Contextual Plasticity in Sound Localization Induced by Passive Exposure to Transient Sounds

Stanislava Linková, Gabriela Andrejková and Norbert Kopčo
Institute of Computer Science, Pavol Jozef Šafárik University in Košice, Slovakia

Introduction

Contextual plasticity (CP) is a localization aftereffect occurring on the time scale of seconds to minutes. It has been observed as a bias in horizontal sound localization of click target stimuli presented alone, when interleaved with contextual distractor-target trials in which the distractor was at a fixed location while the target location varied. The observed bias is always away from the contextual distractor location, even though the distractor is not present on the experimental trials (Kopco et al., 2007, 2017).

Here, two experiments were performed. Exp. 1 examined whether this phenomenon is dependent on engagement of the subject in an active localization task on the contextual trials, as used in previous studies. Here, instead, contextual trials only contained the distractor without any targets, and the listener's task was to passively listen to the context. **It was hypothesized that if CP is mainly caused by adaptation to the distractors, then it would be observed also in this condition.** Exp. 2 examined whether CP is also observed in virtual environments, both reverberant and anechoic. It used a setup similar to Exp. 1 and **it was hypothesized that the observed CP might be stronger than in Exp. 1, in particular in anechoic virtual space, as no real-world anchoring to stimuli in real world is available.** In both experiments, distractor locations were varying from block to block while the target range was fixed across blocks, to examine how CP depends on the distractor location.

Methods

Setup (Fig. 1A and 1B):

- Exp. 1 in real midsize reverberant room, 6 target speakers, 5 adaptor speakers,
- Exp. 2 in virtual midsize reverberant or anechoic room, 6 target speakers, 3 adaptor speakers,
- Projection strap with random number combinations above loudspeakers, with combinations changing on each trial,
- Subject seated, head in headrest, holding numeric keypad.

Stimuli (Fig. 1C):

- 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:

- T (at random location) 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 equiprobable (14 subruns)
- T-only post-adaptation (3 subruns)
- A location fixed within run (silent in baseline).

