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Spatial Aspects of Contextual Plasticity in Sound Localization

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Summary
A previous study examining the effect of a preceding distractor on sound localization found that responses were biased even in control trials in which no distractor was presented before the target sound (Kopco et al., JASA, 121, 420-432, 2007). These shifts in no-distractor responses are referred to as "contextual plasticity". In the current study we examined the spatial aspects of the contextual effect by varying the spatial arrangement of the context. The subject's task in the experiment was to localize a 2-ms noise burst presented from one of seven target loudspeakers spaced symmetrically relative to the medial plane or the interaural axis. In experimental runs, in 75% of the trials (the distractor trials), the target was preceded by an identical distractor presented from the center of the loudspeaker range 25 ms before the target. The remaining 25% of trials (the no-distractor trials) presented the target alone. In baseline runs, no distractor trials were included. Separate experimental runs examined how contextual plasticity was influenced by the distribution of the targets on the distractor trials. In these runs, the distractor targets were presented either from only the three left-most speakers, the three right-most speakers, or from any of the non-distractor speakers. Contextual biases away from the distractor were found for both medial and lateral distractor locations. The biases depended on the configuration of the distractor trials. The half-range configurations elicited biases in the corresponding part of the range while no biases were observed for the other half. The full-range configurations elicited smaller biases. These shifts were observed independent of the orientation of the listener relative to the speaker array or of the half-range region examined. These results provide basic characterization of the neural structure that undergoes the contextual adaptation and they describe how the spatial specifics of context affect contextual plasticity. [Supported by NIH and KEGA #3/7300/09]

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1. Introduction

Various studies showed that spatial hearing is an adaptive process, i.e., the mapping between the values of spatial cues and the perceived sound source location is not fixed but can undergo changes [1]. The changes in localization of a target could be elicited for example by presentation of a distracting sound overlapping in time with the target [2] or by prolonged exposure to sound preceding the target [3]. Kopco et al. [4] studied localization of a transient sound source preceded by an identical distractor coming from a known location. Unexpectedly, localization biases were found not only on the trials on which the target was preceded by the distractor, but also on the interleaved "control" trials on which the target was presented alone. This effect was referred to as "contextual plasticity," since the observed bias was evoked by the context of the other interleaved trials and since it suggests that long-time-scale interactions influence sound localization.

Later studies of the contextual plasticity found that contextual biases build up and decay quickly after

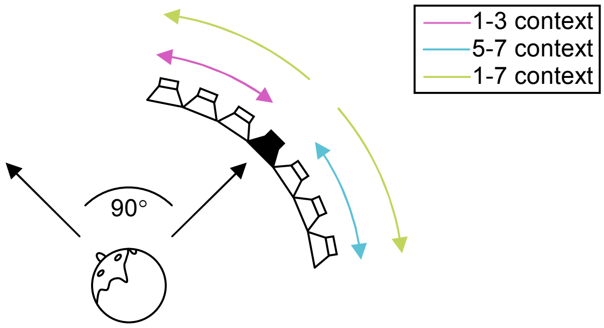

Figure 1. Experimental setup. The distractor was presented solely from the central (filled) loudspeaker. Black arrows indicate two possible subject orientations re. speaker array. Arrows above the loudspeaker array show three possible configurations of the context.

the onset/offset of the distractor trials [5], that they grow with frequency of the distractor trials [5], and that they depend on the spectro-temporal similarity between the target and the distractor sounds [6].

In the current study we examined the spatial aspects of the contextual plasticity. We manipulated the spatial properties of the context by varying the region from which the targets could come (relative to the fixed distractor position) on the distractor trials and by varying the region around the listener from which the experimental stimuli were presented (in front of the listener vs. to the side of the listener; Figure 1).

First, we examined whether the contextual effects differ when the effect is induced in front of the listener (i.e., near the median plane) compared to when the effect is induced on the side (lateral region). We hypothesized that the largest contextual shifts will be evoked near the median plane where the spatial auditory acuity is the largest (hypothesis H1).

Then we examined whether the contextual plasticity induced in one subregion (relative to the distractor location) generalizes to a subregion in which no plasticity was induced. We looked at three conditions differing by whether the distractor targets came only from locations to the left of the distractor, only from locations to the right of the distractor, or from both sides. Assuming that plasticity induced in one subregion generalizes to the other subregion, these different conditions allowed us to examine the nature of neural representation of auditory space in the structures in which contextual plasticity is induced. Specifically, if the representation is Cartesian, then the shift induced in one subregion was expected to generalize to a shift of the same direction in the other subregion (similar to visually induced shifts, e.g., in [7]). On the other hand, if the representation is polar, then inducing a shift in one subregion was expected to generalize to a shift of an opposite direction in the other subregion (because these two subregions lie on the opposite sides relative to the distractor; similar to visually induced expansion observed, e.g., by [8]). Finally, when distractor targets are presented from both sides of the distractor, the Cartesian representation predicts that no shift will be induced (because the induced shifts would cancel out) while the polar representation predicts that the shift will be stronger than when the shift is induced in only one subregion. Since we hypothesized that the adaptation structure is relatively central, we expected the coordinate system to be Cartesian (hypothesis H2).

