Discrimination experiment of sound distance perception for a real source in near-field

Zhenyu Guo, Yigang Lu, Liliang Wang, Guangzheng Yu

DISCRIMINATION EXPERIMENT OF SOUND DISTANCE PERCEPTION FOR A REAL SOURCE IN NEAR-FIELD

Zhenyu GUO[1] **Yigang LU**[1] **Liliang WANG**[1]
Guangzheng YU[1]
[1] School of Physics and Optoelectronics, South China University of Technology, Guangzhou, China
correspondent: scgzyu@scut.edu.cn

ABSTRACT

The ability of distance perception is quite important for our daily life. It helps listeners to perceive an approaching sound source and avoid dangerous objects especially when the vision is unavailable.
Previous researches have proved that the sound pressure has a giant influence on the ability of distance discrimination in both the near field and the far field. However, a few researches attempt to examine the binaural effect alone in distance perception.
To verify the impact of binaural effect on distance discrimination, we conducted an experiment to exam the sound distance perception thresholds via an automatic test system. A loudness-balanced wide band noise was used as test signals to remove the influence of sound level. 5 azimuths (0°, 45°, 90°, 135° and 180°) and 2 reference distance (50 cm and 100 cm) are taken into consideration.
The results show that distance discrimination thresholds of subjects are lower when the sound source is on the side of head compared with front and back. Moreover, this phenomenon is more prominent in 50 cm compared with 100 cm. The results obtained in this study are consistent with previous studies and reveal that the binaural effect indeed contributes to distance discrimination process of human to some degree.

1. INTRODUCTION

Spatial hearing is a vital ability for human beings to percept objects especially when vision system is disabled. Not only spatial angle but also distance of sound sources can be perceived by people when referring to spatial sound location. Vast researches have studied the spatial angle perception of humans [1], however, less literature focus on inquiring distance discrimination ability of humans.
According to previous researches, the following several acoustic cues are considered to be the most vital for distance perception: (1) intensity; (2) direct-to-reverberation energy ratio; (3) spectrum change; (4) dynamic cues; (5) binaural cues [2, 3]. Among all these cues, intensity is the most significant and general one especially in the far field [4]. Since the shadow effect of head could be more significant in the near field, we believe the binaural cues can also be a useful cue for sound source distance discrimination. The propagation process from sound source to two ears can be described by the head-related transfer function (HRTF). Normally, HRTFs contain interaural level difference (ILD), interaural time difference (ITD) and spectrum cues [5]. Both theoretical calculation and measurement demonstrate that distinction of HRTFs between two ears change quite significantly with distance in the near field [6, 7]. For instance, the ratio of two ears' ILD changes with distance and azimuth of sound source dramatically especially in the near field. This is because that shadow effect of head contributes a great deal in the near field. On one hand, the head can be regarded as a rigid reflection panel, and it attenuates the sound wave propagating to the contralateral ear, on the other hand, it will enhance sound wave propagating to the ipsilateral ear due to reflection especially for high frequency components of sound wave. As we know, high-frequency sound is highly directional, in this case high-frequency sound's mask degree can change with sound source distance. Besides, the azimuth related to the lateral ear of sound source vary with its distance to head center, and this is called acoustic parallax [8]. Considering above-mentioned facts, we have enough reasons to believe that distance discrimination ability could make a difference when sound source appears in different lateral azimuths.
Up to now, there were a few literatures conducting experiments to verify the head shadow effect in distance discrimination, or in other words, effect of binaural cue in distance discrimination. Brungart et al. have examined the distance discrimination performance of lateral sound source [9]. However, their experiment failed to exclude other distance perception cues. Therefore, it is necessary to carry out a specific and systematic experiment to examine to what extent binaural cues can make effect in sound source distance perception.
Generally speaking, two categories of sound source are alternative to conduct psychoacoustic experiment. One is virtue auditory display (VAD) sound source [10], while the other is real sound source [9]. In terms of VAD via headsets, signal must be convolved with individual HRTFs with the intention of achieving real spatial perception. Nev-

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ertheless, the accuracy of near-field HRTFs measurement still remains problems [11]. Besides, the coupling problem between headsets and ear canals can be quite tough and uncontrollable, and this problem may influence binaural ITDs a lot. In order to assess the distance discrimination in an environment as real as we can, we choose to use a loudspeaker to playback test signal. We built a moveable loudspeaker playback system by using an electric slideway for the experiment and conducted the complete experiment in an anechoic chamber (background noise below -12.1 dBA) to exclude the impact of reverberation or any other possible hint cues.

