Human's Spatial Cognition Using Auditory Stimulation

M. Yu, Y. G. Park, S. H. Jeong, W. S. Chong, *T. K. Kwon, *C. U. Hong, *N. G. Kim

Dept.of Biomedical Engineeirng, Chonbuk National University, Chonju, Korea
(Tel: +82-63-270-2246; E-mail: yum391, yjpiao, winsomesh, biosuk72 @hotmail.com)
*Division of Bionics and Bioinformaics, Chonbuk National University, Chonju, Korea
(Tel: +82-63-270-2247; E-mail: kwon10, cuhong, ngkim@chonbuk.ac.kr)

Abstract: This paper represents the role of pinna in localizing target direction. Specially, this paper described what is the role of right-side pinna versus left-side pinna. In this experiment, one side of the pinna function was distorted intentionally by inserting a short tube on the ear canal. The localization error caused by right and left side pinna distortion was investigated. Since a laser pointer showed much less error (0.5%) in localizing target position than FASTRAK (30%) that has been generally used, it was used for the pointing task. It was found that harmonic components were not essential for the auditory target localization, however, non-harmonic nearby frequency components were more important to localize target direction of sound. We have found that the right pinna is one of the most important functions in localizing target direction and pure tone with only one frequency component is confusing for localization.

Keywords: **s**patial cognition, auditory stimulation, frequency, pinna

INTRODUCTION

Human cognition does not only depend on the properties of actual stimulation but also on frequency or sensory organ's morphology in which stimuli are embedded. Various condition influences on perceptual judgments caused by a preceding or concurrently presented stimulus have been demonstrated.

A well-known phenomenon is the so-called ventriloquism effect in auditory spatial perception on which the perceived position of an auditory stimulus appears to be shifted in the direction of a simultaneous, spatially disparate visual stimulus [1].

The external ear (pinna) modifies the frequency spectrum of sounds in a fashion that depends on the direction of the sound source. This filtering action of the pinna produces spectral cues for source location, which are most important in determining the elevation of the source and its front-back position in human observers. Auditory space is also constituted from the sound of wind, a voice, the roar of a car heard from back [2, 3, 4, 5, 6, 7].

Accurate spatial perception across a wide frequency range is a prerequisite for music and speech perception, for instance, in melodic, harmonic, and prosodic processing. In all natural pitched sounds, the sound spectrum consists of a time-varying pattern of multiple harmonic partials across a large frequency spectrum. However, the overwhelming majority of the experiments on pitch perception in psychoacoustics and auditory neuroscience used sinusoidal tones consisting of one harmonic partial (fundamental) only. For instance, Wier et al. [8] compared the frequency discrimination accuracy of sinusoidal tones at 8 frequency ranges from 200 to 8000 Hz by presenting 500ms sounds once a second against the background of a low-level broadband noise. More recently, Sek and Moore [9] employed three different psychoacoustic methods (difference limen for single tones, in paired sounds, and for frequency-modulation) at six frequency ranges from 250 to 8000 Hz. Both experiments showed that frequency discrimination is the most accurate up to 2000 Hz, with the accuracy thereafter deteriorating at a rate depending on the method used. Kishon-Rabin et al. [10] compared the frequency discrimination of 300-ms sinusoidal tones at three frequency ranges 250, 1000, and 1500 Hz with each other by using 2 and 3-interval forced-choice methods. They found that the higher the frequency was, the more accurately subjects detected the frequency differences.