Finally, we examined how the pattern of generalization of contextual plasticity from one subregion to another depends on whether plasticity is induced ahead of the listener or to the side of the listener. Specifically, if the representation of auditory space in the adapted structure is polar (e.g., an Interaural-Time-Difference-based representation) then a different pattern of adaptation would be expected on the side (where our spatial set up crosses the pole) and ahead of the listener (where ITD changes uniformly with spatial location). On the other hand, no dependency on the relative subject-to-setup orientation was expected if the representation is Cartesian (or uniform). Again, as in H2, we hypothesized that the observed generalization will be independent of whether it is induced ahead of the listener or to the side of the listener (hypothesis H3) because the adapted structure is relatively central in the processing pathway.

2. Methods

2.1. Experimental Setup and Procedure

The experiment was performed in a sound-proof booth of 3 × 2 × 3.1 m. Seven loudspeakers were spaced with 11.25° separation in an arc around the subject (see Figure 1) 1.1 m away from the subject. The subject could be oriented relative to the center of the loudspeaker arc either medially (i.e., facing the midpoint of the loudspeaker arc) or laterally

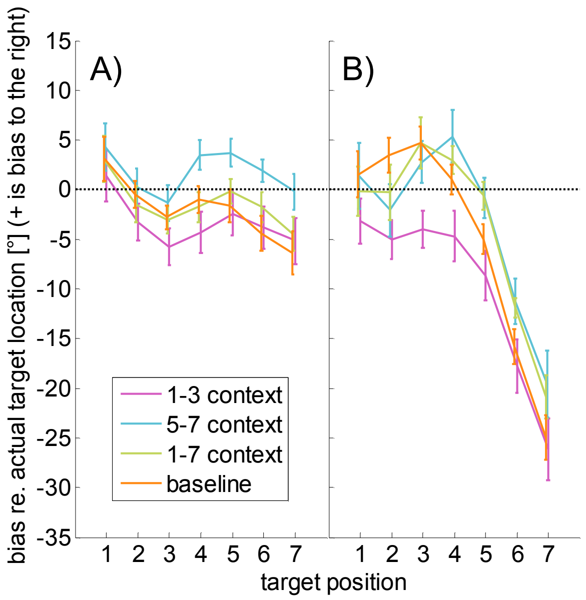

Figure 2. Mean bias in responses for medial (panel A) and lateral (panel B) subject's orientation. Each panel shows across-subject mean and within-subject standard error in biases in responses relative to the actual target positions as a function of actual target position. The distractor was always target position #4. Target position #1 was 33.75° to the left of the distractor, target position #7 was 33.75° to the right of the distractor.

(such that the midpoint was aligned with the subject's interaural axis, either on the left or on the right).

Seven normal-hearing subjects participated in the experiment. Their task was to localize a target presented from one of the loudspeakers by pointing to the perceived location of the target using a hand-held pointer. The subjects were instructed to have their eyes closed during the experimental runs to prevent possible visual feedback.

The experiment contained two types of runs: 1) experimental runs in which in 75% of the trials (the distractor trials) the target was preceded by a distractor coming from the central loudspeaker and in the remaining 25% of the trials only the target was presented; 2) baseline runs in which all trials were without the distractor.

The target and the distractor were identical 2-ms broadband frozen noise bursts. The distractor-to-target onset asynchrony was 25 ms.

In each run the targets in the distractor trials were restricted to be presented from one of three regions (left half of the positions range, referred to in figures as the 1-3 context, right half of the range, 5-7 context, or the whole range except the central position 1-7 context; see Fig. 1), which represented the three possible context configurations. The context configuration (as well as the subject's orientation) was fixed within a run. The no-distractor targets were always presented from the whole speaker range including the central position. The experiment consisted of 12 types of runs: 3 subject's orientations × (3 context configurations + baseline run).

2.2. Data Analysis

The median of the subject's responses was computed for each combination of type of the run, type of the trial (distractor/no-distractor), target speaker and subject. Responses biased more than 20° from the corresponding median were considered to be outliers and were excluded from the analysis.

Data were collapsed across left/right lateral orientation since responses were approximately symmetrical.

