The temporal profile of contextual plasticity in sound localization

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Abstract

This study examines the temporal properties of a new form of auditory spatial plasticity called contextual plasticity. The contextual plasticity is a result of adaptation on the time scale of tens of seconds to minutes, but also shows changes at the scale of seconds. The study analyzes behavioral data from an experimental study in which horizontal-plane sound localization was examined in anechoic and reverberant environments (Kopčo et al., 2005). The results suggest that contextual plasticity has a bi-stable component that is strongly adaptive on the time scale of seconds, while overall the effect is building up over tens of seconds/minutes (Kopčo et al., 2007).

1 Introduction

The problem of sound localization in some context of other sounds is still analyzed from the point of acoustic scene. One of the factors that can influence the listener's ability to localize a target sound presented along with other sounds is perceptual similarity of the stimuli (Best et al., 2008) and temporal distribution of the stimuli. In the (Kopčo et al., 2007), it is described a special type (1-click) of stimuli preceding the target sound on the time scale of seconds to tens of seconds. This spatial auditory plasticity is called a contextual plasticity.

Effects of preceding stimuli on a target localization can be described by various candidate mechanisms operating on time scales from milliseconds to ten of seconds. For example, a precedence effect (Brown et al., 2015), an adaptation of brainstem neural representation due to prolonged exposure (the effects of a stationary adapting noise stimulus on the subsequent auditory localization in the vicinity of the adapting stimulus, 4 min of continuous noise at the start of each block of trials) to the preceding stimuli (Carlile et al., 2001). Best at al., (2008) showed that sequential grouping cues (i.e. effects of preceding distractor types) can have influence on whether binaural interference occurs.

In the current study, click stimuli were used as targets. On some trials they were preceded either by a grouping (1-click) or a streaming (8-click) distractor, coming from the frontal and lateral positions relative to the subject. The contextual plasticity was evaluated as a perceptual bias, computed as the difference between the average target-alone responses in frontal- vs. lateral-distractor runs. The observed bias was up to 10°.

Here, temporal analysis was done by dividing each experimental run with approximate duration of 5 minutes into four equal-duration subruns. When 1-click distractor was used in the contextual trials (a trial when an identical sound target is presented from a random location following after an identical distractor coming from a fixed, a priori known location), the contextual bias built up within first three subruns, reaching magnitude of approx. 7° in classroom, and 10° in anechoic room. When context consisted of both 1-click-distractor and 8-click distractor trials, the contextual bias did not depend on type of the room and its buildup continued up to the last, 4th subrun, where it reached 12°-13°. Separating this bias according to whether it was preceded by 1-click-distractor contextual trial or 8-click-distractor contextual trial showed that the bias built up differently for the two conditions. Specifically, in the 2nd subrun, when target-alone trial target is preceded by 8-click-distracter trial, the bias is approx. 5 degrees larger than when preceded by 1-click-distractor trial.

In this paper, we will first review the results from a previous study (Kopčo et al., 2007). These will be referred to as Exp. 1. The results will be compared to new results from the experiment referred to as Exp 2. The effect of the preceding distractor to biases in Exp 2 was analyzed in (Kopčo et al., 2016).

2 Methods

2.1 Subjects

Seven subjects participated in a classroom and four of them participated in an anechoic room. All subjects had normal hearing as confirmed by audiometric screening, with ages ranking from 23 to 32 years.

2.2 Stimuli and Setup

The nine loudspeakers were equally spaced along quarter circle of diameter 1.2 m with the listener in the center (Fig. 1).

The loudspeakers were fixed on stands 1.5 m above the floor, approximately at the level of the listener's ears. The listener was seated on a chair that could be rotated so that he faced the left-most or the right-most speaker, with the loudspeaker array either in his right or left frontal quadrant. The left-most and right-most loudspeakers were used to present the distractor stimuli only. The remaining seven loudspeakers were used to present target stimuli. An additional loudspeaker directly behind the listener played instructions to the listener during the experiment.

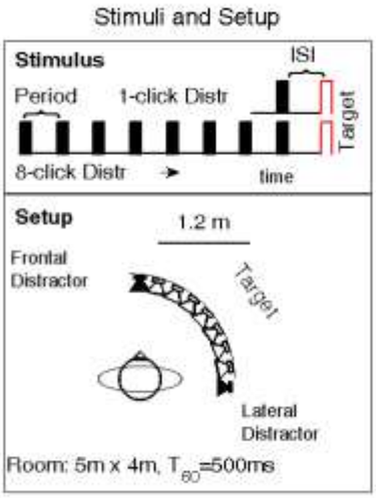


Fig. 1. Stimuli part. The arrangement of preceding stimuli sounds (black filled rectangles and target sounds (the last rectangles in the sequences). **Setup part.** Diagram of listener loudspeakers positions and a listener's orientation in the classroom. The same setup was used in the anechoic room (Department of Psychology of the University of Massachusetts).