2. METHODS

The distance discrimination experiment was conducted with a specially designed platform in an anechoic chamber. The subjects' relative discrimination thresholds in five different azimuths (0°, 45°, 90°, 135°, 180°, in the right half plane) and two distinct reference distances (d_f, 50 cm or 100 cm) were measured via two-interval forced choice (2IFC) [12]. The discrimination performance was evaluated in two distinct conditions (with the intensity cue excluded or included, considered as the experimental group and the control group, respectively). To make a summary, each subject's distance discrimination thresholds were measured in total 20 ($5 \times 2 \times 2$) different conditions.

2.1 Subjects

Eight subjects (four males and four females, denoted as S1 to S8) participated in the discrimination experiment. Subjects' ages range from 23 to 41. Each subject has normal hearing and has experience in participating psychoacoustic experiments. Subjects were paid for their participation.

2.2 Experiment devices

Pervious distance discrimination experiments were commonly implemented with a simple mechanical movable loudspeaker system [9, 13]. The loudspeaker is pushed by the assistant manually. Considering that the assistant may make mistakes in moving the loudspeaker and the action may create noise which may hint the subjects about sound source distance, neither the accuracy nor the reliability of these experiments' result data is doubtful. With the intention of conducting distance discrimination experiment, sound source must appear in different distances to subject rapidly and accurately. To accomplish this aim, we built an automatic moveable loudspeaker playback system. The loudspeaker (Mission M30i) is attached to an electric slide way which is driven by a two-phase stepper motor (57BYGH75). The mechanical system is fixed on a stable aluminum bracket. As for the control system, we use a commonly used embedded control board named Arduino (Arduino Uno) and a two-phase stepper motor driver (DM542). In terms of audio stream, we use an external sound card (RME Fireface UC) to output stimulus signals, an amplifier (ARCAM A65) cascades to the sound card and drives the loudspeaker. The whole control flow is as follows:

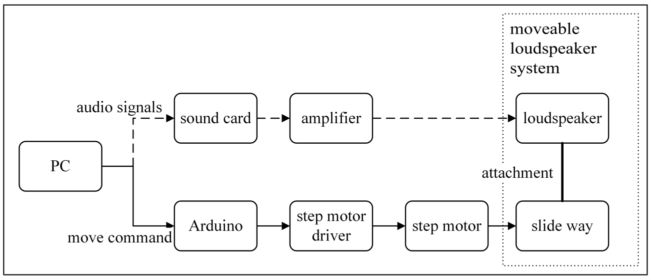

Figure 1. The schematic diagram of experiment device

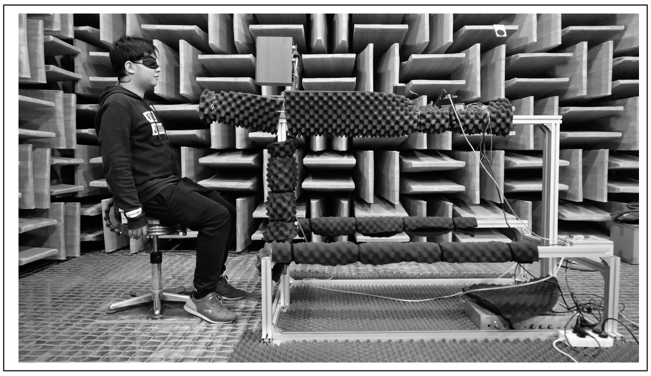

Figure 2. The picture of experiment device.

1. The computer transmits move orders to Arduino through the Universal Serial Bus (USB) port. Meanwhile, the computer transmits the test signal to the audio card.

2. The Arduino receives the move order and translates it into pulse width modulation (PWM) signals and direction control driver signals for DM542.

3. DM542 transforms the PWM signals and direction control signal into two-phase stepper motor code driver signal, then the motor can put loudspeaker in motion.

The schematic diagram and picture of the device are shown in Figure 1, and Figure 2, respectively. The valid move range of loudspeaker can reach to 0.8 m, maximum move speed is 500 mm/s, and the error of move distance is no more than 0.1mm. The whole system is wrapped with sound-absorbing cotton to avoid unnecessary reflection. Although the slide way will make a little noise (less than 35 dBA) during operating, it cannot provide subjects the distance and movement statue information of loudspeaker according to noise evaluation and subjects' feedback.

2.3 Stimuli and self-adaptive procedure

All stimuli used in this study are full-band pink noise. Signal sampling rate is 44.1 kHz, duration time is 1000 ms and the ramp time is 20 ms. Two test conditions are set to exclude the influence of intensity cue. To be specific, signals of the experimental group is balanced sound pressure

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level (SPL) while no compensation is done for signals of the control group. In terms of experimental group, SPL of stimulus in the position of head center is constant 75 dBA no matter how far the sound source is. As for the control group, the SPL of stimuli in the above-mentioned position is calibrated as 75 dBA only when sound source in reference location, and no intensity compensations are made, that means the sound pressure of sound source in the head position obeys the inverse-square law [6].