The effect of the context was computed as the difference between the no-distractor responses in the experimental runs and in the baseline run. This bias was referred to as the "contextual bias". Across-subject mean biases (and within-subject standard errors of the means) were analyzed.

3. Results

Figure 2 shows the biases in subjects' responses relative to the actual target positions for medial (panel A) and lateral (panel B) orientation. The responses for medial orientation were biased approximately up to 5°, and for lateral orientation up to 25°, even in the baseline condition (orange line). The biases in baseline condition suggest that subjects tended to shift their responses towards the center of the positions range. Large biases for lateral orientation for target positions #5-7 (behind the interaural axis) is most likely related to the method of responding (listener's difficulty to point behind the interaural axis) or to the confusion of positions "in front of" and "behind" interaural axis. However, the differences between the context configurations are similar for the two orientations, suggesting that the deviation in the responses to the targets coming from behind the interaural axis did not influence how context affected these responses.

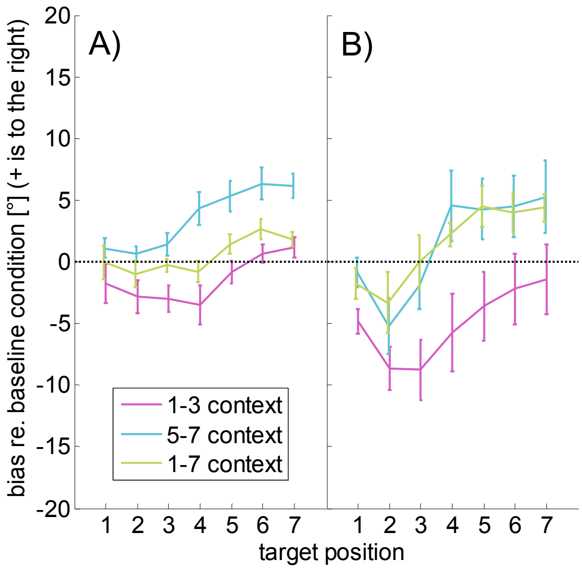

Figure 3. Contextual bias for medial (panel A) and lateral (panel B) orientation. Each panel shows across-subject mean and within-subject standard error in biases of responses relative to baseline conditions as a function of actual target position.

The biases from Figure 2 were subjected to a 3-way repeated measures ANOVA (with Box-Geisser-Greenhouse correction) with factors of target position (#1-7), context (1-3 context, 5-7 context, 1-7 context, baseline) and orientation (medial vs. lateral). The analysis found a significant main effect of the target position ($F_{6,36}$=24.02, p<0.01), a significant main effect of context ($F_{3,18}$=9.99, p<0.01), a significant orientation × target position interaction ($F_{6,36}$=16.93, p<0.01), and a significant context × target position interaction ($F_{18,108}$=4.57, p<0.01).

To examine the effect of the context, we plotted the biases in the experimental conditions from Fig. 2 relative to the baseline condition (Figure 3). In the half-range context conditions (blue and purple lines), biases of 5-10° away from the distractor were observed for targets presented from the same part of the range as context (target positions #1-3 for 1-3-context and #5-7 for 5-7-context). This shift in responses generalized to the middle position (target position #4) from which the distractor was presented. On the other hand, no biases (or small biases) were observed for positions from the other part of the range. This pattern of biases was observed for both the medial and lateral orientations, although for the lateral orientation the pattern was less clear, possibly due to the distortions in responses (note that the standard errors were larger for lateral orientation).

In the whole-range context condition, the contextual effect was smaller than in the half-range context condition (in Fig. 3 green line falls closer to the 0-line than the respective blue or purple lines).

The effect of all three context conditions differed very little within the group of target positions #1-3 or the group of target positions #5-7. Therefore, in the next analysis, the biases were averaged across the target positions within each group. To focus on the effect of presence/absence of the context within a particular subregion on the contextual biases, we re-grouped the data according to target-context spatial coincidence. Specifically, we divided the no-distractor target responses into ON-context group (targets coming from one of the locations from which distractor targets could come as well in the half-range runs), OFF-context (targets coming from one of the locations from which no distractor targets come in a given half-range run), and ON-context-all group (targets in the whole-range context condition). A new three-way, repeated-measures ANOVA was performed,