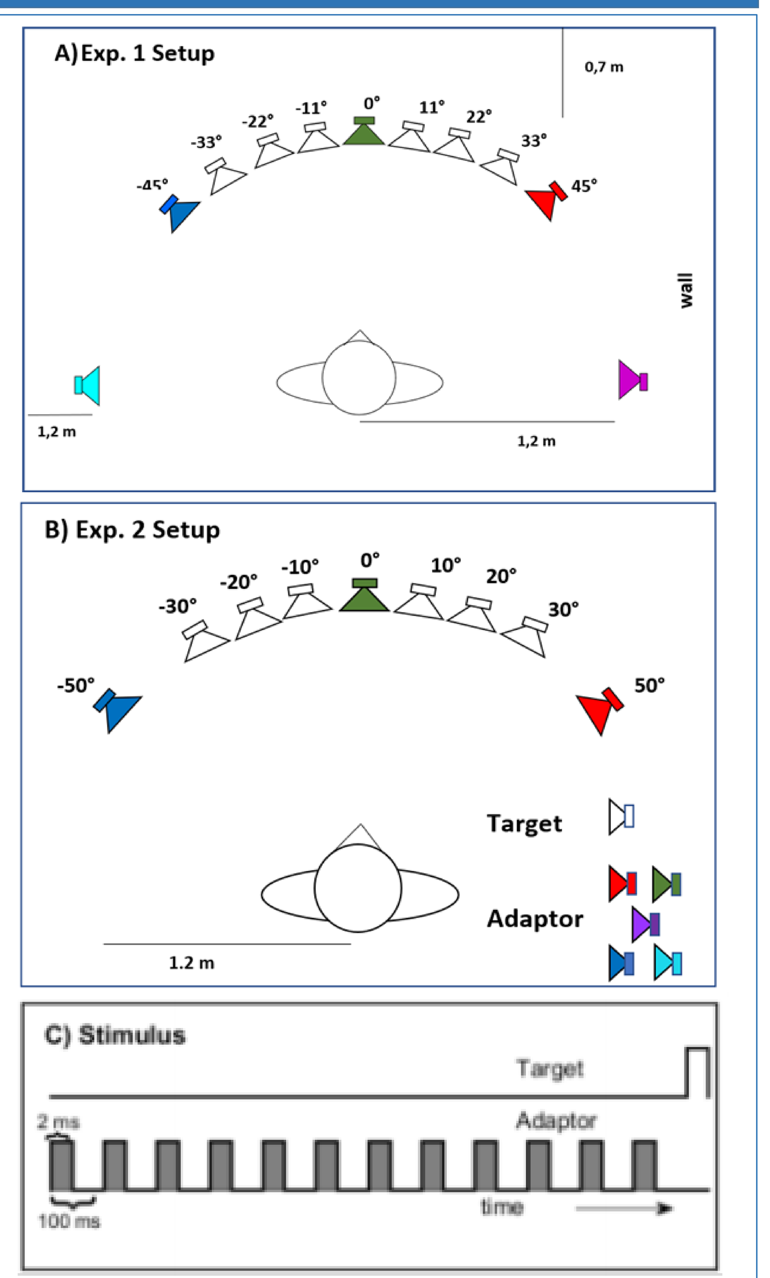

Fig. 1. Setup and stimuli. A) Setup of Exp. 1 in real room. B) Setup of Exp. 2 in virtual anechoic or reverberant rooms. C) Stimuli in both experiments.

Experiment 1 :

- 8 normal-hearing subjects
- 3 sessions, each of 6 randomly ordered runs (1 for each A + baseline)

Experiment 2:

- 10 different normal-hearing subjects
- 3 sessions, each of 8 rand. ordered runs (1 for each A + baseline)*2 environments

Results: Spatial Adaptation

Response biases (Fig. 2):

- depend strongly on adaptor location (compare lines),
- are modulated by Experiment (stronger in virtual Exp. 2),
- in Exp. 2, are modulated by environment (Reverb. vs. Anech),
- in baseline, show compression in real and expansion in virtual environments,
- are approximately left-right symmetric,
- ANOVA on Exp 1: significant A x T interaction ($p < 0.001$)
- ANOVA on Exp. 2: significant A x T x Env. int. ($p < 0.001$)

