Vision-based Adaptation of the Frequency-dependent Weighting of the Localization Cues

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INTRODUCTION

- Sound localization in the horizontal plane is largely determined by two physical cues: interaural time difference (ITD) and interaural level difference (ILD).
- For low-frequency (LF) sounds, the interaural time difference (ITD) is the dominant cue, while for high-frequency (HF) sounds, the interaural level difference (ILD) dominates.
- Previous experiments showed that changing the weighting of ITD and ILD while determining the location of a sound source is not always successful (Jeffress & McFadden, 1971), but possible in virtual environment (Ferber, Laback, & Kopčo, 2018).
- Here we examined whether it is possible to change the spectral weighting of high (HF) vs. low (LF) components of sound in real environment.

HYPOTESIS

1. Change of weighting of HF vs. LF components of sound in real environment will occur as result of training reinforcing either of the two components.
2. The reweighting of spectral components will generalize to new (untrained) spectral components, and a change of ITD/ILD weighting in virtual environment.

METHODS

Design: Day 1: Virtual Environment (VE) Pre-training – VE Posttest – Real Env: (RE) Pretest Day 2-4: RE Training, on Day 4 followed by RE Posttest & VE Posttest

Participants: 25 subjects with normal hearing, 2 experimental groups:
- LF target group (13 S): Trained on low-frequency components
- HF target group (12 S): Trained on high-frequency components

Apparatus: VE setup - VR glasses, headphones
- RE setup - electromagnetically tracking, loudspeakers, LED projector

Stimuli: VE. Narrow-band, 1-octave noises with center frequency of 2.8 kHz; independent combinations of ITD and ILD in range from -70° to 70°, with an inconsistency between ILD and ITD positions of up to 25°.
- RE: 0.5-octave noise bands centered at HF (11.2 or 5.6 kHz, LF (0.7 or 0.35 kHz) and medium frequency (MF, 2.8 kHz). 3 types of stimuli: 2-channel (1 HF & 1 LF), 4-channel (2 HF & 2 LF), 2-channel stimulus with MF (1 MF & 1 LF or 1 HF); 11 speakers were spread in the range from -56° to 56° (11.25° spacing) with an inconsistency between positions of HF and LF components up to 22.5°. Visual feedback projected on top of speakers.

Task: - Pretest/Posttest: localize a sound by performing a head-turn towards it.
- Training:
  - Head-turn to 0°: Present stimulus once
  - Head-turn to perceived target location & press Enter
  - Visual feedback
  - Head-turn to visual feedback & press Enter
  - Stimulus continuously
  - Head-turn to 0° & press Enter
  - Stimulus stops

Figure 1. Training procedure

Analysis using a regression model fitted separately for each target azimuth $\alpha$.

RE model: $R(\alpha, \Delta_LF, \Delta_HF) = \kappa_LF(\alpha) \cdot \Delta_LF + \kappa_HF(\alpha) \cdot \Delta_HF + Q(\alpha)$; $w_{\text{LF}} = \frac{\kappa_LF(\alpha)}{\sum \kappa_LF(k)}$ and $w_{\text{HF}} = \frac{\kappa_HF(\alpha)}{\sum \kappa_HF(k)}$

$R$ is a subject’s response azimuth in a trial with LF and HF components at positions $\alpha \pm \Delta_LF$ and $\alpha + \Delta_HF$, respectively ($\alpha$ is between -56.25° and 56.25° with 11.25° steps). $\kappa_LF$ and $\kappa_HF$ are regression slopes (determining the weights of the frequency components) and $Q$ is the overall bias for azimuth $\alpha$.

VE model: $R(\alpha, \Delta_LD_T, \Delta_LD_R) = \kappa_T(\alpha) \cdot \Delta_LD_T + \kappa_R(\alpha) \cdot \Delta_LD_R + Q(\alpha)$; $w_{\text{LD_T}} = \frac{\kappa_T(\alpha)}{\sum \kappa_T(k)}$ and $w_{\text{LD_R}} = \frac{\kappa_R(\alpha)}{\sum \kappa_R(k)}$

$R$ is a subject’s response azimuth in a trial where the ITD and ILD corresponded to positions $\alpha + \Delta_LD_T$ and $\alpha + \Delta_LD_R$, respectively ($\alpha$ is between -45° and 45° with 3.6° steps). $\kappa_T$ and $\kappa_R$ are regression slopes (determining the binaural cue weights) and $Q$ is overall bias for azimuth $\alpha$.

$w_{\text{ITD}}$ and $w_{\text{ILD}}$ are, respectively, estimated weights of HF vs. LF and ILD vs. ITD components.

RESULTS

- The HF group’s HF weight in the posttest is significantly higher than in the pretest ($F(1,12) = 5.98; p = 0.0308$), while no effect of training is observed for the LF group ($F(1,11) = 0.65; p=0.4367$).

- HF training generalizes to sounds consisting of trained frequencies and a new 2.8-kHz component, but only for trained low-frequency components (0.35-0.7 kHz).

REAL ENVIRONMENT

- No significant group-specific change in ILD weights was observed, even though an increase in ILD weights from pre- to posttest is observed for both groups ($F(1,12) = 13.02; p = 0.0016$).

VIRTUAL ENVIRONMENT

- No significant group-specific change in ILD weights was observed, even though an increase in ILD weights from pre- to posttest is observed for both groups ($F(1,12) = 13.02; p = 0.0016$).

CONCLUSIONS

- The results show that it is possible to change the weighting with which individual spectral components contribute to sound localization in a real environment.
- The HF-training was successful but LF-training not, possibly because the LF components are strongly weighted already in the pretest. The HF-training generalized to the untrained frequencies (2-channel stimuli with MF), but only when combined with LF components.
- The HF-training did not generalize to a group-specific change in the ITD/ILD weighting, suggesting that it is spectrum-specific. However, other differences between the real and VR stimuli, like the presence of reverberation in the real environment, might also have played a role.

ACKNOWLEDGMENT AND REFERENCES

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