Mechanisms of Contextual Plasticity vs. Shifts in Human Sound Localization

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ABSTRACT

Contextual plasticity is a form of plasticity in sound localization induced by preceding stimulations. It is observed as shifts in responses and in standard deviations to a target click stimulus when, on interleaved trials, the target is preceded by an identical adaptor coming from a fixed location. Here we present the results of two experiments, one performed in real and one in virtual environment, evaluated in the context of two models of the neural mechanisms underlying spatial hearing in humans. The first model (Carlile et al., 2001) encodes spatial location by activity of a large population of neurons aimed at accurately encoding the stimulus location. The second model (Lingner et al., 2018) assumes that spatial location is encoded in activity of 4 opponent-processing channels optimized for sound source separation, not localization. The modeling found that performance in the real environment is more aligned with the first model, while performance in the virtual environment is more aligned with the second model, suggesting that listeners use different strategies and/or neural mechanisms when localizing sounds in real vs. virtual environments.

CURRENT STUDY

Two candidate mechanisms have been proposed to explain adaptation phenomena similar to CP:
- **Carlile et al. (2001):** fatigue due to extended activation reduces responses in spatial channels near adaptor location.
- **Lingner et al. (2018):** spatial representation adapts to improve source separation at the cost of introducing localization biases.

Predictions for location discrimination performance after adaptation:
- Carlile et al. (2001): worse for targets near adaptor (vs. far from adaptor),
- Lingner et al. (2018): better for targets near adaptor in virtual environments.

Here, we evaluate these opposing predictions for two bias-independent localization measures: stimulus-response correlation, response standard deviation and information transfer rate.

BEHAVIORAL DATA (Linková, 2022)

Methods

Setup (Fig. 1A):
- Exp. 1 in real midsize reverberant room (RRE), 6 target speakers, 5 adaptor speakers
- Exp. 2 in virtual environment (VE) using headphones, midsize reverberant (VRE) or anechoic room (VAE), 6 target speakers, 3 adaptor speakers (slightly shifted locations),

Stimuli (Fig. 1B):
- Target (T): 2-ms frozen noise click
- Adaptor (A): train of 12 such clicks presented at rate of 10/sec
- In Exp. 2 created by convolving with non-individualized BRIRs/HRTFs from a similar room.

One trial:
- only T or A presented
- If T presented, respond by entering number combination seen at perceived location
- If A presented, just hit Enter.

Runs:
- Divided into subruns (1 presentation of each T)
  - T-only pre-adaptation, 2 subruns
  - adaptation w/ T & A equiprob, 14 subruns
  - T-only post-adaptation, 3 subruns
- A location fixed within run (silent in baseline).

Subjects and Experiments:
- Exp. 1: 8 normal-hearing subjects, Exp.2: 9 subjects (+1 excluded due to outliers)
- Exp. 1: 3 sessions, each of 6 randomly ordered runs
- Exp. 2: 3 sessions, 8 rand. ordered runs (1 for each A + baseline)*2 environments

Data Analysis:
- Only later portion of adaptation parts considered (subruns 7-16)
- Triplets of targets are analysed to compare effects of near and far targets to adaptor

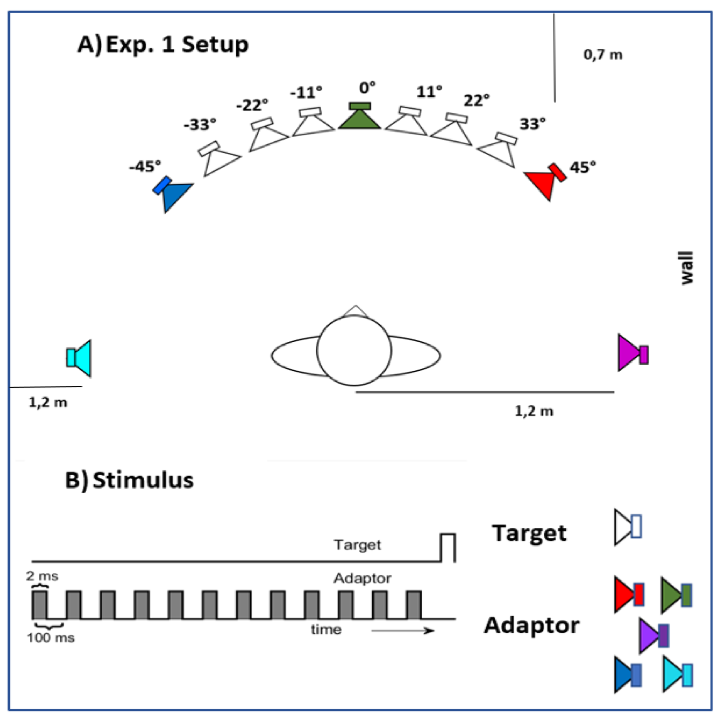

Fig. 1. Setup and stimuli. A) Setup of Exp. 1 in real room. B) Stimuli in both experiments.

