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Effect of a known environment on the estimation of sound source distance

1. Introduction

The estimation of sound source distance has been a topic of research interest for a number of decades now. Humans are good at localizing sound in the azimuth and elevation, but are poor at estimating the sound source distance. This project looks at examining the effect of a known environment on the estimation of sound source distance. The project aims at initially testing the subjects perception of sound source in an unknown environment and then examining the effect of training the subject to the environment to see if training/learning the acoustics of the environment improves the estimation of the source distance.

2. Prior Work

The estimation of sound source distance has been a popular research topic for a number of years. Studies in the past have shown that we are good at estimating the relative distance of sources (Cochran, Throop, Simpson, 1968). However, estimating the absolute source distance has always been poor. Zahorik (2002) showed that humans tend to overestimate source distance that is less than 1m away and underestimate source distance for sources greater than 1m. This behavior has been well captured and explained in the figure below.

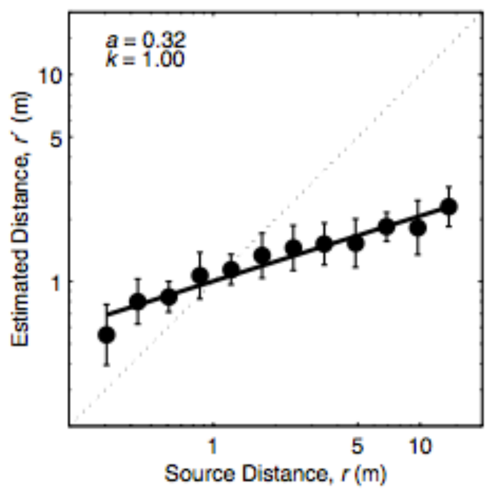

Figure 1: Plot showing source distance (x-axis) vs. estimated distance (y-axis). Figure borrowed from Zahorik (2002)

As seen from the figure, the underestimation of sound source distance gets worse with increase in distance. Zahorik (2001) and Zahorik & Wightman (2001) showed the effects of vision and loudness on the source distance estimation. Vision as with other spatial cues, has a positive effect on the source distance estimation. Perceived loudness, however, does not change with change in source distance. This is thought off as the primary reason for poor estimation of source distance.

However, it has also been shown that the accuracy of distance estimation improves when the experimentee is presented with known stimuli (Zahorik, 2002; Cochran et al., 1968), e.g. a friend's voice or a sound heard in daily life as opposed to stimuli usually used in localization experiments, e.g. sine sweep or pink noise bursts.

Given the above observations, the author hypothesizes that, "If there is a 'known' factor associated with the accuracy of estimation of sound source distance, then a 'known' acoustic environment should also improve our sound source distance estimates."

The goals of this project are two fold: a) To design an experiment to examine the effect of environment on sound source distance and b) To conduct a subjective analysis and assess the effects in an empirical manner.

3. Methodology

3.1 Experiment Design

To test the above hypothesis, a subjective experiment was designed. A large room was selected and loudspeakers were lined up one behind the other to play the stimulus. The experiment setup is explained in detail in section 3.2.

As the stimulus, a sine sweep from 100Hz to 5000Hz was created using MATLAB. The design choice was between a sine sweep and pink noise bursts. Eventually, the author decided to use sine sweeps as he felt they covered a large frequency range and stayed in the environment for a little longer than noise bursts, thereby giving the subject a better opportunity to estimate the distance from which it was played from.

There were three testing phases in the experiment. All testing phases involved playing the sine sweep randomly from one of the loudspeakers in the configuration and asking the subject to name the loudspeaker number from which the sound was being played. The three testing phases were:

- Pre-training phase: This was the first testing phase. Participants were tested on their distance localization accuracy as soon as they came into the environment.
- Self-training phase: After the pre-training test, the subject was asked to explore the environment and figure out the acoustics of the room in whatever manner he/she deemed appropriate. The experimenter assisted the subject as requested (clapping from various parts of the room, etc.). Once the subject felt he/she had trained sufficiently, a round of distance localization test was performed.
- Forced training phase: In this phase, training took place in the form of sine sweeps being played from the loudspeakers, much like the testing phase.

