes to binaural reweighting at mid frequencies** in a virtual environment (like in Klingel et al., 2021), i.e., whether:
   - increased HF weight leads to increased ILD weight, and/or,
   - increased LF weight leads to increased ITD weight.

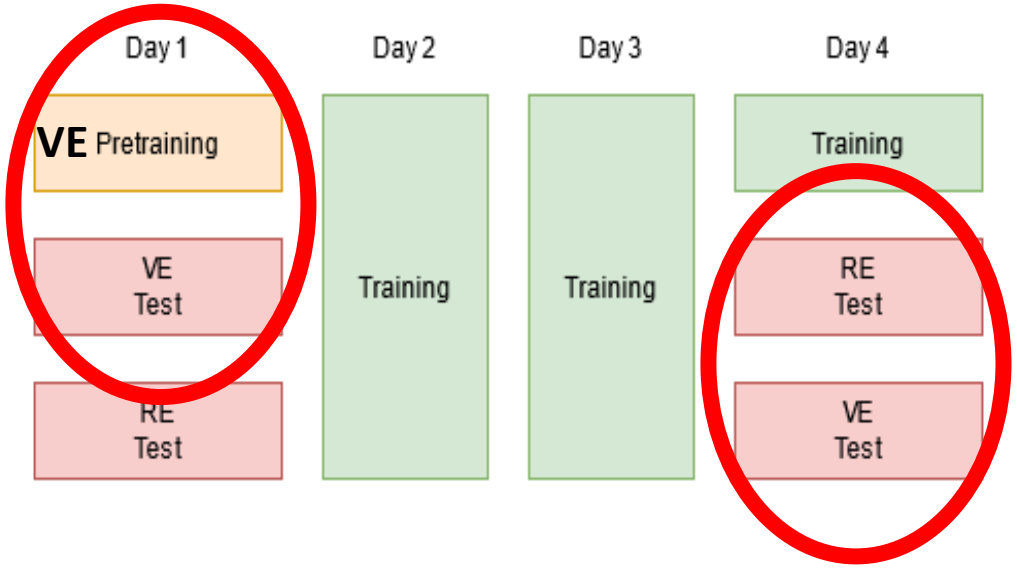
   Found that both HF and LF reweighting training resulted in increase in ILD weight.

Discussion from original study and Current Exp

Generalization of **spectral reweighting** to **ITD/ILD reweighting at mid frequencies**:
- **no direct evidence of generalization**, possibly due to testing not at trained frequencies.

Alternative interpretation:
- for **HF (& HFI) training**, increased ILD weighting, as expected,
- for **LF training**, increased ILD weighting, contrary to expectation,
  - partially explainable by no generalization to mid frequencies.

Possible explanations of all groups increasing ILD weight:
- **Procedural training in VE** (no no-training baseline)
  - not likely because no such effect in Klingel et al. (2021).
- **Adaptation to immediately preceding environment ---------->**
  (**i.e., no effect of training**)
  - anechoic VE pretraining preceded VE pretest, but reverberant RE posttest preceded VE posttest,
  - adaptation to reverberation observed for localization (Shinn-Cunningham, 2000) or speech perception (Vlahou et al., 2021).



Current study: **test explanation about adaptation to immediately preceding environment.**

Approach (original study)

Methods:

- Behavioral experiment using broadband multi-component noise stimuli in **real & virtual environment.**
- Train **two groups** of subjects using visual guiding signals:
    - to increase the weight of HF (f > 2.8 kHz) components – **HF group** (12 normal-hearing listeners)
    - to increase the weight of LF (f < 2.8kHz) components – **LF group** (12 normal-hearing listeners)

Questions:

- Test:
    - whether the training induces spectral reweighting,
    - whether the spectral reweighting generalizes to stimuli with an untrained frequency component (2.8 kHz),
    - whether the spectral reweighting generalizes to ITD/ILD reweighting at 2.8 kHz (using VR).

Real Environment (re. Virtual Environment):

- no issues with veridicality/accuracy of localization, externalization, easy to generate dynamic cues,
- cannot independently manipulate binaural cues (therefore spectral reweighting).

