# Build-up of Contextual Plasticity in Anechoic and Reverberant Rooms

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## ABSTRACT

Contextual plasticity (CP; Kopčo et al., 2007) is a form of spatial auditory plasticity observed in localization experiments in which distractor-target click pairs with a fixed distractor location (the context) are interleaved with target-alone trials. CP is observed as biases in localization of the target-alone clicks of up to 10° in the direction away from the distractor (presented only on interleaved trials). This adaptation occurs on the time scale of seconds to minutes.

Here we examine the hypothesis that CP is related to the spatial distribution of the stimuli within experimental blocks. A linear model is fitted to temporal data in which distractor location (frontal vs. lateral), context distractor type (single click vs. multiple clicks), and environment (anechoic vs. reverberant) are manipulated.

The results show that the rate of temporal drift in responses during the experimental runs is proportional to the lateral offset of the mean of the stimulus distribution. This distribution-sensitive drift can explain up to 45% of the observed CP. Thus, contextual plasticity is likely a result of a combination of adaptive processes in multiple auditory spatial representations, sensitive to both the stimulus distribution and to other factors like reverberation processing.

## 1. INTRODUCTION

The perceived location of a sound source is often affected by preceding auditory stimulation [1, 6]. Kopčo et al. [4] observed a new form of plasticity, called *contextual plasticity (CP)*, characterized as biases away from the distractor on trials with no distractor, when interleaved with distractor + target trials in which distractor comes from a fixed location (Fig. 1).

Here, modelling and analysis is performed on data from 2 previous studies [4, 5] to evaluate the hypothesis that CP can be partially explained by assuming that the auditory system adapts to the asymmetry in the distribution of the stimuli in the experiments. Specifically, in the previous CP studies, all stimuli, distractors and targets, were identical clicks. The drifts might be related to the fact that the stimuli were not distributed symmetrically around the midline and, instead, they were concentrated at the side. Because of that, the auditory system might undergo a process to adjust the auditory spatial representation such that the mean of the distribution becomes more aligned with the midline (e.g., to increase spatial sensitivity). Similar mechanisms were proposed in [2] and [7]. We predicted that the more lateral the mean of the stimulus distribution is for a given condition, the larger the observed medial drift will be.

## 2. EXPERIMENTS AND METHODS

### 2.1 Experimental methods

Results of two experiments are analyzed, both performed in a classroom and in an anechoic room. Seven listeners participated in the classroom, and four of them also participated in the anechoic room in both experiments [1], [3]. Target stimulus was always a 2-ms noise burst (click) coming from one of 7 target speakers (Fig 1).

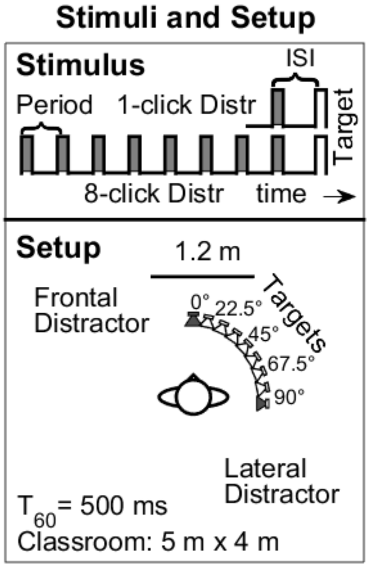

**Figure 1.** Experimental setup and stimuli. Upper panel: Temporal profile of distractor-target stimuli, with distractor in grey and target in white. ISI (25 – 400 ms) is time interval between the final distractor click and the target click. Period (100 ms) is the time interval between distractor clicks. On some trials, no-distractor stimuli were presented (not shown). Lower panel: Arrangement of the speaker array which is oriented on the subject's right-hand side. A half of the runs was performed with the array on the subject's left. Distractor (speaker in grey color) was in the frontal position for a half of runs and in the rest of runs distractor was in the lateral position.

On some trials (distractor-target trials), it was preceded by a distractor coming from frontal or lateral speaker (fixed within a block) and consisting of 1 click (Exp. 1) or 1 click or 8 clicks (Exp. 2; number of click was randomized from trial to trial). Target-alone and distractor-target trials were randomly interleaved with a ratio of 1:5 (Exp. 1) and 1:4 (Exp. 2). The distractor-target inter-stimulus interval was between 25 and 400 ms. Each experiment consisted of 5-min runs during which distractor locations were fixed and the speaker array was either on the subject's left-hand side or right-hand side. All the data collected with the speakers on the left were mirror-flipped, combined with the right-hand side data, and plotted as if they were on the right. Temporal drifts in target-alone responses within the experimental runs are analyzed here.