The distance discrimination thresholds of different conditions were measured via implementing 2IFC and 2-down-1-up self-adaption method. To be specific, loudspeaker will playback two stimulus in a round. Before each round, control computer plays a prompt message to hint subject. One stimulus appears in reference location while other one appears in a forward location (test distance, d_t) which is closer to the subject, besides, the order of two stimuli was random. After two stimuli are played over, subjects are required to choose which stimulus is more near to them and feedback their choices to the assistant in oral. The interval time between two stimuli ranges from 1 s to 2 s (depending on distance difference between two stimuli). In the first round of each block, the initial d_t is 30% less than the d_f when sound source's azimuth was 0°, 45°, 90° or 135°, and this value was adjusted to 40% for 180° particularly (e.g. d_t is 0.35 m for the condition that d_f is 50 cm and sound source azimuth is 0°). After subjects feedbacked their judgement, d_t would be adjusted automatically with the 2-down-1-up method. That means only when subjects fetch correct answer twice continuously will d_t be shorten a step length, on the other hand, d_t will be extended following each error responding, otherwise, d_t keeps constant in the next round. This procedure guarantees that the correction rate of subjects will not be under 70.7% [14]. With regard to the step length for each adjustment of d_t, it is 3% before the first mistake just for accelerating the convergence speed. After a mistake choice is made, the step value will become 1% (that is 0.5 cm when d_f is 50 cm or 1cm when d_f is 100 cm) for subsequent test rounds. Particularly, if subjects fetch correct responding four times in a row, the step length is adjusted to 2% until next mistake appears. The whole self-adaptive procedure finish when action of decreasing or increasing d_t reverses 12 times. The final discrimination distance d_t' is determined on the mean value of d_t in the last 5 reversal rounds.

The distance discrimination threshold was measured by Weber ratios [15] as following:

$$threshold = \frac{d_f - d_t'}{d_f} \quad (1)$$

threshold under 20 discrimination condition of each subject were measured. Figure 3 presents a round of discrimination threshold measurement.

2.4 Procedure

The experiment procedure for each subject is depicted as followings:

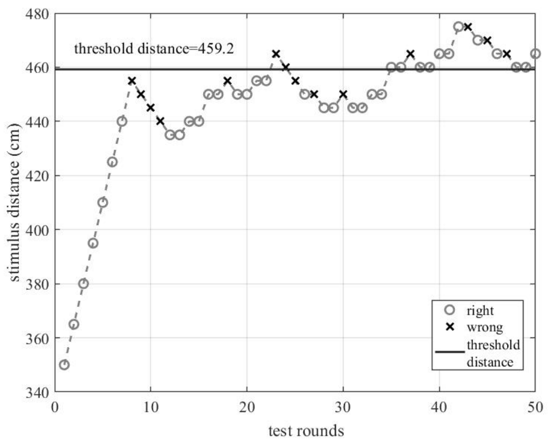

Figure 3. A block of discrimination threshold measurement. In this test, d_t' is 459.2 cm while *threshold* is 8.2% in the condition that reference distance is 500 cm and the intensity of stimulus is unbalanced.

1. Choose one from five test azimuth in random, and adjust the subject's azimuth relative to slideway. After that, we asked the subject to wear a blinder to guarantee they would not get any clues from vision.

2. Select one reference distance between two alternative choices.

3. Measure the *threshold* values of control group and experimental group in sequence by the scheme described in section 2.3.

4. Repeat above-mentioned process until *threshold* in total 20 different conditions was measured completely..

The full test for each subject consumed about 6 hours, and each subject only participated the experiment for 2 hours a day, besides, subjects had 10 minutes for rest after completing each test block. Before the experiment, subjects got a simple training (play ten rounds of stimuli) to familiarize themselves with the stimuli.

3. RESULTS AND DISCUSSIONS

3.1 Results of *threshold* measurement

8 participators' *threshold* in all condition was obtained in this experiment and presented in Figure 4, in this figure, black line and gray line indicates the control group and experimental group, respectively. Besides, the circle marks and the square marks represent the 50 cm and 100 cm reference distance, respectively.