Pearson's Correlation Coefficient:
- Targets divided into triplets of 3 right-most (RT) and 3 left-most targets (LT)
- Responses for each triplet correlated with real positions within a run
- Results combined across left-right symmetric positions (-90° LT, +90° RT)

Standard Deviations:
- SD computed separately for each combination of session, target, run and subject; then averaged
- Results combined across left-right symmetric conditions

Information Transfer Rate:
- ITR is a measure of how much information about the actual target location can be extracted by observing the responses, and it does not assume a linear relationship (based on Shannon's information theory).

PREVIOUS RESULTS

Passive exposure to adaptors induces a repulsive **contextual bias** (to baseline) in responses, Fig.2 upper panels, that:
- depends strongly on adaptor location (compare lines) and target locations
- is modulated by environment (stronger in Virtual environments than in RRE and the strongest in VAE)

Build-up (to baseline) of Contextual Plasticity, Fig. 2 lower panels) depends on:
- adaptor location (slowest for frontal adaptor)
- the environment (slowest for RRE and fastest for VAE)
- in RRE Anova showed main effects adaptor (p=0.01) and subrun (p=0.05) and interaction adaptor x subrun (p=0.01).
- In VE Anova showed the similar results and for parameter environment (reverberant, anechoic) p=0.057

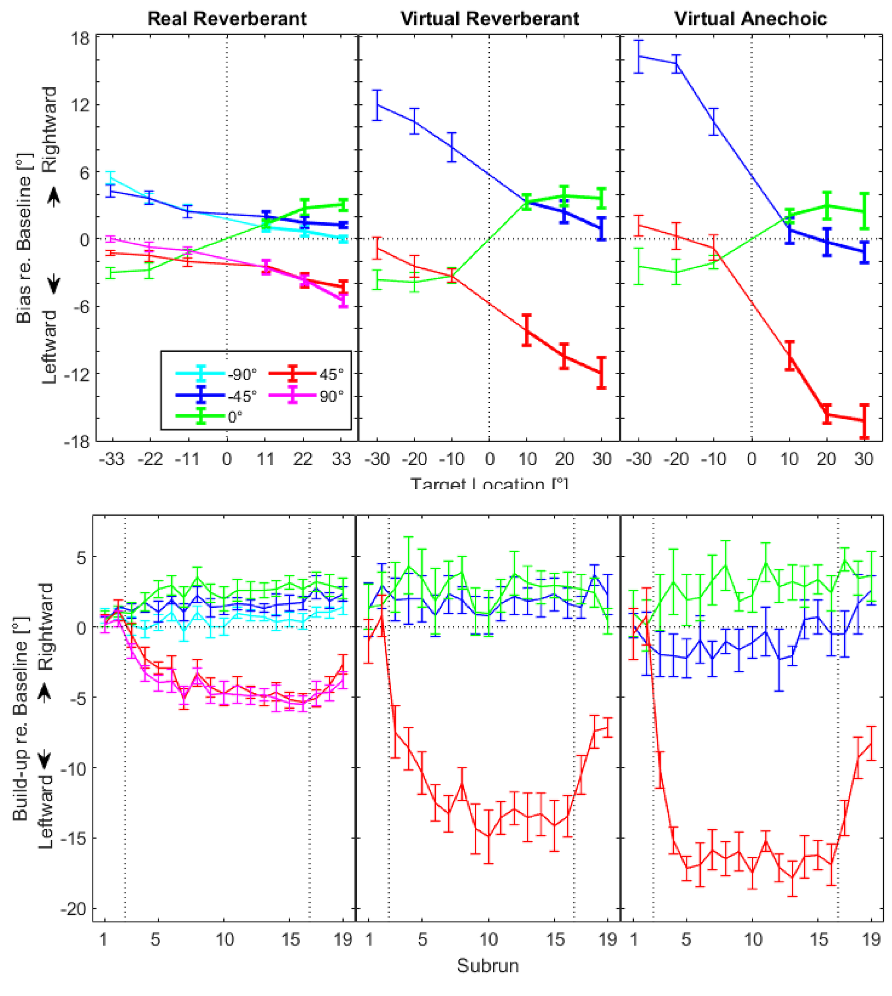

Fig. 2. Top: Bias re. Baseline – results averaged across time. Bottom: Temporal profile of build-up in contextual bias averaged across target locations and referenced to baseline

