Reweighting of binaural localization cues in virtual environment

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Introduction

The auditory system combines the binaural cues of interaural time difference (**ITD**) and interaural level difference (**ILD**) to determine the sound source location. The combining is frequency dependent. ITD dominates for low-frequency (**LF**) sounds and ILD for high-frequency (**HF**) sounds. We can experimentally measure the relative ITD/ILD weight by a localization task. A previous study (Spišák et al., 2021) showed that **visually guided training** on HF vs LF components in real environment can lead to an increase in the weighting of the trained spectral region (HF or LF). However, this spectral reweighting induced an **unexpected pattern** of **reweighting** in the **binaural** localization cues such that the **ILD weight increased** for both LF and HF training. Here, we performed a **follow-up experiment** in real reverberant (RE) and virtual anechoic (VE) environments **without training** to examine the cause of the observed ILD weight increase. We hypothesized that the previously observed binaural reweighting was due to performance of RE posttest immediately prior to VE posttest, and thus it would be observed even in this setup.

Methods

Participants: Two groups, one performed experiment in real and virtual environment (7 subjects, ***OR group***) and one performed only virtual part (7 subjects, ***O group***).
Design for the OR group: ***Day 1*** (VE pretraining, VE pretest, RE pretest); ***Day 2-3*** (no training); ***Day 4*** (RE posttest, VE posttest)
Design for the O group: Same as for the OR group except that no RE tests were performed.
Apparatus: ***VE setup-*** VR glasses (Oculus), headphones
RE setup – headtracker, loudspeakers, LED projector

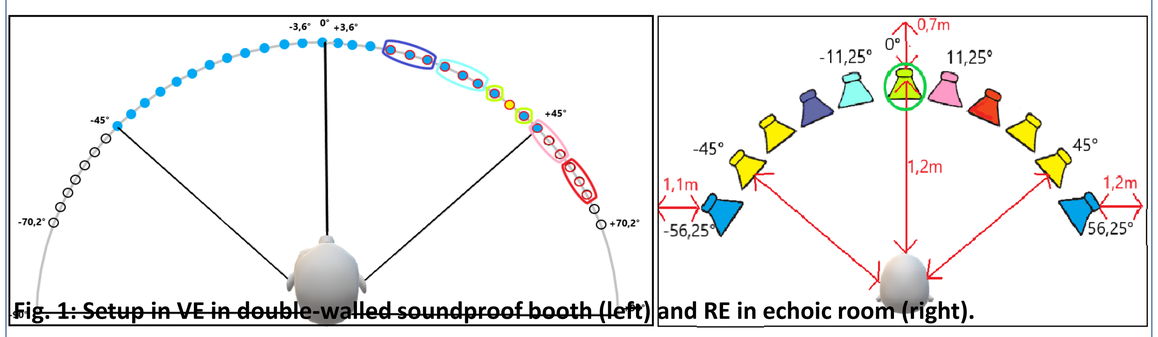

Fig. 1: Setup in VE in double-walled soundproof booth (left) and RE in echoic room (right).

Stimuli:
RE: 5 types of stimuli were presented, created using 0.5-octave noise bands at different frequencies. Stimuli consisted of 2 or 4 spectral components (LF - 0.35 kHz, 0.7 kHz; HF - 5.6 kHz, 11.2 kHz) such that different LF/HF components were played from different speakers.
VE: ITD/ILD combinations corresponding to one of 40 possible positions in horizontal plane. 1-octave noises, f_c = 2.8 kHz with ITD and ILD corresponding to different locations (separation up to 25.2°).
Task: Rotate head towards the perceived sound location. Position of the head was guided with visual feedback.

Analysis

Regression model fitted separately for each target azimuth α.

RE model: $R(\alpha, \Delta_{LF}, \Delta_{HF}) = k_{LF}(\alpha) * \Delta_{LF} + k_{HF}(\alpha) * \Delta_{HF} + Q(\alpha))$; $w_{HL} = \frac{\operatorname{atan}\left(\frac{k_{ILD}(\alpha)}{k_{ITD}(\alpha)}\right)}{90}$

R is a subject's response azimuth in a trial with LF and HF components at positions $\alpha + \Delta_{LF}$ and $\alpha + \Delta_{HF}$, respectively k_{LF}, k_{HF} and Q are approximated parameters of a regression model and Q is the overall bias for azimuth α.
VE model: Equivalent to RE model except α is between -45° and 45° with 3.6° steps. $\boldsymbol{w_{HL}}$ and $\boldsymbol{w_{LT}}$ are, respectively, estimated weights of HF vs. LF and ILD vs. ITD components. Weights were averaged across azimuth as training effects were similar across azimuth.