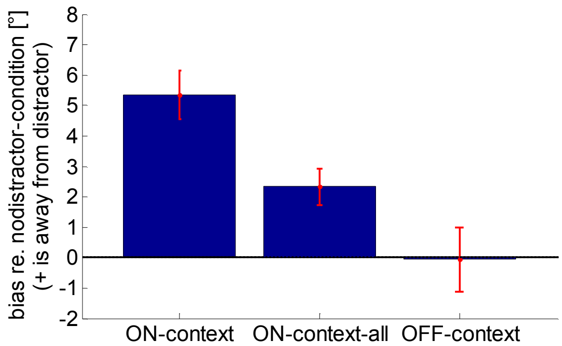

Figure 4. Bias relative to baseline condition. Data were divided according to target-context spatial coincidence into ON-context, OFF-context and ON-context-all groups. ON-context indicate the data from the subregion where context was presented (targets from positions #1-3 for 1-3 context and #5-7 for 5-7 context), OFF-context group indicate the data from subregion where no context was presented (targets from positions #1-3 for 5-7 context and positions #5-7 for 1-3 context) and ON-context-all represent the 1-7 context condition. Data were averaged across target positions within subregion and across orientation. Bars show across-subject mean and within-subject standard error.

with the factors of orientation, target-context spatial coincidence (ON-context, OFF-context, ON-context-all) and subregion (1-3, 5-7). The analysis found a significant main effect of context ($F_{2,12}$=13.19, p<0.01) while no other main effect or interaction was significant. The absence of significant interaction suggests that the contextual effect did not depend on whether the distractor-targets were presented to the left or to the right of the distractor, or whether the orientation was medial or lateral.

Figure 4 summarizes the overall pattern of the effect of the context by plotting the biases for each context subregion averaged across target positions within the 1-3 or 5-7 subregions, across the two subregions, and across orientation. Contextual biases of up to 5° were observed in the subregion in which the context was presented (ON-context group), while no contextual biases were observed in the subregion in which no context was presented (OFF-context group). Finally, when context was presented on both sides of the distractor, the biases were smaller than when the context was on only one side (ON-context-all is smaller than the ON-context group).

4. Conclusions

The current study examined contextual biases induced when localization task was performed either near the median plane or for lateral sources. No difference was found between the contextual effects for the two orientations (not consistent with H1), suggesting that the contextual effect is not dependent on localization acuity.

In the half-range runs, the biases were observed in the subregion of auditory space in which the contextual trials were presented, but not in the other subregion. This indicates that no generalization of the contextual effect occurs. However, when the context was presented on both sides relative to the distractor, the contextual biases for the targets in either subregion were smaller than when the context was presented solely within one subregion, indicating that some form of generalization or interaction between the two subregions did occur. These ambiguous results for generalization of the contextual effect make it difficult to identify the form of neural representation in which the contextual effect is induced, since our predictions were based on an assumption that generalization to a no-distractor subregion would occur. Since no biases were observed for subregion with no context, we will consider only whole-range context condition. The contextual biases in this condition were smaller compared to when the context was presented solely within the subregion. This pattern of results is consistent with a topographic Cartesian population code (consistent with hypothesis H2) in which each spatial location is represented by a single neural unit and in which each unit influences the activation of its neighbors within a certain radius [3]. In such a population code, it is expected that the shift will be induced at the locations from which contextual targets were presented. If it is assumed that the shifts generalize to the neighborhood of the contextual targets, it is expected that the perceived location of the central speaker, but not of the speakers from the region in which no context was presented, shifts because the central speaker is closest to the contextual targets. It is also expected that the whole-range context condition induces a weaker contextual shift if it is assumed that the units interact across a wide enough neighborhood because the shifts in spatial representation of the units sensitive to locations from opposite sides of the distractor partially cancel each other. A quantitative analysis needs to be performed in order to confirm that such model is consistent with the experimental data.

The dependency of the generalization of the contextual effect on whether the plasticity was induced ahead of the listener or to the side of the listener was not found, again supporting the Cartesian form of neural representation (consistent with H3).

While the model described above can account for the observed pattern of results, it does not explain the cause of the observed shifts. Specifically, the shifts in responses could be caused by a range of factors, including a simple bottom-up adaptation of the neural spatial representation, a top-down effect of a change in attentional distribution, or changes of listeners' expectation caused by the presence of the contextual trials.

Also, the current results and the proposed model do not allow us to determine where in the neural pathway the effect occurred, beyond saying that the representation does not appear to be polar (like the early, ITD-based spatial representations).

In summary, these results suggest that the contextual effect is more complex than simple uniform shifting or expanding of whole auditory spatial representation and that it is potentially influenced by top-down processes such as attention. Also, they suggest that the effect is probably induced in a neural structure located in later stages of the processing pathway. The contextual effect can be expected to influence perception in many everyday situations in which sequences of multiple sounds need to be individually and differently processed. Additional studies need to be performed to explore how contextual plasticity is influenced by other, non-spatial characteristics of the context.

Acknowledgments

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