CARLILE's and LINGNER's MODELS

Carlile's model (Carlile et al., 2001) - a population of units, each tuned to a different spatial location, encodes auditory space

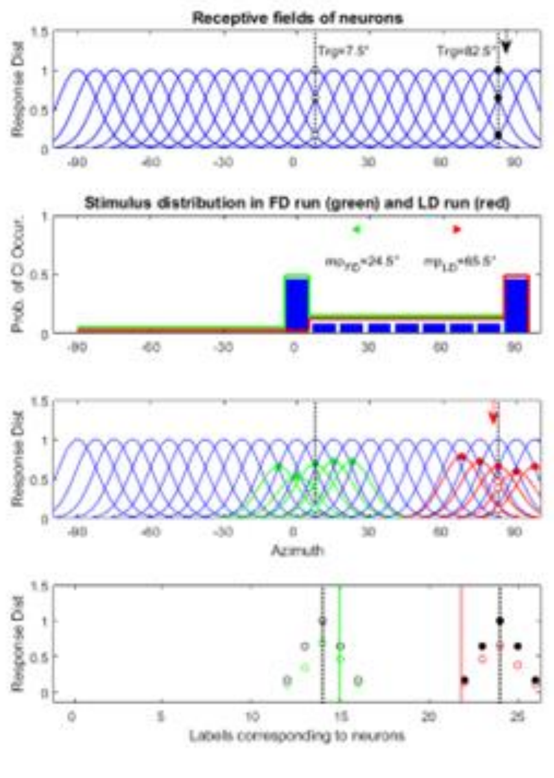

Fig 3. Carlile's model

Lingner's model (Lingner et al., 2018) - an alternative coding model, called a hemispheric balanced model (HBM), it uses independently calculated results for sound localization from both hemispheres, and combines these results

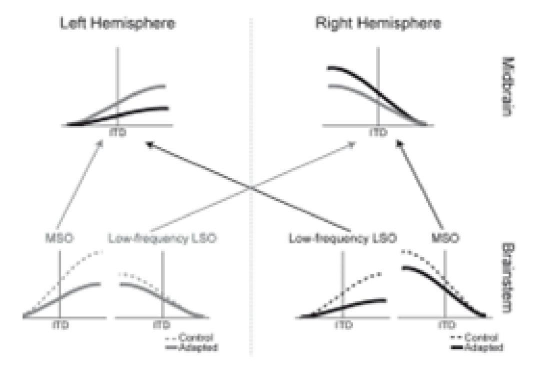

Fig. 4. Lingner's model.

Important for the current study:
Carlile's: it is assumed that since the auditory space representation is suppressed near the adaptor due to this adaptation, the SD in responses to target near the adaptor will be increased in the adapted vs. unadapted population
Lingner's: the goal of the adaptation is to increase separability sources in the region from which most stimuli are presented, resulting in increased discriminability between targets presented near the adaptor

CP RESULTS IN CONSISTENCY WITH MODELS

Standard deviation re. baseline
- increases for targets near adaptor in RRE ($p < 0.05$)
- no significant effect in VRE
- in VAE, SD decreases near adaptor and increases further away ($p = 0.09$)
- SD for frontal adaptor tended to be on the same level as for baseline in both experiments

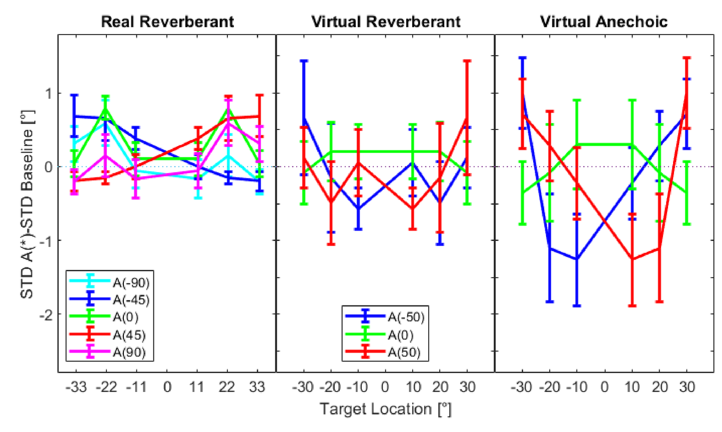

Fig. 5 SD Adaptors re. SD Baseline

Correlations in responses - Pearson's correlation coefficient, r:
- better in RRE than in VE, and in VRE better than VAE,
- better for targets far (Contra) than near (Ipsi) in the lateral adaptor, and in RRE ($p < 0.0001$),
- better in no-adaptor baseline than with frontal adaptor in all environments

Information Transfer Rate
- is higher for contralateral adaptors than for ipsilateral ones in all environments; presented information is more exact for contralateral adaptor in considering targets,
- no consistent trend is observed for the information transmission for baseline vs. the frontal adapter.