Five rounds of training were conducted with sounds being played from the loudspeakers in a random order. At the end of each sound, the subject was informed of the loudspeaker it was played from. Thus with this, the subject got an idea of how the sweep sounded from different places in the room. At the end of five rounds, another test was conducted.

In all the testing rounds, the sound was played only once from the loudspeaker. The subject could take their time to decide on their answer.

3.2 Experiment Setup

The experiment was conducted in a room in the Bobst Library at New York University. A picture of the experiment room is shown below. The room was rectangular and had the dimensions – 17.5ft x 13.5ft x 10ft. This space was fairly reverberant[1].

Figure 2: Experiment Setup

[1] No measurements were done to measure room acoustics.

Eight loudspeakers (Yamaha -) were used for the experiment. They were placed in an array fashion, one behind the other, and 1.5ft apart. The first speaker was 1ft away from the listener. This configuration allowed the first 2 loudspeakers to be within 1m from the listener, the third ~1m from the listener and the rest farther away.

3.3 Participants

Thirteen graduate students (9 male and 4 female) of New York University with varied experience with concepts of spatial sound and sound localization took part in the experiment. Their mean age was 28.07 (SD = 3.48). Although background information on their familiarity with spatial sound concepts and their prior participation in sound localization experiments were collected, this factor was not eventually used in analysis. All participants fell into the same pool. No participant had been to the room before this experiment.

4. Results

Data collected was analyzed using SPSS software. A repeated measures ANOVA was performed to measure the mean error of the participants across the three testing phases. Thus the measure of error in performance became the dependent variable and three testing phases became the independent variables. This gave a measure on how accurate/inaccurate they were across the phases. If the hypothesis were to be satisfied, there should be a reduction in the mean error in performance across the testing phases.

Session	Mean Error	Standard Deviation
T1	2.0431	2.0017
T2	1.9655	1.9119
T3	1.2802	1.7610

p = 0.003 (Huynh-Feldt Corrected)

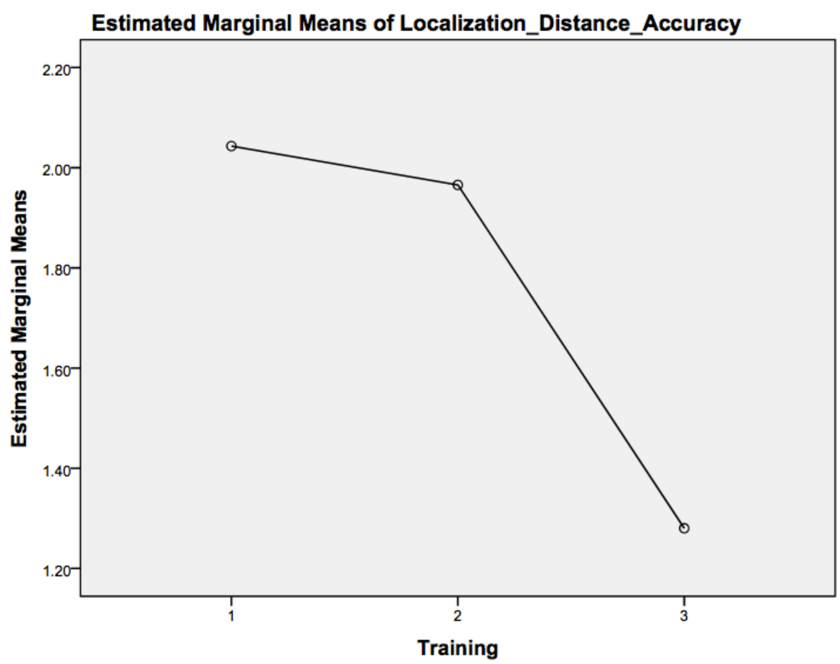

Figure 3: Plot showing the mean error across testing phases

The table and graph above show the mean error or the participants across the different testing phases. As seen, there is a clear reduction in the mean error.