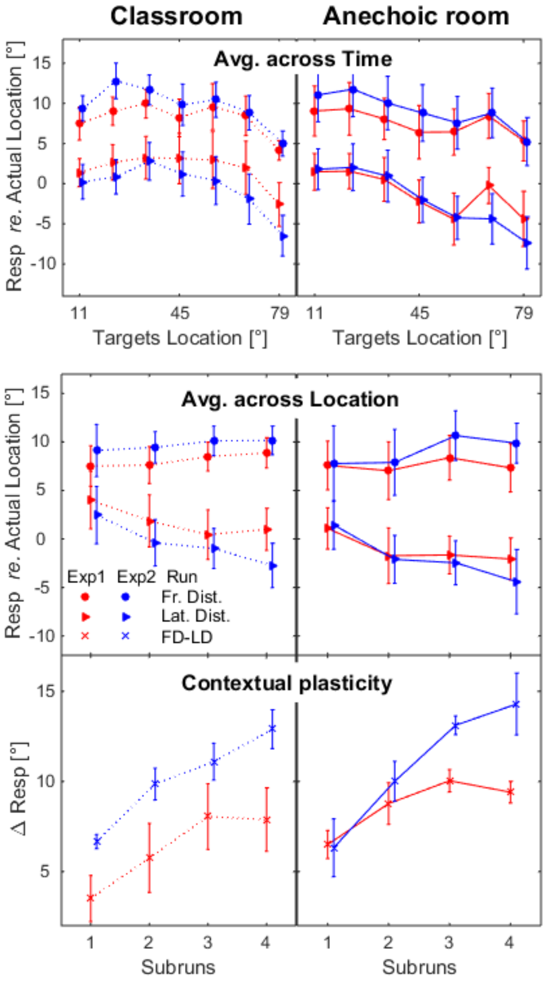

**Figure 2.** Top panel: Experimental data showing contextual plasticity as biases in no-distractor trials in anechoic room (right-hand column) and in classroom (left-hand column) in Exp. 1 (red) and Exp. 2 (blue). Across-subject mean (±SEM, standard error of the mean) response bias in target-alone trials as a function of azimuth. Middle panel: Across-subject mean (±SEM) response contextual buildup as a function of subrun in target-alone trials for data averaged across target locations. Bottom panel: Across-subject mean (±SEM) of difference between responses in runs with the frontal distractor and responses in runs with lateral distractor (from the middle panel).

## 2.2 Experimental results

In Fig. 2, contextual effects on the no-distractor responses are shown in the classroom and the anechoic room (columns), for both Exps. 1 and 2 (color), and for the runs with frontal distractors vs. runs with lateral distractors (circles vs. triangles; difference shown by crosses). The top-row of panels (*Avg. across Time*) shows the no-distractor response bias *re*. actual target location as a function of target location, averaged across trials within runs. The middle row (*Avg. across Location*) shows the same data as a function of time within a run (runs divided into 4 subruns) and averaged across target locations. The bottom row (*Contextual Plasticity*) shows the CP defined as the difference between biases induced in the frontal-distractor runs vs. lateral-distractor runs (i.e., the difference between the frontal-distractor and frontal-distractor run data from the middle panels).

The main effects shown in Fig. 2 are that Contextual plasticity (bottom row) grows over time and is larger for Exp. 2 than Exp. 1, and also for anechoic room vs. classroom. CP is approximately independent of target location, even though the differences between Exp. 1 and Exp. 2 data tend to be larger near the distractors (top row of Fig. 2). Confirming these observations, a 5-way repeated measures ANOVA (Experiment, Room, Target, Subrun, Distractor), performed on the bias data found a significant 4-way interaction of Experiment x Room x Subrun x Distractor ($F_{3,9}$=4.84, p=0.0285) and a significant 2-way interaction of Experiment x Target ($F_{6,18}$=6.19, p=0.0012). Given these results, we averaged the data across targets as shown in the middle panel of Fig. 2, and considered the trends in CP as a function of the subrun.

## 2.3 Modeling

For each condition, the mean lateral position (*mp*) was computed as the mean of stimulus locations used in that condition, such that each click was included independent of whether it was a target stimulus, a 1-click distractor, or a part of a 8-click distractor (Fig. 3A). To evaluate the slope of the drift, a linear fit of the temporal profile of responses (from middle panel of Fig. 2) during the adaptation part of the run was performed separately for each subject & condition:

$$y=k*x+q, \tag{1}$$

where $y$ corresponds to bias, $x$ corresponds to subrun, and parameters $k$ and $q$ represent the slope of the drift and its intercept, respectively. The resulting fits averaged across subjects are shown in Fig. 3B. The relationship between laterality of the distribution mean (*mp*) and the slope of the drift ($k$) was directly evaluated in Fig. 3C. In addition, the effect of reverberation on the drifts was examined.