Overall Procedure (original study)

Experiment consisted of four 2-3 hr sessions, performed on consecutive days:

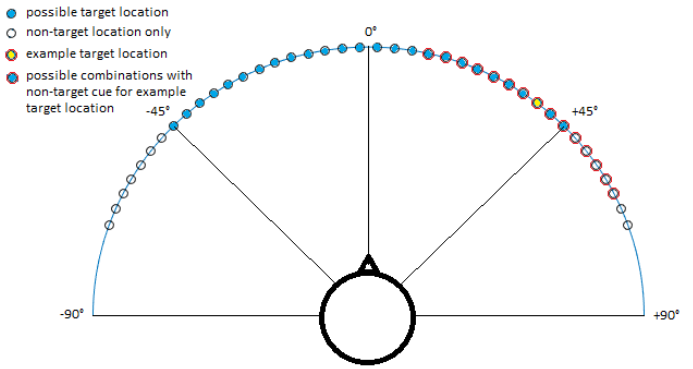
Setup (original study)

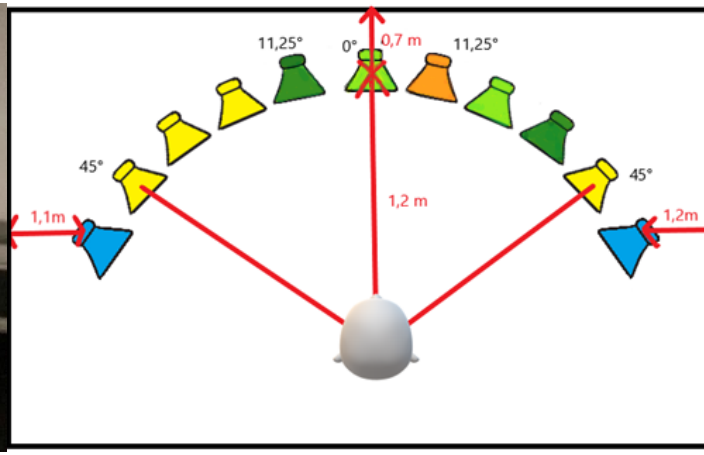
Virtual environment (VE) – binaural testing only

- 1-octave noise bursts (Fc=2.8 kHz) presented with ITD/ILD location inconsistency of up to 25° within a range of ±70°.
- Head-mounted display (*Oculus*) used to track head turns to perceived location.

Real environment (RE) – spect. testing & training

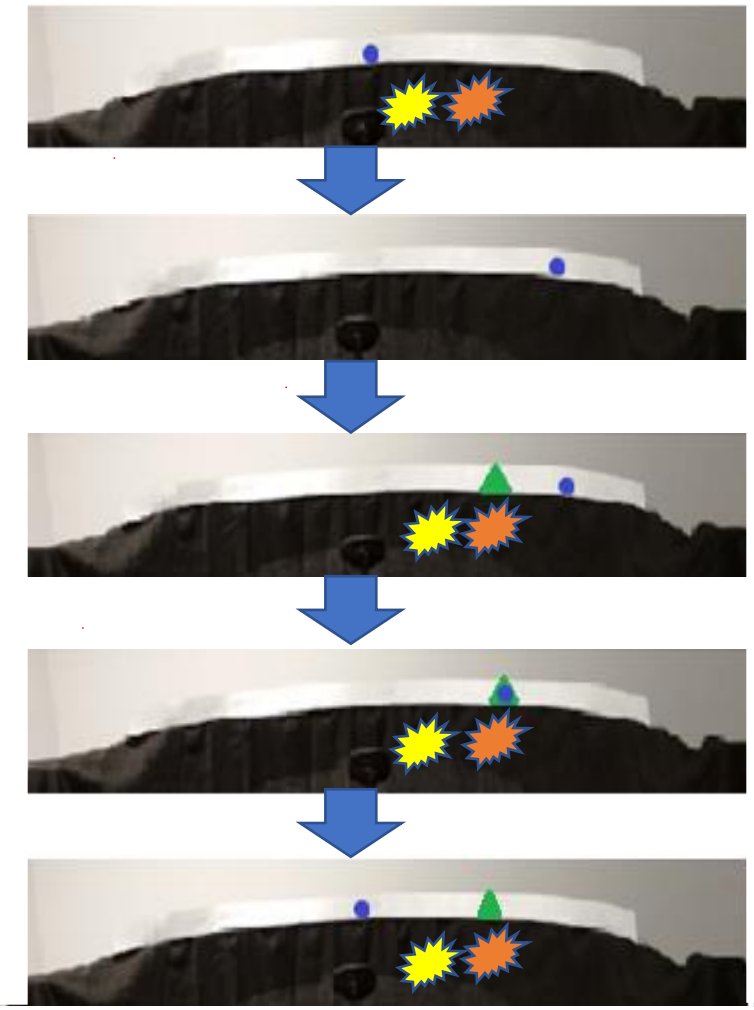
- 11 speakers in semicircle from -56° to 56 (11° spacing),
- 300-ms 0.5-oct noise bursts in channels centered at:
  - LF: .35 or .7 kHz, and
  - HF: 5.6 or 11.2 kHz
- 2 (1 LF & 1 HF) or 4 components (2 LF & 2HF) played from the same or neighboring speakers (up to 2 speakers apart),
- visual stimuli projected on screen above speakers,
- head-turns used to indicate perceived location.





