Learning to judge distance of nearby sounds in reverberant and anechoic environments

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Introduction

Some recent studies of auditory distance perception in real rooms [1,2] report that listeners steadily improve their distance judgments with practice over fairly long periods (hours to days). Similar improvement is not observed in an anechoic environment [3], suggesting that listeners learn (through experience) how to interpret reverberation cues and map these cues to different distances in a particular room. However, it is not clear how such "room learning" takes place. Here, we present results of two experiments that evaluate how the changes in reverberation cues associated with changes in the listener's position in a room influence this process of learning to judge sound source distance.

Experiment 1: Real Environment

The first study was performed in a single real classroom. The listener's position in the room was fixed during two-hour-long sessions (each of which consisted of 300 experimental trials) and changed only between sessions. Four listener positions were used, ranging from the room *center* (where the reflections of the distant walls are relatively late and arrive from multiple directions at roughly the same time) to the room *corner* (where the reflections from the two nearby walls are relatively intense and early).

Methods

Two groups of three normal-hearing subjects participated in the study, each performing four experimental sessions. Group A started in the *center* and ended in the *corner* of the room. The listener position order was reversed for subjects in Group B. The stimulus consisted of five 150-ms-long pink-noise bursts presented at a level first equalized at the head and then roved by 15 dB rms. The sound source was hand-positioned by the experimenter so that locations were roughly uniformly distributed within the right frontal part of the horizontal plane (0-90˚ azimuth) at nearby distances (from 15 cm – 1 m from the center of the head) at the height of the listener's ears (see Figure 1a). Results were analyzed by computing the mean and variance of the log of the ratio between the actual distance and the response distance.

Results

The mean value of the ratio between actual and perceived distances was generally less than one (listeners tended to overestimate the distance of the nearby sources). Furthermore, there was no evidence for learning, as the mean ratio did not change consistently with experience. However, variance in the responses did show systematic changes with experience that depended upon the listener location in the room. Figure 1b shows that the variance of the distance ratios decreased dramatically between the first and the last session when the listener started in the *corner* (acoustically complex) position and ended in the *center* position (Group B). On the other hand, listeners starting in the *center* and ending in the acoustically complex *corner* (Group A) exhibited very little change in response variability. These results suggest that, while the changes in the reverberation between the *center* and the *corner* of the room are sufficient to cause a difference in the accuracy of distance judgments, listeners learn something about the room that improves their judgment consistency. Furthermore, this learning generalizes across the tested listener locations in the room. Further analysis, binning the data by sound source location as shown in Figure 1a, showed that most of the learning occurred for sources off the midline at 45 or 90° azimuth.

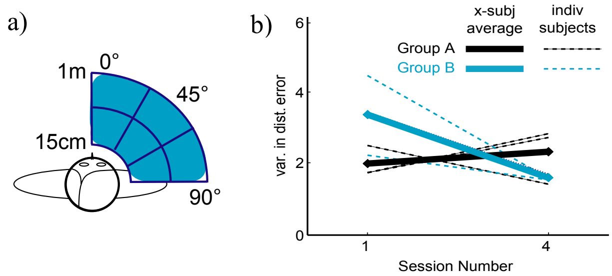

Figure 1: a) Sound source locations used in Exp 1. b) Results of Exp 1 in which the listener position was changed in a real room after every session of 300 trials. The plot shows the variance of the log of the ratio between actual and response distances for initial and final experimental sessions. Listeners in Group A performed the initial session in the *center* and ended in the *corner* of the room; Group B performed the sessions in the opposite order. For more details see [4].

Experiment 2: Virtual Environment

Results of Experiment 1 suggest that past experience in a particular room leads to improvements in distance accuracy. In order to test whether trial-to-trial consistency is important for this kind of "room learning," a second study was performed in virtual auditory space (VAS) [6], Stimuli simulating different room conditions were generated by convolving the stimuli with individually measured reverberant head-related transfer functions (HRTFs).