Hypotheses

1. Weights of HF and LF spectral components in real environment will not increase because training of components is omitted.
2. Re-weighting of binaural components ITD and ILD in virtual environment is affected by prior posttest in real environment, resulting in ILD weight increase.

Results

Real environment (Fig. 2):
LF and HF training groups from Spišák et al. changed their weighting from pretest to posttest according to the training region. No re-weighting is happening without training (NoT corresponds to the OR group). ANOVA showed a significant Time X Group interaction ($F(2,39)=10.98$, $p<0.01$), with no significant effect of time for the OR group ($F(3,18) = 2.48$, $p>0.05$).

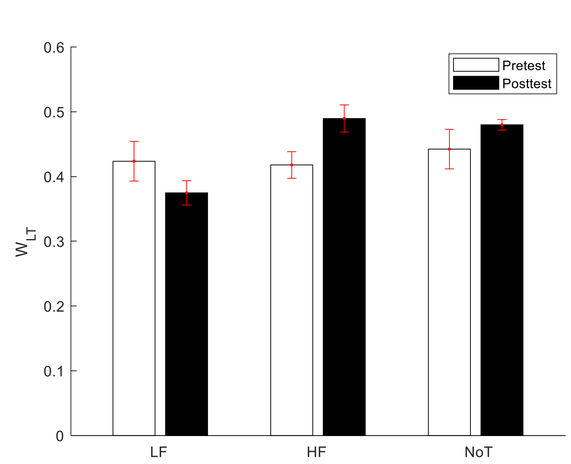

Fig. 2: Mean (±SEM) weights w_{HL} for different groups in pretest and posttest, averaged across locations.

Virtual environment (Fig. 3):
Based on hypothesis #2, reweighting resulting in increased ILD weight was expected for the OR but not the O group. No effect was observed for either group.
LF & HF training groups LF/HF from Spišák et al. showed an increase of ILD weight, independent of the type of training group.
For our no training groups (NoT = O+OR groups combained) change in pretest to posttest was not significant and change in reweighting was not dependent on group, meaning that RE posttest done before VE posttest has no effect.
ANOVA on O and OR group data showed no effect of time $F(1,12)=0.28$, $p>0.05$) or group ($F(1,12)=3.35$, $p>0.05$). ANOVA on training (HF+LF) vs. no-training (O+OR) groups showed a near-significant Time X Group interaction ($F(1,45)=3.13$, $p=0.0835$).

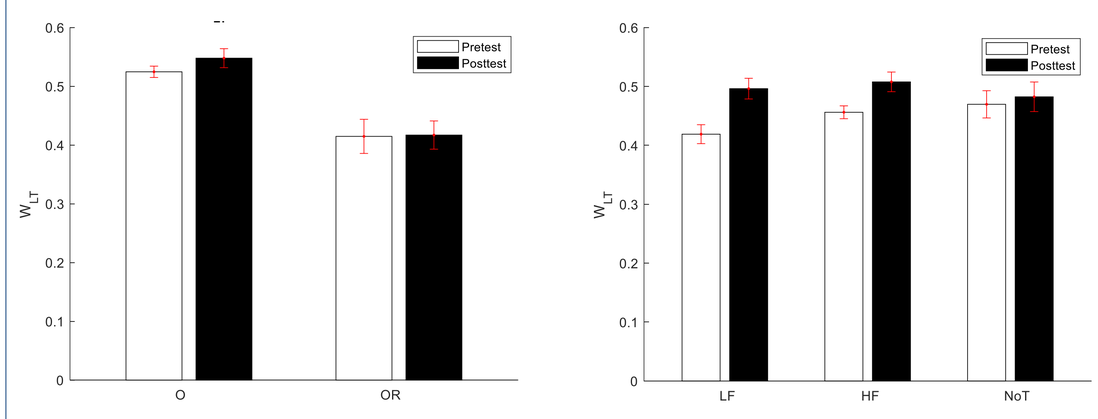

Fig. 3: Mean (±SEM) weights w_{LT} for O and OR group on the left and for trained and no trained groups in pretest and posttest on the right, averaged across locations.

Summary and Discusion

Results from RE show that change in spectral weighting does not occur, as we expected because no training of HF and LF components was performed.
Based on previous results we hypothesized that performing a posttest in RE immediately before the VE posttest may have caused the increased ILD weight. However, the current follow-up results do not show the expected effect as no significant re-weighting occurred from pretest to posttest. Thus, a change in weighting cannot occur by changing from an anechoic environment to an echoic one, nor does it occur by getting used to an echoic room. Thus, it is due to the visual training in real environment performed by Spisak et al. However, what aspect of the training is important is still unknown.
These results are important for designing training protocols for improving spatial hearing in normal-hearing as well as in hearing-impaired listeners, in particular those with cochlear implants.

Acknowledgment and References

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