Training Procedure (original study)

Procedure for 2-component sounds (identical procedure for 4-component sounds):



Initial position & stimulus presentation

Head-turn to 0° | Present stimulus once

Response

Head-turn to perceived target location & press Enter

Visual feedback

Green triangle shows correct location | Present stimulus continuously (200 ms gap)

Training with dynamic cues

Head-turn to visual feedback & press Enter | Stimulus continues

Return to initial position while stimulus playback continues

Head-turn to 0° & press Enter | Stimulus stops

Head orientation

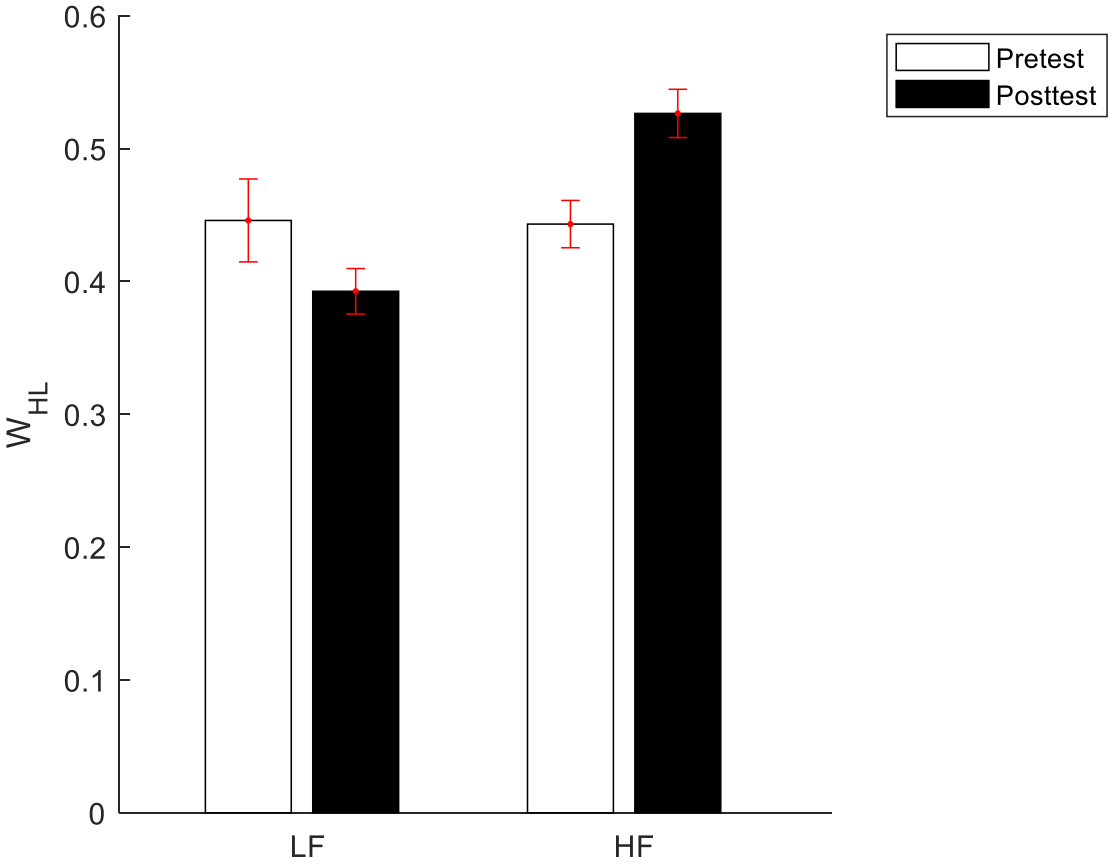
Visual feedback

HF sound
LF sound