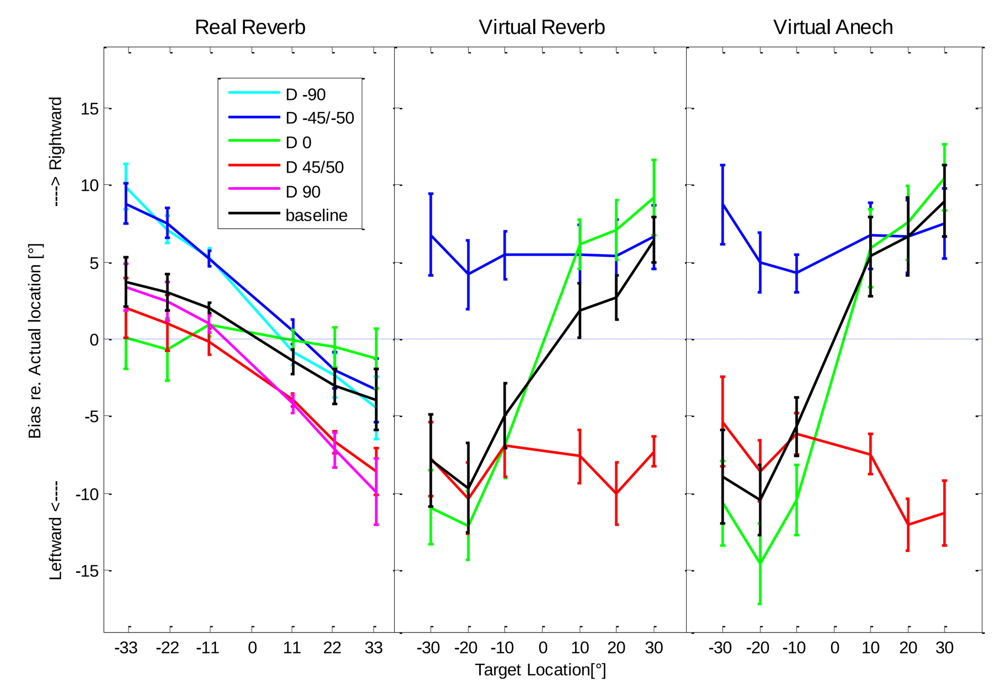

Fig. 2. Results of Exps. 1 (left-hand panel) and 2 (middle, right-hand panel) averaged across time. Each graph shows the across-subject bias in responses re. actual target location for one distractor location (±SEM).

Passive exposure to Adaptors induces Contextual bias in responses that is:
- **depends on the Adaptor and Target locations, and**
- **is modulated by the simulation and environment.**

Biases re. baseline (Fig. 3)

- always away from A,
- always stronger for Lateral Adaptors (±45°,90°) than Frontal Adaptor., especially near A → possibly due to expansion (green) vs. shift (blue)
- in Exp. 1 different between 45° and 90° (significant interaction).
- In Exp. 2, Lat. A stronger for Anech (19°) than Reverb (15°) env (signif. Int.).
- Frontal A has similar effect (expansion up to 3°) in all 3 environments (signif. diff. in Real vs. Virtual Reverb).

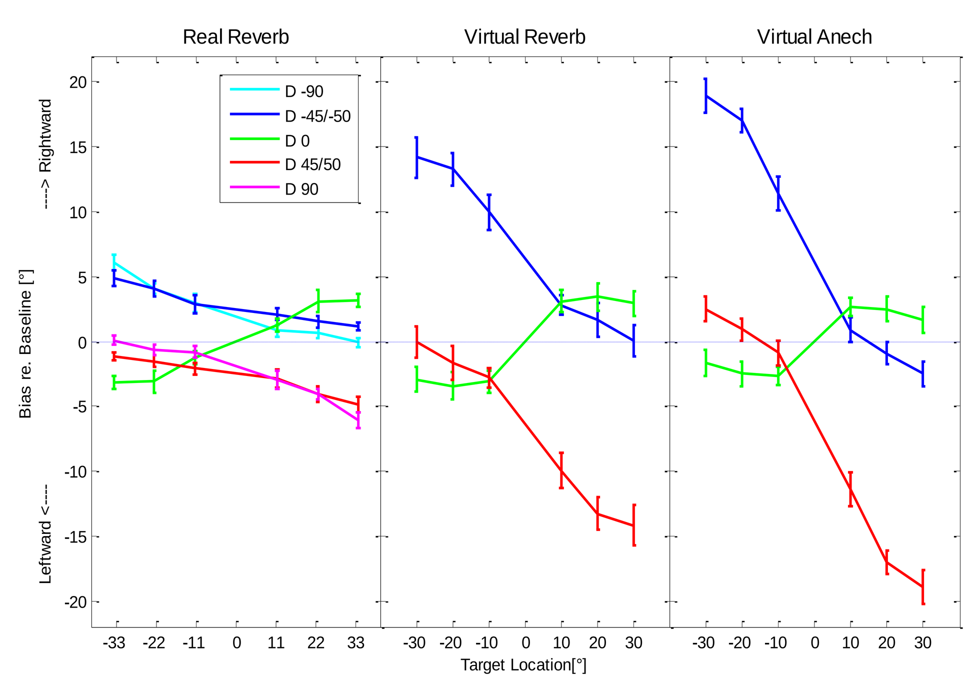

Fig. 3. Results from Fig. 2 replotted after combining data across left-right symmetric conditions and referencing them to the baseline. Each graph shows the across-subject bias in responses re. baseline for one distractor location (±SEM).