# 3. MODELING RESULTS

Fig. 3A shows the distribution of stimulus clicks in Exp. 1 (left-hand column) and Exp. 2 (right-hand column) for the frontal distractor runs (top row) and lateral distractor runs (bottom row). Since Exp. 2 included 8-click distractor trials, the proportion of clicks presented from the distractor locations was much larger in Exp. 2 than in Exp. 1. This is reflected in the mean lateral position computed over the runs which is approximately 10° from the edges of the distribution (i.e., from the distractor locations at 0 or 90°) in Exp. 2 and 25° in Exp. 1, as shown by the *mp* values. On the other hand, the *mp* values were unaffected by the type of room (anechoic or reverberant). Also note that the distribution was always shifted laterally in the same direction (i.e., *mp* values are always positive), as the speakers were always in the same listener's quadrant. Thus, if the stimulus distribution affects contextual plasticity the same way, all the drifts caused by the distribution should be in the same direction, and only differ by their size.

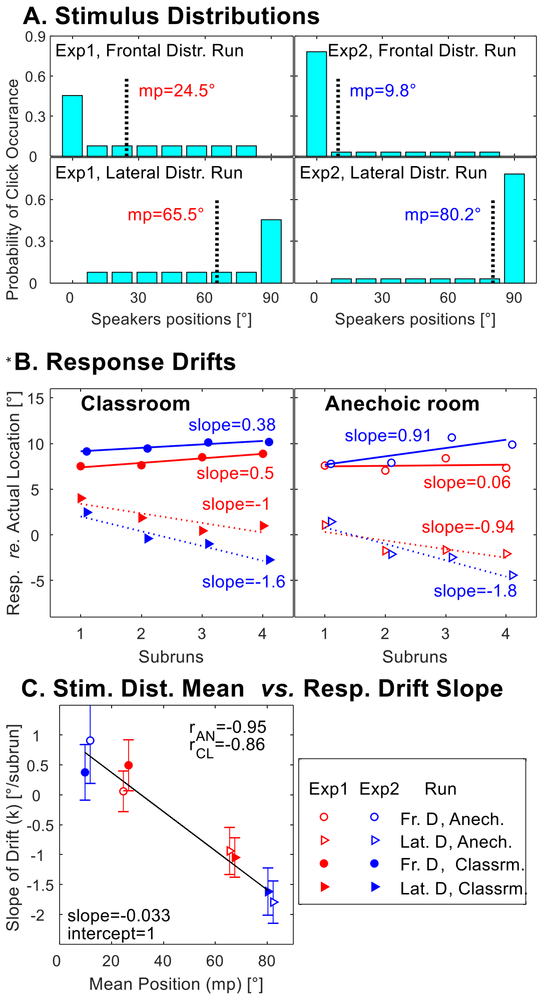

**Figure 3. A.** Distributions of stimulus clicks in different experimental conditions, disregarding whether the clicks came from the distractor or the target (note that the large bars at the edges are always due to the distractor, while the small values at angles 11 to 79° correspond to the targets). Black dotted lines indicate the mean of stimulus lateral positions, represented by the value *mp*. **B.** Temporal profile of adaptation in subruns for different experimental conditions (from middle panel of Fig. 2) along with linear fits (slopes *k* are shown next to each fit). **C.** Across-subject means (and standard error) of the linear fit slope (*k*, from panel B) as a function of mean lateral stimulus location (*mp*, from panel A), shown separately for each combination of room type and run type (runs with frontal vs. lateral distractor). The black line shows a linear fit of this relationship. Across-subject average correlations, computed separately for the classroom and anechoic room, are also shown.

Fig. 3B shows the linear fits to the data from the frontal distractor and lateral distractor runs (different symbols), for the two experiments (different colors), and the classroom vs. anechoic room (filled vs open symbols). The slopes of linear fits for each condition are shown next to the corresponding line. The response drifts had a large range, from -1.8 to 0.9 °/subrun. There is a systematic pattern, with the lateral-distractor-run slopes having large negative values, while the frontal-distractor-run slopes have small positive values. Also, the slopes tend to have larger absolute values for Exp. 2 than the corresponding values for Exp. 1, especially in the anechoic room. These trends were confirmed by a 3-way repeated-measures ANOVA (factors: Experiment, Room, Distractor) performed on the slopes of linear fits, which found a significant 3-way interaction of Experiment x Room x Distractor ($F_{1,3}$=10.43, p=0.048) and a significant main effect for Distractor ($F_{1,3}$=105.87, p=0.002).