Beside these examples of cross-modality context influence, a growing body of evidence shows that a preceding sound can also influence the localization of a subsequent sound. Under certain conditions, the position of the subsequent sound appears to be shifted in the direction opposite to the location of the prior sound. This auditory contrast effect has been reported for sound lateralization [11, 12] and for sound localization [12, 13, 14, 15, 16, 17]. In general, these studies showed that the occurrence of displacements depends strongly on certain conditions regarding timing, spectral characteristics, and spatial configuration of the preceding and the subsequent sounds. In a lateralization task based on interaural time differences (ITDs), Kashino and Nishida [18] found that the apparent displacements in sound position occurred only when the frequencies of preceding and the subsequent sounds were similar and when the two sounds were perceived to be in immediate vicinity. Thus, the contrast effect can be characterized as both frequency- and location-specific. The origin of this psychophysical effect is still unclear. However the basic mechanism of the cognition of the auditory target direction has been studied in terms of inter aural correlation of the sound intensity or time and phase of auditory stimulus. However, it still remains uncertain how the position of an auditory target is coded by the brain and what is the exact role of the pinna in localizing target direction [19, 20, 21, 22]. We are interested in what the role is of the right-side pinna versus the left-side pinna. In traditional anatomy textbooks, the left ear was known to be better for hearing and analyzing language, and right ear was better for non-linguistic sound like music or whispers [23].

In this paper, we studied the relationship between sound color and the accuracy in the cognition of target localization and found the exact role of pinna in localizing target direction.

METHOD

1. Auditory stimulation

Sound sources which include various sound color type were generated by computer. Each sound wave had 1 sec duration with a 3 sec interval and was delivered from a random position by LabVIEW software program. The sound source can be divided into four groups as shown in table 1. The first group was a pure sine wave with the frequency band of 1000Hz. The second group was a harmonics wave that was generated by summing the component of sine waves. The third group was a non-harmonics wave that was generated by summing sine waves with near-by the frequencies of sine waves. Thus these sounds do not contain harmonic components at all. The fourth one was the white noise that contains all possible frequencies. Sound pressure level was 57dB as measured at the subject's head position.

Table 1 Sound source type of auditory target

Sound source type
Pure tone: 1000Hz sine wave
Harmonic tone: 1000Hz + 2000Hz 1000Hz + 2000Hz +4000Hz 1000Hz + 2000Hz +4000Hz + 8000Hz
Non-Harmonic tone: 1000Hz + 1100Hz 1000Hz + 1100Hz +1200Hz 1000Hz + 1100Hz +1200Hz + 1300Hz
White noise

2. Experimental instrument

Figure 1 shows the block diagram of the experimental system to investigate the human's spatial cognition by auditory stimulation. Since a laser pointer (error 0.5%) showed much less error in localizing target position especially for the left side angle of the subject position than FASTRAK (error 30%), it was used for the pointing task.

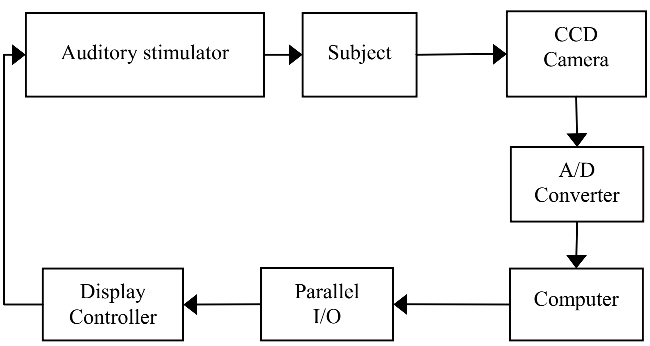
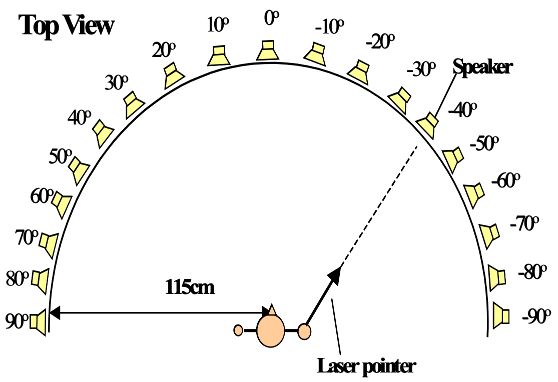


Fig. 1 Block diagram of stimulation system

The experiment was performed in a soundproof chamber as shown in Fig. 2. For the localization test, 19 numbered loud speakers arrayed in the horizontal plane of 1.15m radiuses were used and each target was 10 degree apart from each other. In this experiment, one side of the pinna function was distorted intentionally by inserting a short tube on the ear canal. The localization error caused by right and left side pinna distortion was investigated.