Contextual Bias/Repulsion induced by Adaptors:
- **is in direction away from Adaptor,**
- **grows with Adaptor laterality & decreases with T/A separation,**
- **is stronger in virtual environments than real environment, and**
- **is stronger in virtual anechoic than reverberant environment.**

References

Carlile, S., Hyams, S., & Delaney, S. (2001). Systematic distortions of auditory space perception following prolonged exposure to broadband noise. J Acoust Soc Am, 110(1), 416–424.
Dahmen, J. C., Keating, P., Nodal, F. R., Schulz, A. L., & King, A. J. (2010). Adaptation to Stimulus Statistics in the Perception and Neural Representation of Auditory Space. Neuron, 66(6), 937–948.
Kopčo, N., G. Andrejkova (2020). " Build-up of Contextual Plasticity in Anechoic and Reverberant Rooms ", presented at the Forum Acusticum, Lyon, Dec 7-11, 2020.
Kopčo, N., Best, V., & Shinn-Cunningham, B. G. (2007). Sound localization with a preceding distractor. J Acoust Soc Am, 121(1), 420–432.
Kopčo, N., Andrejková, G., Best, V., & Shinn-Cunningham, B. (2017). Streaming and sound localization with a preceding distractor. J Acoust Soc Am, 141(4), EL331–EL337.
Piková V. (2018). Mechanizmy kontextuálnej plasticity v lokalizácií zvukov: bakalárska práca. Univerzita Pavla Jozefa Šafárika v Košiciach.

Acknowledgement

Work supported by Slovak Research and Development Agency grant APVV DS-FR-19-0025.

Results: Temporal Profile

Build-up of Bias (Fig. 4)

- is very small for baselines (black),
- varies strongly for different Adaptors (non-black colors),
- grows slightly with T laterality (rows),
- depends strongly on environment (columns).

Build-up re. baseline averaged across Targets (subruns 3-16 in Fig. 5):

- very slow for the Frontal A in all environments,
- environment-dependent for Ipsilateral A:
  - fastest in Virtual Anech,
  - slower in Virtual Reverb,
  - Slowest in Real Reverb.
- no clear pattern for Contralateral A.

Post-adaptation decay (subruns 17-19 in Fig. 5):

- slower than build-up for Ipsilateral A in all environments,
- visible in all environments for Frontal A,
- not present or **rebound** for Contralateral A.