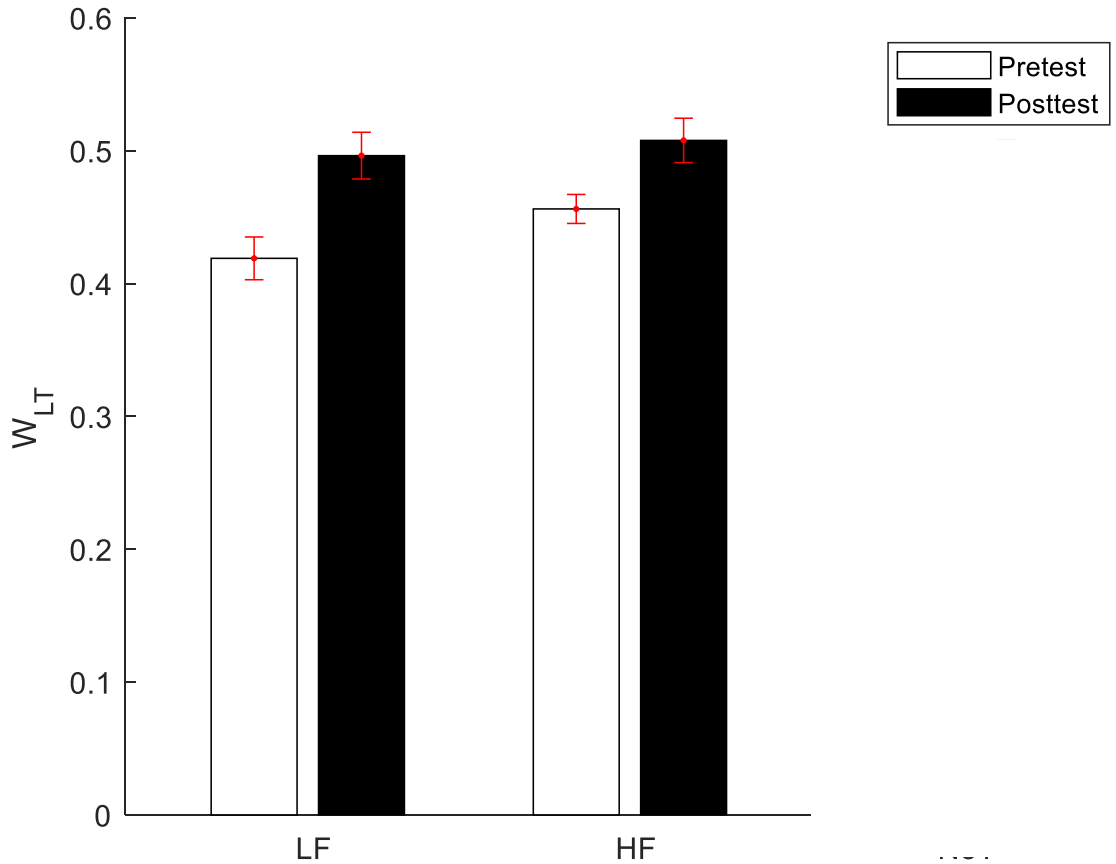
Visual feedback aligned with HF component(s) for HF group, with LF component(s) for LF group.

Test procedure identical to steps 1 & 2 of training procedure.

Results w_{HL} (HF vs. LF) and w_{LT} (ILD vs. ITD) (orig. study)



Spectral reweighting successful.



Binaural reweighting: ILD weight increase in both groups.

Current Experiment (Follow-up)

Hypothesis:

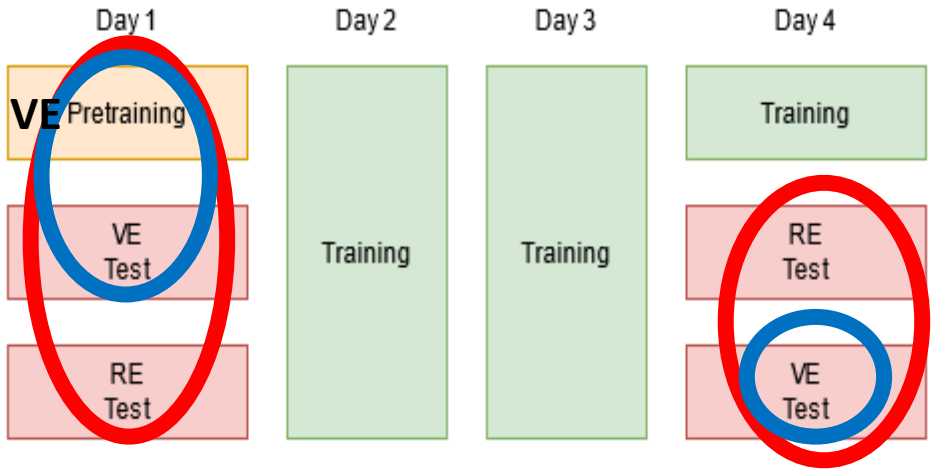
- RE posttest preceding the VE posttest, not the Training per se, caused the increased w_{LT} in the original experiment.
- I.e., adaptation to immediately preceding reverb environment causes the increased ILD weight.