RRE
- The increased SD is consistent with the Carlile's model.
- It is likely that the listeners use absolute localization, allowing them to map the acoustic cues to an actual sound source location.

VE, VAE
- The decreased SD are more consistent with the Lingner's model.
- Although SD is high for the farest target, it quickly decreases afterwards, becoming lower than in the baseline.
- On average, the presence of the adaptor helped reduce the variability of responses for nearby targets in VE.
- In VE, listeners might be changing their strategy and using relative localization, e.g., localizing the targets relative to the known location of the adaptor.

- **SD: Results of SD are more consistent with Carlile's model, but there is some exception in VAE .**
- **CC: Correlations always consistent with Carlile et al. model.**
- **ITR: Consistent with Carlile's model for lateral adaptors**

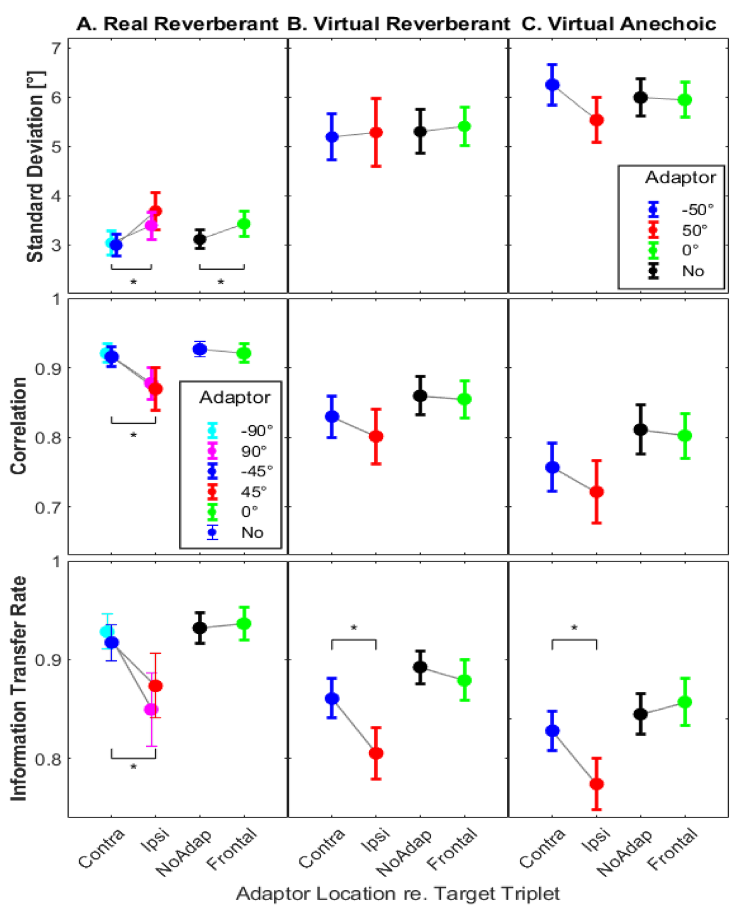

Fig. 6. Evaluation of target triplets – near to adaptor (Ipsi) versus far from adaptor (Contra)

CONCLUSIONS AND DISCUSSION

Since it is very unlikely that two different neural mechanisms would be implemented in the brain, driving the different results, it is more likely that listeners use different strategies when localizing sounds in the real and virtual (particularly anechoic virtual) environments. Specifically, it is likely that in real environments listeners use absolute localization allowing them to map the acoustic cues to an actual sound source location. On the other hand, in virtual environments in which the cue- to-location mapping is ambiguous, listeners might be changing their strategy and using relative localization, e.g., localizing the targets relative to the known location of the adaptor.

This interpretation is also consistent with the Carlile and Lingner studies, as the former one was performed in real environment while the latter one was performed in a virtual anechoic environment.
Future directions: In Virtual environments to analyze responses for lateral adaptors in positions +90° and -90°.

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