2.3 Experimental Procedure

The experiment consisted of four blocks (30 min, subject separated by breaks) of runs containing trials with fixed distractor location and fixed position.

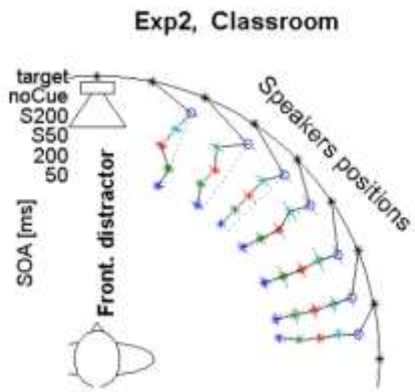
Within each block, the listener performed four runs, one run for each combination of a distractor and a listener orientation, (facing the left-most or the right-most loudspeaker) and distractor location (from left-most or right-most loudspeaker). The order of runs within each block was random, and differed from subject to subject.

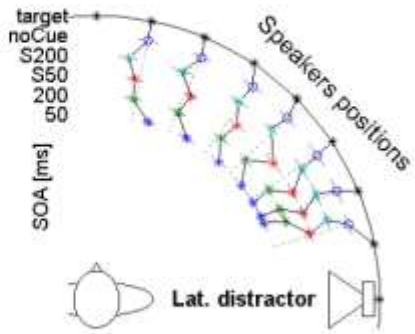
Each run contained 140 trials [7 (target loudspeaker locations) x 5 (four ISIs + no distractor) x 4 (repetitions)]. In each run 3 types of sound presentations in a random order:
(1) Click2,
(2) Click1 ISI Click2,
(3) Click1 ISI Click1 ISI Click1 ISI Click1 ISI Click1 ISI Click1 ISI Click1 ISI Click1 ISI Click2.
Click1 is distractor (frontal, lateral), Click2 is from one of 7 loudspeakers; a listener identifies a loudspeaker of Click2. Inter-stimulus intervals (ISI) was 50 or 200 ms.

The run has four subruns, one subrun contains all combinations of target angle and ISI + no distractor without repetitions (7 targets x 5 ISI + no distractor).

3 Data Analysis

All subjects' responses were recorded by the tracker in the form of Cartesian coordinates and then transformed to response angles (the lateral angle between the response direction and straight ahead). Four positions of a subject and a distractor were transformed to two positions according to the frontal distractor and the lateral distractor.





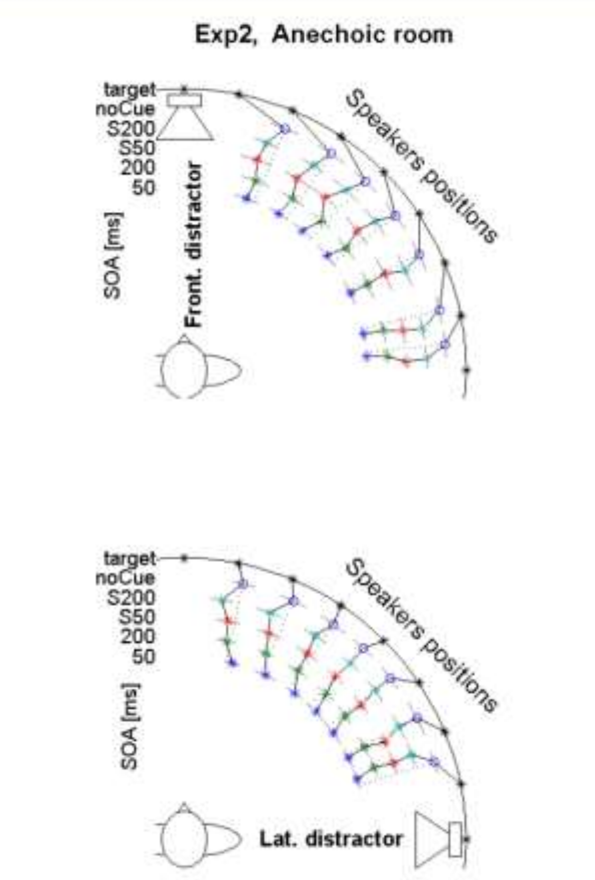


Fig. 2. Mean localization responses in the classroom and in the anechoic room separated according to the frontal and the lateral distractor. Each panel shows the across-subject mean and standard error in perceived target lateral angle as a function of actual target lateral angle for different ISI.