Two control groups, only performing pre/posttests:

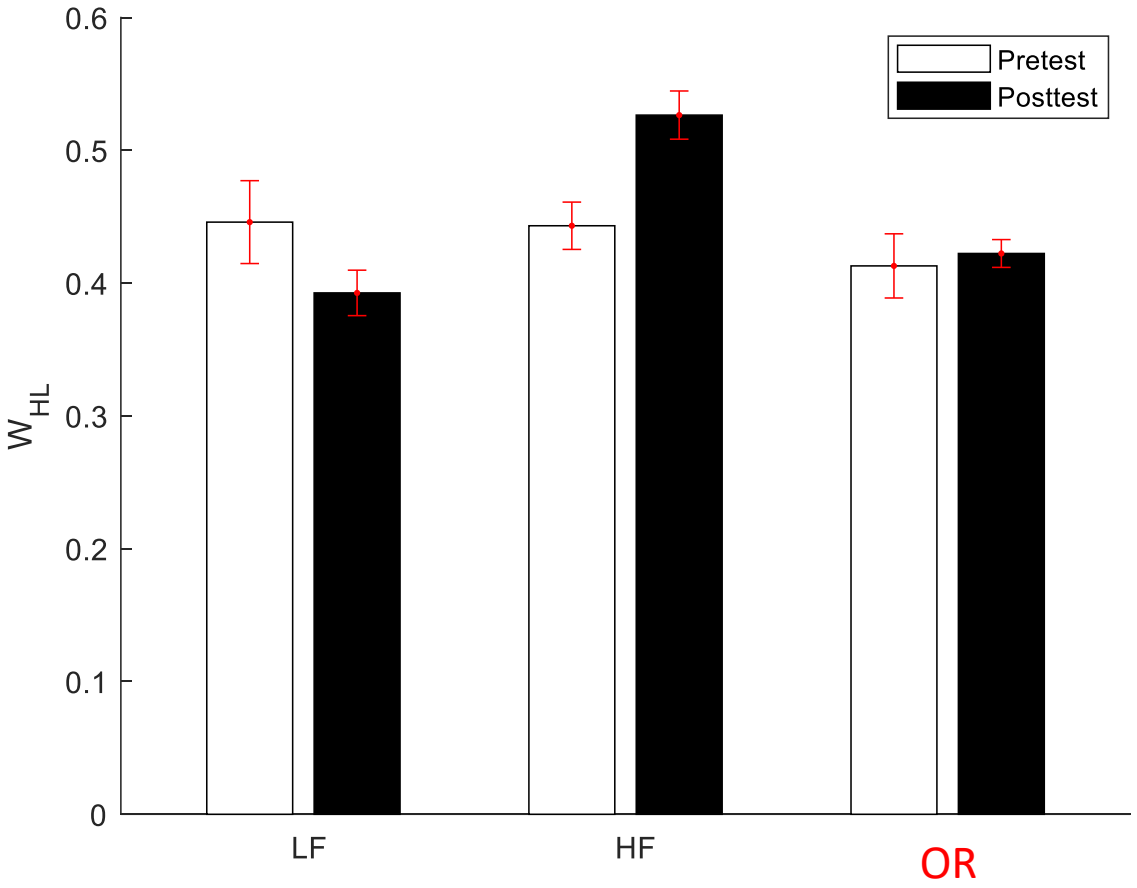
- O: only VE pre/posttest (N=5)
- OR: VE+VR pre/posttest (N=5)

Prediction:

w_{LT} will increase in the OR, but not in the O group.