Methods

The study was divided into two halves. In the "change-after-session" portion, the listener's position in the room was fixed during each session and changed only between sessions. In the "change-after-trial" portion, the listener's position was randomly chosen on each trial. Two groups of four normal-hearing subjects participated in the study. Subjects in Group A performed the change-after-session portion of the study first and the change-after-trial part second, while Group B did the two portions in the reverse order.

Each portion of the study consisted of six experimental sessions of 8 runs; each run consisted of 45 trials (360 trials per session). Three different listener locations were simulated: *center* and *corner* room locations were generated using HRTFs measured in the same classroom used in Experiment 1; an *anechoic* location was simulated using time-windowed *center* HRTFs (see [1] and [2]). The random order of the room locations simulated in the change-after-session portion differed for each subject. Stimuli were similar to those used in Experiment 1; however, sources were simulated as coming either from directly in front or to the right of the listener. Nine different distances, logarithmically spaced between 15 and 170 cm, were simulated. Results were analyzed by computing the square of the correlation coefficient *r* between the log of the response distance and the log of the simulated source distance.

Results

Overall, the accuracy of distance judgments observed in this study was fairly low, in particular with the anechoic stimuli and in the change-after-trial sessions.

To evaluate the effect of learning, r^2 was computed separately for the initial three and the final three sessions making up each portion of the experiment. Figure 2 shows the difference between these values of r^2 for all subjects (small symbols) as well as the across-subject means (large symbols). The results were very similar for the two subject groups, therefore the means in the graphs were computed across listeners in both groups. There is a weak trend towards improvement in the change-after-session data (squares in Figure 2), in particular for trials in the *center* of the room. However, this effect is relatively small compared to the inter-subject variability. When reverberation cues are changed after every trial, no improvement is observed and the across-subject variability is much smaller.

Discussion and conclusions

The absence of learning observed in the change-after-trial portion of Exp 2 might arise if, in this experiment, the reverberation cues were changing from trial to trial so dramatically that the listeners learned to *ignore* the reverberation cue. This hypothesis is supported by the observation that the listeners who first did the change-after-trial portion of the study performed worse in the change-after-session portion than those who started in the change-after-session portion, presumably because they "gave up" on using reverberation as a distance cue [5].

Exp 1 and the change-after-session portion of Exp 2 were very similar, except that 1) Exp 1 was performed in the real world and Exp 2 in virtual space, and 2) Exp 2 contained an *anechoic* condition.. It may be that the smaller amount of learning observed in Exp 2 is a consequence of one of these differences. A follow-up to Exp 2 is currently underway in which the *anechoic* condition is left out. Preliminary results of this study show a much smaller difference between change-after-trial and change-after-session performance, suggesting that it is the inclusion of the *anechoic* condition that causes the differences observed between Exp 1 and Exp 2.

Overall, these results suggest that listeners can generalize "room learning" across different listener locations within a single room, even when the listener position changes randomly between trials. However, generalization of learning does not occur across dramatically different acoustic environments.

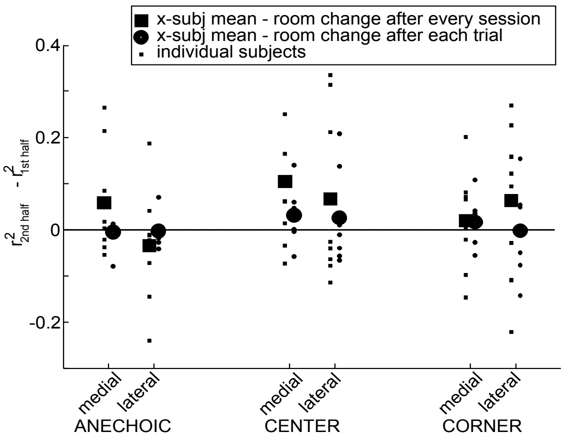

Figure 2: Results of a VAS study in which the listener position in room was simulated to be changed after every session of 360 trials or after each trial. Graph shows the difference in performance between the first 360 trials and the last 360 trials performed in a given room computed as a square of the correlation between the log of the simulated distance and the log of the perceived distance. For more details see [4].

References

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