3.2 Intensity cue

There is no doubt that the intensity cue is the primary cue for sound source distance prescription. The results verify this conclusion again considering that *threshold* values in unbalanced intensity condition are 10% to 20%

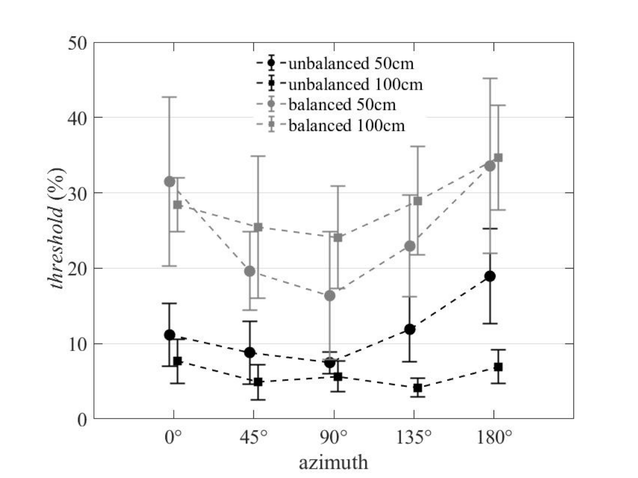

Figure 4. *threshold* measurement results. The marks and the caps indicate the mean values and the standard deviation values among 8 subjects, respectively.

lower than values in balanced intensity condition. Conducting multivariate analysis of variance (ANOVA) which include three factors as mentioned in section 2, result comes out that intensity cue has significance in main effect ($F(1,140)=287.542$, $p<0.05$).

3.3 Reference distance

Both in experimental group and control group, reference distances make significance effect to *threshold* value. The ANOVA results come out that $F(1,140)=15.224$, $p<0.05$ and $F(1,140)=5.653$, $p=0.019$ for experimental group and control group, respectively. Especially for control group which includes intensity cue, the result demonstrates that the father the sound source is, the lower the *threshold* is. Strybel et.al. [15] and Simpson et al. [16] reported similar phenomenon before. In terms of experimental group which exclude intensity cue, the results don't meet abovementioned regulation. To be specific, the *threshold* value becomes lower rather than higher in 50 cm reference distance when sound source is lateral. This phenome reflects head shadow effect in sound source distance prescription considering that head shadow makes significance effect in ILD especially for lateral sound source in the near field and the ILD cue (or say binaural cue) can be used to estimate sound source distance by auditory system especially when the intensity cue is unavailable.

3.4 Binaural cue

When we refer to binaural cues, ILD and ITD are both necessary to be considered. However, previous study has proved that ITD provide less information in distant perception [11]. Accordingly, this study focuses on discuss the influence of ILD but not ITD in distance perception.

The experiment in this study measured 5 different azimuth of sound source in the horizontal plane to uncover whether binaural cue make effect in distance discrimination. Figure 4 demonstrates that threshold values tend to be smaller when sound source is in the lateral direction (45°, 90°, 135°) compared with the medium plane (0° and 180°), and the results reveal that distance discrimination ability is better for lateral sound source than sound source in the medium plane and some researches have similar conclusion as well [9, 10].

This pattern appears both in experimental group and control group, especially for the case which excludes the intensity cue. That is due to that the ILD change with sound source distance dramatically in the near field. As the sound source becomes closer to listener, the ILD becomes larger gradually. This ILD changing pattern has been calculated via analytical solution of the rigid sphere model [6]. Considering sound source appear in medium plane, the loudness of source in two ears would be the same hence no ILD cue is available. On one hand, ILD cue which caused by head shadow effect become a main distance perception cue and lead to huge threshold distinction between lateral and front (or rear) direction in the experimental group as the gray curve in Figure 4 shows. On the other hand, ILD become a supplementary cue considering that *threshold* value increase below 5% when sound source appears in lateral direction comparing with medium plane.

As the reference distance decreases, the head shadow effect will become more significant, or in other words, the ILD cue become more obvious. This object cue also makes sense in auditory perception according to Figure 4. The round markers represent 50 cm reference distance while the square markers denote 100 cm reference distance. The curve of 50 cm changes with different azimuths more comparing with the curve of 100 cm especially when intensity cue is unavailable.

4. CONCLUSIONS

The study built a fast and accurate experiment platform for measuring distance discrimination threshold of human beings. The intention of this study is to reveal to what degree can the binaural cue make impact on distance discrimination. 5 different azimuths from 0° to 180° with a step of 45°, 2 discrete reference distances and 2 types of stimuli are taken into considering. Utilizing the experiment platform, total 160 *threshold* values (8 subjects, 20 *threshold* values in different conditions for each subjects) are measured.

The results demonstrate intensity cue is indeed the main cue for distance discrimination. Meanwhile, the reference distance also makes effect in distance discrimination, that is, particularly speaking, the father the sound source is, the lower the distance discrimination threshold is when sounds include intensity cue.

In addition, the results reveal that the binaural cues definitely have influence on sound source distance perception:

1. The lateral direction distance discrimination ability is better compared with medium plane

2. The binaural cue is less important when intensity cue is available although it indeed makes influence.

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3. The influence of binaural cue on distance discrimination increases when sound source gets closer.

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