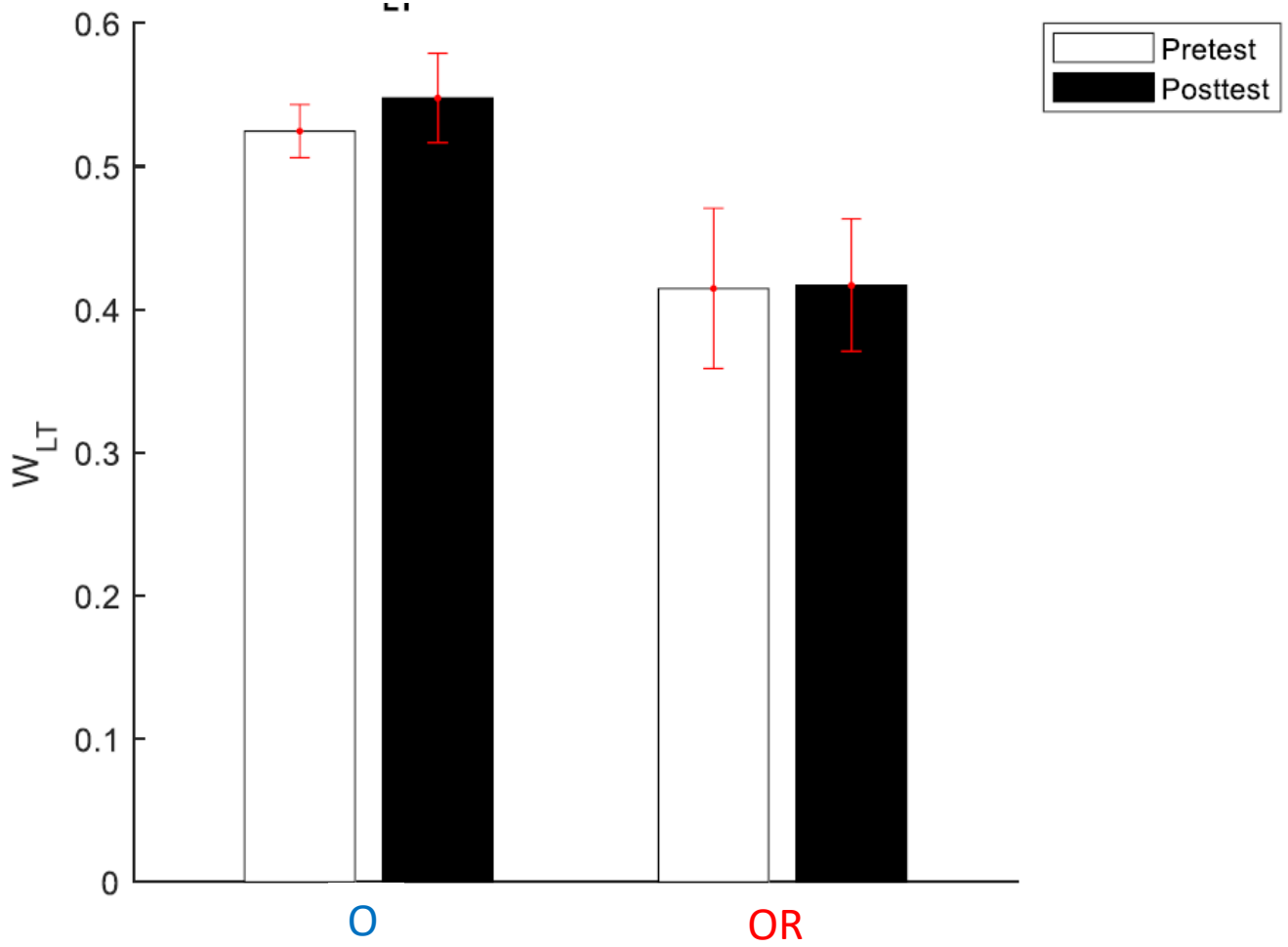


Results: w_{HL} (HF vs. LF) in OR group



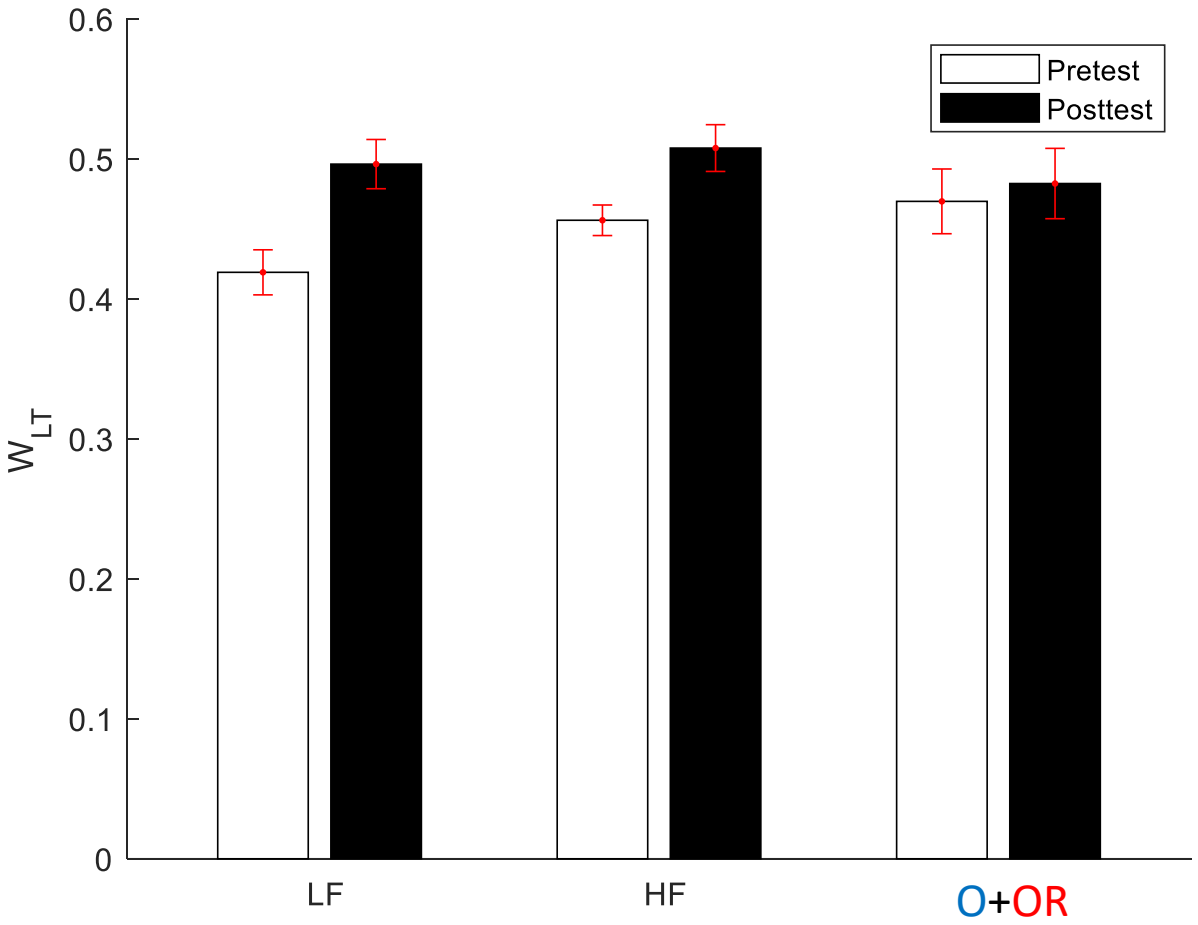
No spectral reweighting observed without training.