3. Subjects

Data were obtained from ten subjects (four women and six men) with normal visual, head and arm motor function. Their ages ranged from 24-34 years. Each subject had clinically normal hearing in both ears as determined by a pure-tone audiogram. Subjects were asked to participate in these experiments with full knowledge that they could withdraw at any time

RESULTS

1. Harmonic vs. Non-harmonic

Table 2 shows the average RMS cognition errors for various sound sources. Figure 3 shows pointing errors (root mean square (RMS) error) in locating target direction that was measured for the groups of various sound sources. It shows quite a large dependence on sound types. The RMS pointing error for the pure tone of 1000 Hz sine wave appeared to have large error. The pure tone and white noise were not very good sounds for localizing direction of targets.

The harmonic groups shows better results but non-harmonic groups shows much better results. Sound source type A (1000Hz+1100Hz) showed the best value, which had a less than 8 degrees error.

In general, the cochlear's function is a harmonic analyzer [24], however the harmonic components were not helpful in localizing sound direction. Pure sine wave was even more confusing. This result reveals cochlea-brain interaction to localizing target direction was independent path from harmonic recognition. And directional filtering action of pinna for non-harmonic near-by frequency sound source was more important for localization of auditory target.

Table 2 Average RMS cognition errors for various sound sources

Sound source	Average rms cognition error (degree)
Pure tone	10.49 ± 1.05
Non-Harmonic tone	8.54 ± 0.76
Harmonic tone	10,45 ± 0.47
White noise	11.10 ± 1.08

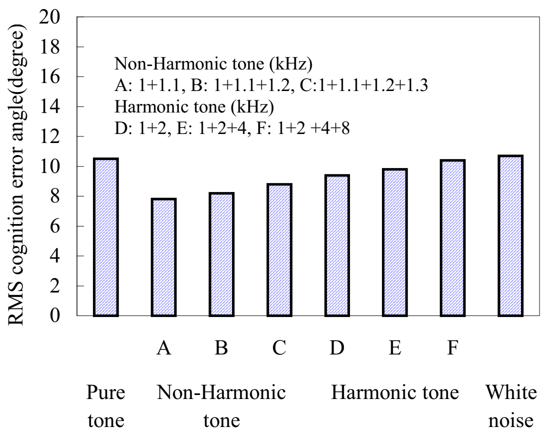


Fig. 3 Cognition errors for various sound source type

2. Right pinna vs. Left pinna

Figure 4 shows the pinna distortion effect. The localization error of the distorted right pinna was higher than that of the distorted left pinna. However left pinna distortion did not any large change compared to non-pinna distorted normal condition. It also showed that it did not depend on sound source type very much. Thus we knew that the right pinna was one most important function in localizing target direction.

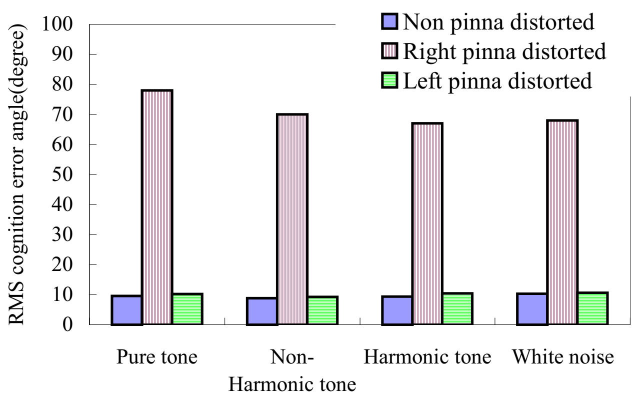


Fig. 4 Pinna distortion effect

Table 3 Direction dependence cognition errors for various sound source types

Sound type	RMS cognition error (degree)		
	Center	Right side	Left side
Pure tone	15.25 ± 0.79	9.86 ± 0.81	10.61 ± 0.75
Non-Harmonic tone	5.02 ± 0.39	7.37 ± 0.42	11.19 ± 0.58
Harmonic tone	6.06 ± 0.46	13.14 ± 0.41	17.25 ± 0.56
White noise	5.69 ± 0.24	14.78 ± 0.35	15.19 ± 0.27
Average	8.05 ± 0.47	11.29 ± 0.42	13.56 ± 0.62