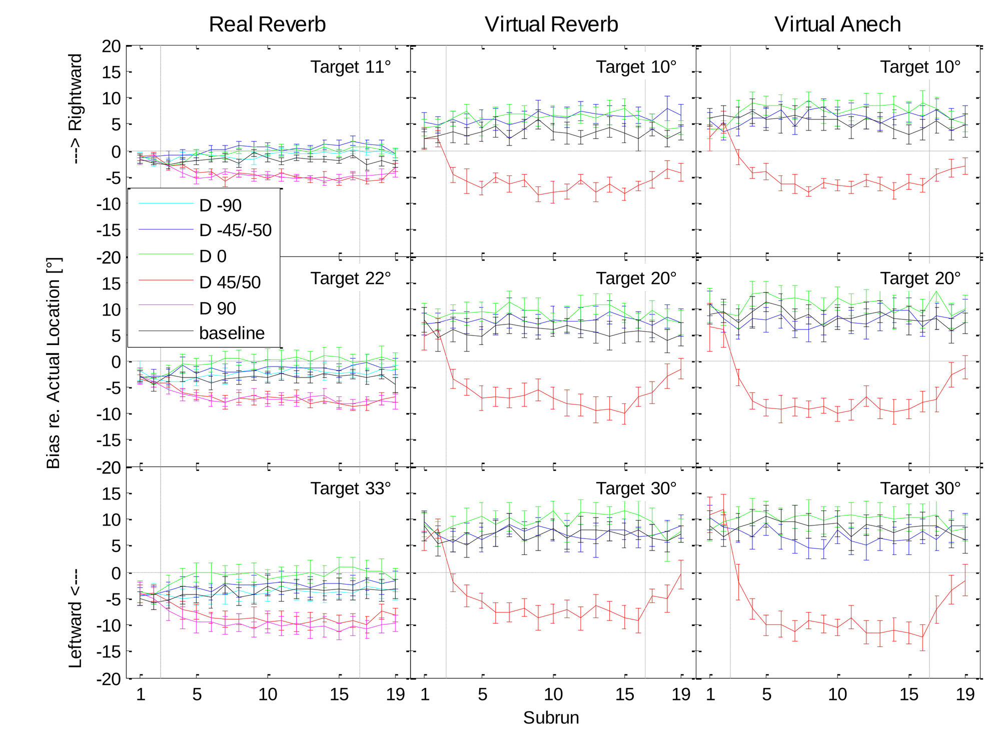

Fig. 4. Temporal profile of build-up in contextual bias for each independent Adaptor/Target combination from Fig. 3 (i.e., only at positive T locations). Red vertical lines mark the beginning and end of the adaptation portion of the runs.

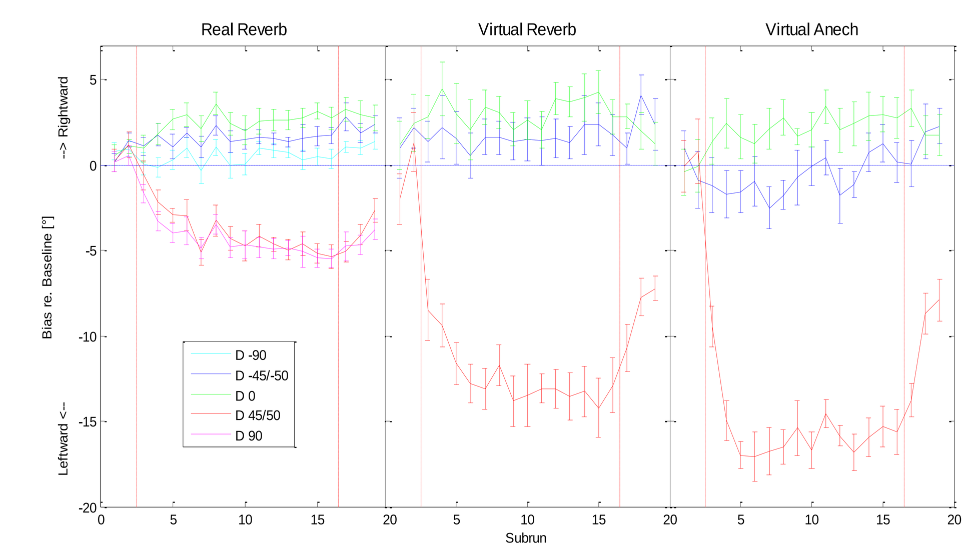

Fig. 5. Temporal profile of build-up in contextual bias from Fig. 4 averaged across Target locations and referenced to baseline.

Build-up of Contextual Plasticity:
- **depends on Adaptor location - slowest for Frontal Adaptor,**
- **depends on the environment - slowest for Real Reverberant and fastest for Virtual Anech.**

Discussion and Conclusions

Passive exposure to adaptors is sufficient to induce **CP** → CP is likely adaptation to stimulus distribution (Dahmen et al., 2010; Kopco & Andrejkova, 2020) or fatigue (Carlile et al., 2001). This is supported by the stronger CP for D90 than D45 in Exp 1. However, other factors also possible.

CP observed in **virtual environment** in Exp. 2 → confirms robustness of phenomenon.
CP much stronger and faster in virtual than real environment:
- with less certainty about the virtual environment and no chance to naturally tune to it with visual/proprioceptive/motor feedback, subjects might try to use relative vs. absolute localization strategies, interpreting A as an anchor and responding relatively to it (Kopco et al., 2010, 2017),
- uncertainty also partly due to non-individual HRTF/BRIR.

CP slightly **stronger in anechoic than reverberant** simulated environment: reflections omni-directional in reverberation → distribution more uniform; better awareness of the cue range.

CP weaker and slower for Frontal than Lateral A's → expansion of representation more difficult than shift, but possible. Alternatively, multiple adaptive processes (some shift-only and some allowing shift+expansion) – only latter one for Front. Multiple adaptations hypothesis supported by build-up/decay asymmetry (build-up is faster, e.g., in Virtual Anech completed in 3 subruns).