To directly evaluate the relationship between the distribution of the stimuli and the response drifts, Fig. 3C plots the slope *k* of the response drifts (form Fig. 3B) as a function of the mean lateral position of the stimuli (*mp* value) in a given condition (from Fig. 3A). A strong correlation between the *k* and *mp* values is observed, with across-subject average reaching 0.95 in the anechoic room and 0.86 in the classroom (the difference between the two rooms was not significant; paired t-test). Also, separate slopes were fitted to all the combinations of room and distractor location. A two-way repeated-measures ANOVA performed on these values did not find any significant main effect or interaction. So, a single linear fit to the data was found (Fig. 3C). This fit shows that the magnitude of the drift observed in the CP data is proportional to the mean of the distribution of the stimuli in each condition, confirming that the drifts in responses are inversely correlated, and therefore likely caused, by the changes in stimulus distribution. However, while the *mp* values are all positive, the *k* values switch from negative to positive, as the *mp* values decrease, even though if the stimulus distribution mean was the only cause of CP, it would be expected that all the *k* values will have the same sign. Therefore, it is likely that other factors, like the specific task (here, distractor clicks were to be ignored while target clicks were to be focused to and localized) are also important. Specifically, it is likely that the listeners were gradually building up a bias away from the distractor, knowing that it was to be ignored, and this bias was combined with the stimulus-distribution-dependent bias towards the midline.

## 4. DISCUSSION AND CONCLUSIONS

The current study showed that the drift in response biases in contextual plasticity experiments is proportional to the mean lateral position of the stimuli. Specifically, stronger drifts towards midline were observed with increased laterality of the distribution mean, consistent with the hypothesis that contextual plasticity might be partially dependent on the stimulus distribution in the experiments. Table 1 summarizes the proportion of CP explainable by this drift for the two experiments and two rooms examined here. This proportion, computed by considering the proportion of the overall CP that cannot be explained by the CP observed in the first subrun, ranges from 25 to 44%, indicating that while a portion of CP can be explained by the linear drift in subruns 2-4, most of the contextual plasticity occurred by the first subrun. Importantly, this does not mean that more of CP cannot be explained by the drift, since the design of the two experiments does not allow us to evaluate the effect of the distribution prior to and up to the first subrun (there was no pre-adaptation baseline measurement, and different combinations of stimulus conditions only repeated 4 times during each run). Data with a denser temporal sampling needs to be used to analyze how the CP builds up right after the distribution of stimuli changes, i.e., after the distractor-target trial onset, and to determine whether this build-up is due to the change in the stimulus distribution or due to other factors.

The second factor likely contributing to CP is the task in the contextual distractor-target trials which might be also influencing the target-only trials. Specifically, if the listeners are biased away from the distractor in an effort to ignore it, this bias might be affecting the target-only trials as well. However, a previous study found that contextual plasticity was largely unaffected by whether the distractor was presented before or after the target [10], suggesting that this factor might be relatively minor.

Finally, the effect of environment (anechoic vs. reverberation) is clearly present in the overall CP data, with the CP effect stronger in the anechoic room. However, the environment only influences the drift analyzed here to a small extent, with stronger drifts observed in anechoic room. This small modulation might still be explained by the stimulus distribution, as reverberation makes this distribution more even (energy from the reverberation being uniformly distributed), a factor that was not considered in the current study.

The current study has several limitations. Specifically, so far only the linear portion of the drifts was analyzed. The responses' initial positions (starting point of the drift) need to be considered to understand how the drift might influence CP. Also, the temporal sampling of the drift was very sparse, with the 5-minute runs only divided into 4 subruns, which might mask some non-linearity. And, no no-distractor baseline runs were included, even though such drifts are likely to be observed even in the baseline [3, 10]. Finally, the mean lateral position statistic used here might not be the appropriate statistic for characterizing how the auditory system adapts to the non-uniformity of the stimulus distribution. E.g., max, median, skewness or other statistic of the distribution might better characterize the effect. However, the current data do not allow distinguish between these options.

| | Exp. 1 | Exp. 2 |
|---|---|---|
| Classroom | 44.4 | 34.2 |
| Anechoic room | 25.1 | 42.2 |

**Table 1.** Proportion (in per cent) of Contextual Plasticity observed over the whole experiment that can be explained by the stimulus-distribution-depended drift analyzed here.

## 5. ACKNOWLEDGEMENTS

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