For each subject, 32 responses were collected in total for each combination of (4 ISI + no distractor), two distractors and seven target lateral angles.

The first analysis is shown in the Fig 2. It shows the raw data, plotting the across-subject mean and standard error in the perceived target location as a function of the actual source lateral angle for frontal and lateral distractor in the classroom and in the anechoic room.

The black asterisks are drawn in the actual angles of the target loudspeakers. The results are drawn in the parts of circles according to the legend (no Cue, S200 - ISI 200 ms, 8-click distractor, S50 - ISI 50 ms, 8-click distractor, 200 - ISI 200 ms, 1-click distractor, 50 - ISI 50 ms, 1-click distractor).

The analysis of the biases shows that for the data of the frontal distractor, localization responses are biased towards the side. For the data of lateral distractor, the most of localization responses are biased towards the midline. The detailed analysis of distractor effects can be found in (Kopco et al., 2016).

4 Temporal Profile of Plasticity

Kopčo et al. (2007) presented an analysis of the temporal profile of the contextual effect of 1-click distractor. The results are presented using the across-subject mean in the contextual difference as a function of subruns. The experimental runs were subdivided into 4 subruns for this analysis. The main results are (Fig. 3A):

Results in the anechoic room: The contextual bias of no distractor trials built up over the four subruns, growing from roughly 6 to 9°.

Results in the classroom: The contextual effect increased with subruns, it grew from 4 to 8° across the four subruns for no distractor trials.

The new experiment follows more complex auditory scene - trials using two types of distractor, 1-click and 8-click.

4.1 1-click versus (1-click + 8-click)

Fig. 3, panel A contains temporal profile of the contextual bias for the experiment Exp 1 described in (Kopčo et al., 2007) and of the new experiment Exp 2.

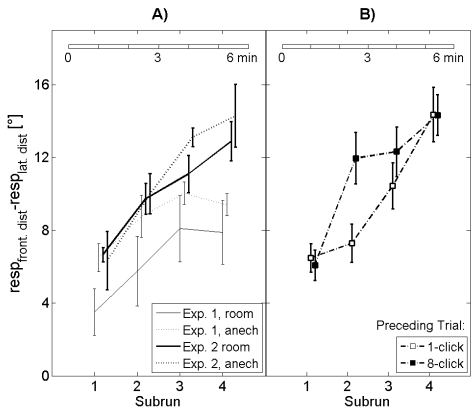


Fig. 3. The contextual bias - across lateral angle average difference in responses as a function of subruns within experimental runs (no distractor trials). Panel A) contains the results of Exp1 and Exp2. Panel B) shows contextual bias for 1-click and 8-click distractor trials in Exp2.

When 1-click distractor was used in the contextual trials in experiment Exp1 (thin lines in the panel A, the contextual bias increases within first three subruns and it was reached 7° approximately in the classroom and 10° in the anechoic room.

In the experiment Exp 2 the context was mixed using 1-click and 8-click distractor trials. The contextual bias here (thick lines in the panel A) was increasing within four subruns and it does not depend on the type of the room. The maximum magnitude was approximately 12-13°. It is possible to suppose that the magnitude should increase in prolonged subruns. The results of the analysis of variance (ANOVA) are in the Tab. 1.

Factor	**df**	**F Significant**
Experiment (Exp)	1, 3	15.36 **
Room (R)	1, 3	
Subrun (S)	3, 9	32.16 ***
Target (T)	6, 18	
Ex *x* Room	1, 3	
Ex *x* Target	6, 18	
Ex *x* Subrun	3, 9	
Room x Subrun	3, 9	
Room x Target	6, 18	
Target x Subrun	18, 54	
Exp x R x T	6, 18	
Exp x R x S	3, 9	5.03 **
Exp x T x S	18, 54	
R x T *x* S	18, 54	
Exp x R x T x S	18, 54	

Significance levels are as follows: ** $p<0.001$ and *** $p < 0.005$.

Tab. 1: Results of four-way repeated measures ANOVA performed on the response bias data in both experiments and both rooms for targets and subruns. F values and significance values are listed only for effects and interactions with significance level $p<0.05$.

Separating this bias according to a conditions in a preceding trial, especially 1-click or 8-click distractor trial, Fig. 3, panel B, showed that the bias increases in a different way for them. It is possible to follow it from the 2nd subrun, when the no distractor target trail is preceded by 8-click distractor trial has the bias approximately 5° larger than preceded 1-click distractor trials. The results of two-way repeated measures ANOVA are in the Tab. 2.