Table 3 shows right-left-center localization error for various sound types. As you shown in the table 3, it showed that the total average of RMS cognition error on the center was best (8.05°), the next was right side (11.29°) and the left side was worst (13.56°).However, when we compared with various sound groups; center than right side and left side was not true for pure tone. This hierarchy can also be seen in the Fig. 4. Figure 4 illustrated cognition error angle for various sound source type classified by direction. In right side, cognition

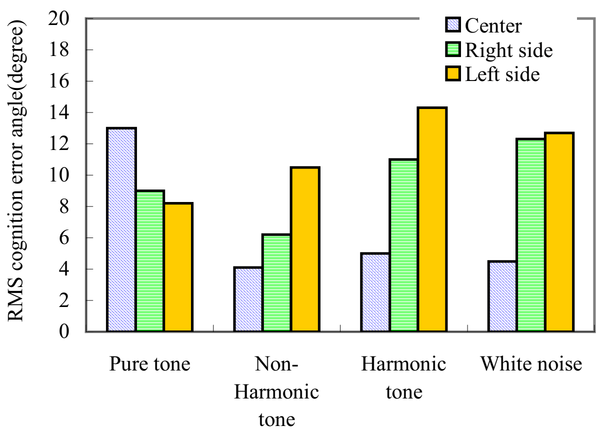


Fig. 4 Cognition error of direction dependence for various sound source type

CONCLUSION

In this paper, the human's spatial cognition using auditory stimulation was investigated. Our results clearly indicated the spectral response, due to directionally different pinna resonance effects, was the basic mechanism in the auditory cognition of direction.

1. It was found that harmonic components were not essential for the auditory target localization, however, non- harmonic nearby frequency components were more important to localize target direction of sound.

2. The right pinna had one most important function in localizing target direction and pure tone with only one frequency component was confusing for localization.

ACKNOWLEDGMENTS

The paper was supported by a grant of the Major R&D programs; Ministry of Science & Technology, Republic of Korea.

REFERENCES

[1] Radeau, M., "Auditory-visual interaction and modularity", *Curr. Psychol. Cogm.*, Vol. 13, pp. 3-51, 1994.

[2] E.A.C. Shaw, "External ear" response and sound localization" in Localization of Sound: Theory and applications, edited by R.W. Gatehouse (Amphora, Groton, CT), pp. 30-42, 1982.

[3] J. Blauert, "Spatial Hearing: The Psychophysics of Human Sound localization", (MIT, Cambridge, MA), 1983.

[4] G.F. Kuhn, "Physical acoustics and measurements pertaining to directional hearing", *in Directional Hearing*, edited by W.A. Yost and G. Gourevitch (Springer-Verlag, New York), pp. 3-25, 1987.

[5] J.C. Middlebrooks and D.M. Green, "Sound localization by human listeners", *Ann. Rev Psychol.* Vol. 42, pp. 135-159, 1991.

[6] S. Perrett and W. Noble, "The effect of head rotations on vertical plane sound localization", *J. Acoust. Soc. Am.*, Vol. 102, pp. 2325-2332, 1997.

[7] J.J. Rice, E.D. Young and G.A. Spirou, "Auditory-nerve encoding of pinna-based spectral cues: Rate representation of high-frequency stimuli", *J. Acoust. Soc. Am.*, Vol. 97, pp. 1764-1774, 1995.

[8] L. Kishon-Rabin, O. Amir, Y. Vexler, Y. Zaltz, " Pitch discrimination: are professional musicians better than non-musicians", *J. Basic. Clin. Physiol. Pharmacol.,* Vol. 12, pp. 125- 143, 2001.

[9] C.C. Wier, W. