Mechanisms of Contextual Plasticity 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 to a target click stimulus when, on interleaved trials, the target is preceded by an identical distractor coming from a fixed location. Here we present the results of two experiments, one performed in real sound (using speakers) and one in virtual sound (using headphones) environment, evaluated in the context of two models of the neural mechanisms underlying spatial hearing in humans. The first model encodes spatial location by activity of a large population of neurons aimed at accurately encoding the stimulus location. The second model 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.

1 Introduction

Contextual plasticity (CP) is a slow adaptive process in spatial hearing induced by a context containing repeated identical stimuli (Andrejková et al., 2023; Kopčo et al., 2007). Little is known about the neural mechanisms underlying the effect (Jeffress, 1948). Here we perform analysis of results from recent series of CP experiments (Piková, 2018; Linková et al., 2022) to examine what mechanisms likely underly the contextual adaptation.

2 Experiments

The experimental methods are briefly summarized here. Two similar experiments were performed in a quiet darkened midsize reverberant room, one in real sound (RE) using speakers and one in virtual sound (VE) anechoic and reverberant environment using headphones. Each trial consisted either of a presentation of a target or an adaptor (50% probability). The target was a 2-ms noise burst (click). The adaptor was a click train consisting of 12 such clicks. Six target locations were used (Fig. 1). Adaptor locations were fixed within a block at 0°, ±45°, or ±90° in Experiment 1, and 0° or ±50° in Experiment 2. Experiments were divided into blocks which kept the adaptor location fixed. Baseline blocks contained no adapter. Eight subjects participated in Exp. 1, nine in Exp. 2. The subjects indicated the perceived target location while seated with their heads supported by a headrest. Response standard deviations were computed for each target in the block to evaluate the models in this study.

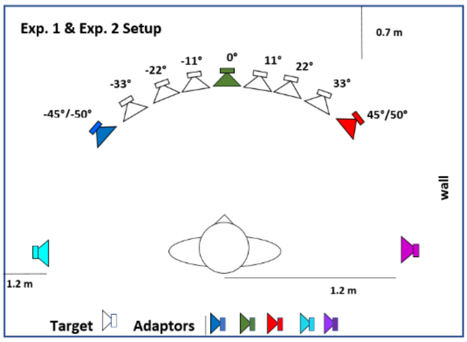

Fig. 1. Setup of experiments.

3 Neural mechanisms

The neural processing can be outlined as follows: Sound waves reaching the ears are first decomposed into frequency channels. Then the signals in each frequency channel from ears are compared in the brainstem and the interaural time differences and level differences are extracted. These two types of cues for azimuthal sound localization are processed separately by specialized neural mechanisms. Two mechanisms for encoding auditory space are considered here:

1. Carlile's model - (Carlile et al., 2001) proposed a model in which a population of units, each tuned to a different spatial location, encodes auditory space. This model assumes that the primary goal of auditory spatial perception is to accurately encode the sound source location, and that the result of adaptation to a repeated presentation of a stimulus from the same location is a fatiguing, causing a suppressed response from the corresponding channel.

2. Lingner's model - (Lingner et al., 2018) introduced an alternative coding model, called a hemispheric balanced model, because it uses independently calculated results for sound localization from both hemispheres, and then combines these results. The model assumes that 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.
In the current study it is assumed that in localization this increased discriminability should be accompanied by decreased variance in the localization responses.

4 Results

Fig. 2, upper panels, shows across-listener mean standard deviation (SD) in responses as a function of the target location, separately for the 3 environments (two experiments), and separately for the different adaptor blocks. SD is computed separately for each combination of session, run, target and listener, and then averaged across sessions, runs and listeners. The standard deviations in RE are in the range of 2-4°, with the largest values in positions close to the adaptor for the 45° adaptor and the smallest values in positions far from the adaptor for the -45° adaptor. In VE, errors are larger 3.5-7° and have greater variability.

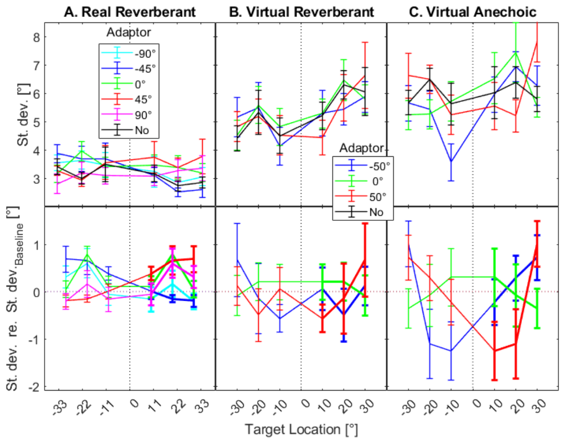

Fig. 2. Standard deviations of raw data (upper row) and a comparison to No adaptor baseline run (lower row) for Exp. 1 (panel A) and Exp. 2 (panels B, C).

The lower panels show the effect of different adaptors by subtracting the no-adaptor data from the respective graphs in the upper panels, and by assuming left-right symmetry in the adaptor effect (thus, e.g., the red and blue graphs are mirrored version of each other).
The adaptors always caused an increase in the response variance in RE (Fig. 2A). ANOVA performed on the Exp. 1 data with factors of *target* (11 to 33°) and *adaptor* (+45, +90°) found a significant main effect of *adaptor* [$F(1, 7)=16.13$, $p = 0.005$]. ANOVA performed on the Exp. 2 data with the factors of *target*, *adaptor*, and *environment* (anechoic, reverberant) found a significant interaction of target and adaptor for the lateral adaptors [$F(2, 16) = 3.75$, $p = 0.05$] (the red line for targets at 10-30° in Fig. 2C). This interaction indicates that variance in responses is lowered in presence of the adaptors, however not for the nearest target but for the slightly more distant targets (10 and 20°). Note that no significant interaction with the factor of *environment* was observed. However, visual comparison of panels B and C shows that the effect was observed mostly in the anechoic VE.

5 Conclusion

The increased variance in RE is consistent with the Carlile's model. On the other hand, the decreased variances in the anechoic VE are more consistent with the Lingner's model. Although the standard deviation is high for the nearest 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. Thus, it is likely that in RE the listeners use absolute localization, allowing them to map the acoustic cues to an actual sound source location. On the other hand, 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. This interpretation is also consistent with the Carlile and Lingner studies, as the former was performed in RE while the latter was performed in an anechoic VE.

Acknowledgements
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Literature

Andrejková, G., Best, V., & Kopčo, N. (2023). Time scales of adaptation to context in horizontal sound localization. *J. Acoust. Soc. Am.*, *154*(4), 2191–2202.

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.

Jeffress, L. A. (1948). A place theory of sound localization. *Journal of Comparative Physiology and Psychology*, *41*, 35–39.

Kopčo, N., Best, V., & Shinn-Cunningham, B. G. (2007). Sound localization with a preceding distractor. *J. Acoust. Soc. Am.*, *121*, 420–432.

Lingner, A., Pecka, M., Leibold, C., & Grothe, B., A. (2018). A novel concept for dynamic adjustment of auditory space. *Sci. Rep.*, *8*(1), 1–12.

Linková, S., Andrejková, G., & Kopčo, N. (2022). Contextual plasticity in sound localization vs. source separation in real and virtual environments. *Kognice a Umelý Život XX*, 162–163.

Piková, V. (2018). Mechanizmy kontextuálnej plasticity v lokalizacii zvukov. *Bachalor Thesis*, P. J. Šafárik University in Košice.

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