Factor	**df**	**F Significant**
Distractor type (DT)	1, 6	7.23 **
Subrun	3, 18	22.98 ***
DT *x* Subrun	3, 18	4.67 **

Significance levels are as follows: ** $p<0.001$ and *** $p < 0.005$.

Tab. 2: Results 2-way ANOVA applied to subruns and the type of distractors (1-click and 8-click).

4.2 Context biases in rooms

In Fig. 4, it is shown a comparison of the contextual bias (analyzed as a difference of the frontal and lateral distractor responses in trials) in the anechoic room and in the classroom separately.

Results in the anechoic room: The contextual biases of all three trial types are increasing in the second subrun, approximately in 4° for no distractor trials and 2° for 1-click and 8-click distractor trials. In the third subrun the increasing continues for no and 1-click distractor trials, it is larger for no distractor trials, the contextual bias of 8-click distractor trials show a stable value. The differences among contextual biases in the fourth subrun are very close to the differences in the first subrun, but a different trend is followed in the second and the third subrun. The results of two-way repeated measures ANOVA are in the Tab. 3.

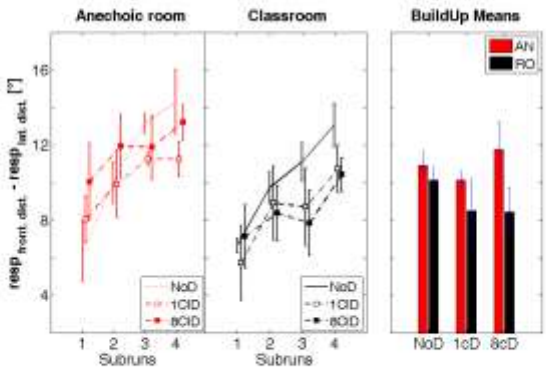


Fig. 4. The contextual bias analyzed in the rooms. In both rooms, it is shown contextual bias for no distractor, 1-click, and 8-click distractor trails. The last panel shows mean values and standard errors for all responses in the anechoic room (the red columns) and the classroom (the black columns).

Anechoic room		
Factor	**df**	**F Significant**
Distractor type (DT) - no distractor, 1-click, 8-click distractor	2, 6	
Subrun	3, 9	10.34 ***
DT *x* Subrun	6, 18	

Significance levels are as follows: *** $p < 0.005$

Tab. 3: Results 2-way ANOVA applied to subruns and the type of distractors (no distractor, 1-click and 8-click) in the anechoic room.

Results in the classroom: The contextual effect of no distractor trials has an increasing trend, approximately 4.5°, but it is not as large as in the anechoic room. The contextual effect trends of 1-click and 8-click distractor trials are very similar. The values in the fourth subrun are very similar. The results of two-way repeated measures ANOVA are in the Tab. 4.

The comparison of results in both rooms for across-subrun-average values of all three trial types is in Fig.

4, the third panel. The 8-click distractor trials show the largest difference of the contextual bias means in rooms. The result of the contextual bias trends together in both rooms is shown in Fig. 3, panel B. The influence of 8-click distractor trials in the contextual bias is larger than the influence of 1-click distractor trials in the second and in the third subrun. The fourth subrun presents that using different build up the contextual effect finish with very similar values.

Classroom		
Factor	**df**	**F Significant**
Distractor type (DT) - no distractor, 1-click, 8-click distractor	2, 12	
Subrun	3, 18	11. 37 ***
DT *x* Subrun	6, 36	

Significance levels are as follows: *** $p < 0.005$

Tab. 4: Results 2-way ANOVA applied to subruns and the type of distractors (no distractor, 1-click and 8-click) in the classroom.

5 Discussion

Kopčo et al. (2007) showed that the contextual bias occurs in trials with and without distractor. It causes a shift in the perceived locations of the targets for both distractors. This bias is systematically away from the distractor position in the run and builds up over the course of minutes. In the anechoic room, it is possible to observe that the lateral distractor suppresses the spatial percept of lateral target.

Experiment Exp 2 showed that the contextual effect is stronger for the trials consisted from 1-click and 8-click distractor in comparison to Exp 1 (Kopčo et al., 2007) with 1-click distractor trials only (see Fig. 3, panel A). It suggests that the contextual effect of the distractor - target trials on no distractor trials responses is more complex than a simple adaptation in the spatial map.

6 Conclusion

The contextual bias induced by 8-click distractor is stronger than the contextual bias induced by 1-click distractor and it is larger in the classroom than in the anechoic room. This observation is consistent with a bottom up adaptation mechanism sensitive to the distribution stimuli (Kopčo et al., 2015).

Acknowledgement

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