The sphericity test was not violated in the repeated measures ANOVA and therefore sphericity had to be assumed and the data had to be corrected for using the Huynd-Feldt Correction. This gave $p = 0.003$, thus showing the data collected and analyzed was statistically significant.

4.1 Discussion

The analysis shows that there is a drop in the mean error in performance of the participant with training. This drop in error is prominent from test 1 to test 3, but not as significant from test 1 to test 2. This seems to suggest that the training definitely had an affect on the performance of the participant. He/she became more acquainted with the acoustics of the space and could localize better along the distance axis. Mean error fell from 2.04 in test session 1 to 1.28 in session 3. That is a 37.25% improvement in performance, indicating that the hypothesis is supported. The p-test showing statistical significance of the data further supports the hypothesis.

5. Conclusions and Future Work

5.1 Conclusions

An experiment was designed to test the effect of training on the estimation of sound source distance and successfully conducted. The results showed that there was a reduction in the mean error of performance across participants. The mean error reduced from 2.04ft pre-training to 1.28ft post training. The p value was measured to be 0.003 thus showing statistical significance of the data. All this seems to support the author's hypothesis. This gives an insight into how the depth perception of an acoustic space changes over time.

5.2 Future Work

This study was conducted on a small scale from a pilot study point of view. The significance of data obtained encourages a more robust test with better equipment, more test signals (familiar and unfamiliar), and more locations. Adding more training and testing sessions in a location can be indicative of any stabilization in the learning phase.

References

[1] A. W. Bronkhorst and T. Houtgast, "Auditory distance perception in rooms," *Nature*, vol. 397, pp. 517-520., 1999.

[2] D. H. Mershon and J. N. Bowers, "Absolute and relative cues for the auditory perception of egocentric distance," *Perception*, vol. 8, pp. 311-322, 1979.

[3] S. H. Nielsen, "Auditory distance perception in different rooms," *J. Audio Eng. Soc.*, vol. 41, pp. 755-770, 1993.

[4] A. W. Bronkhorst, "Effects of stimulus properties on auditory distance perception in rooms," in *Proceedings of the 12th International Symposium on Hearing (ISH): Physiological and Psychological Bases of Auditory Function*, Mierlo, The Netherlands, 2000, pp. 184-191.

[5] P. Zahorik, "Estimating sound source distance with and without vision," *Optom. Vis. Sci.*, vol. 78, pp. 270-275, 2001.

[6] P. McGregor, A. G. Horn, and M. A. Todd, "Are familiar sounds ranged more accurately?," *Percept. Mot. Skills*, vol. 61, pp. 1082, 1985.

[7] P. D. Coleman, "Failure to localize the source distance of an unfamiliar sound," *J. Acoust. Soc. Am.*, vol. 34, pp. 345-346, 1962.

[8] W. Philbeck and D. H. Mershon, "Knowledge about typical source output influences perceived auditory distance," *J. Acoust. Soc. Am.*, vol. 115, pp. 1980-1983, 2002.

[9] W. M. Hartmann, "Localization of sound in rooms," *J. Acoust. Soc. Am.*, vol. 74, pp. 1380-1391, 1983.

[10] P. Zahorik, D. J. Kistler, and F. L. Wightman, "Sound localization in varying virtual acoustic environments," in *Proceedings of the Second International Conference on Auditory Display*, Santa Fe, NM., 1994, pp. 179-186.

[11] Cochran P, Throop J, Simpson WE. Estimation of distance of a source of sound. Am J Psychol 1968, 81:198–206.

[12] Holt RE, Thurlow WR. Subject orientation and judgment of distance of a sound source. J Acoust Soc. Am. 1969; 46:1584–5.

[13] Mershon DH, King E. Intensity and reverberation as factors in the auditory perception of egocentric distance. . Percept Psychophysics 1975; 18:409–15.