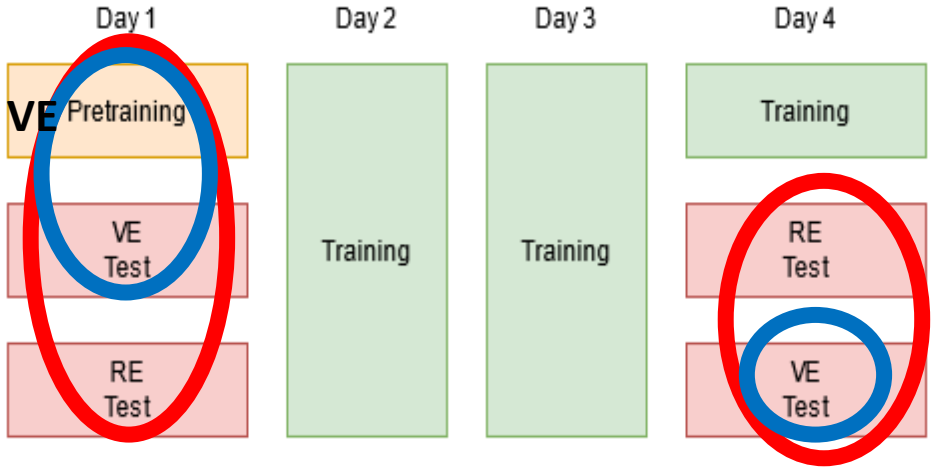
Results: w_{LT} (ILD vs. ITD) in OR and O groups



No pre-post change in either group, especially not for OR (difference between groups not significant).

Results: w_{LT} (ILD vs. ITD) OR+O vs. LF & HF groups





Training effect (w_{LT} increase) observed in Spisak (2021) not driven by adaptation reverberant environment in immediately preceding session.

Conclusion and Next Steps

Possible explanations of all groups increasing ILD weight:

- ~~**Adaptation to immediately preceding environment**~~

→ **Effect caused by participation in the training sessions**

Alternative:

- long-term adaptation due to **presence of reverberation** during training sessions (which makes **ITD less reliable → down-weighted**)

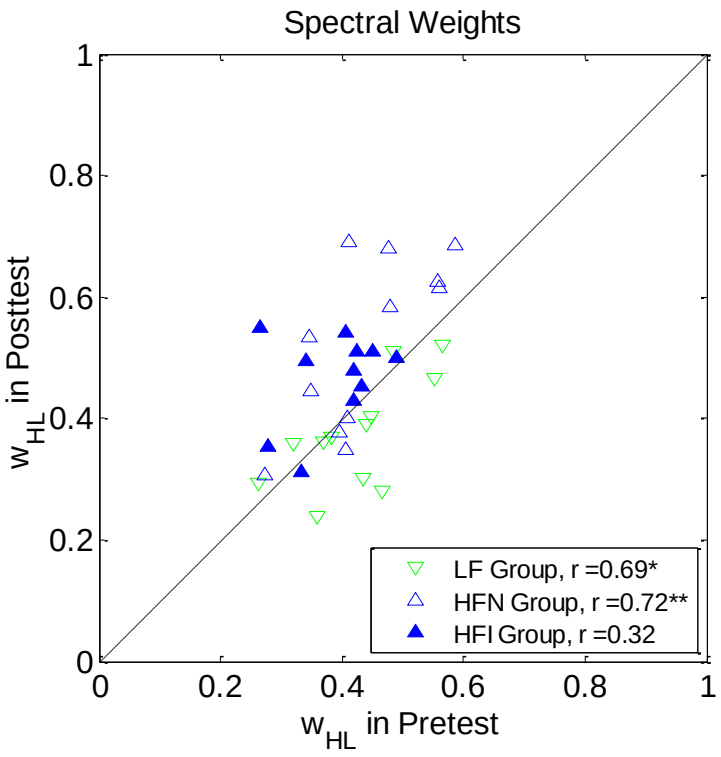
But:

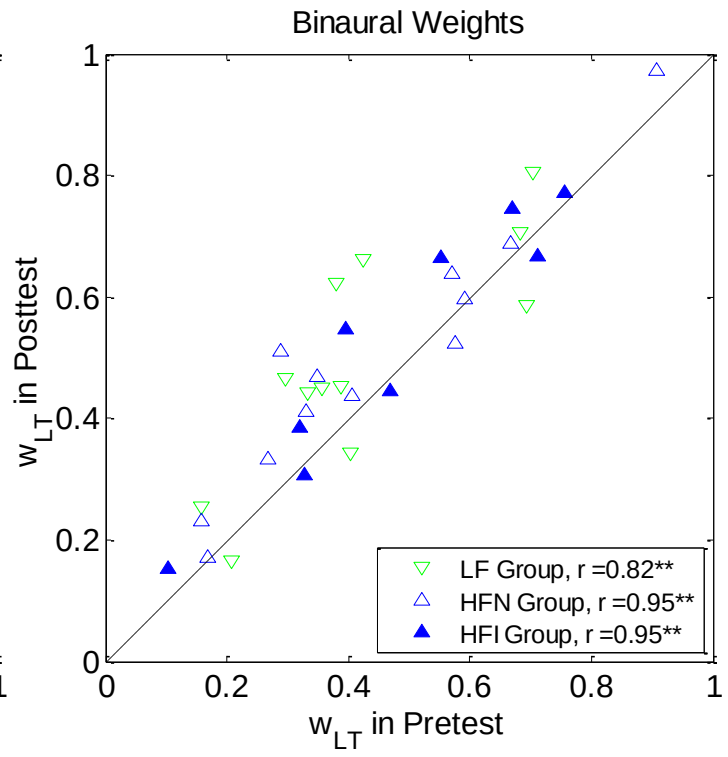
- Is passive exposure to reverberation enough?
- Is it necessary to perform a localization task in reverberation?
- Is it necessary to do the spectral-reweighting training?
- Is just one training session enough?
- Can the reweighting be enhanced, eg, in more reverberation?

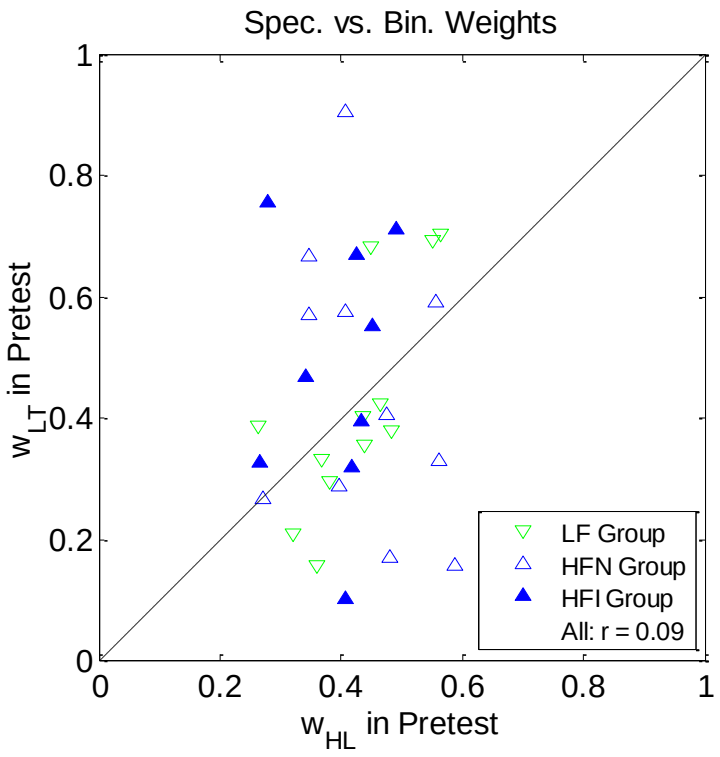
Next step:

- new experiment to explore hypothesis that **presence of reverberation during training sessions is critical**.
- in virtual environment. Use two groups, both with LF training:
  - anechoic VE: expected no effect or decrease in w_{LT},
  - reverberant VE with T_{60}>current room: expected w_{LT} increase larger than in current study.

PS: Spectral & Binaural weights Correlation (orig study)







Small inter-subj. variation, weak correlation

Large inter-subj. variation, strong correlation

No correlation: **spectral weighting not predictive of binaural weighting**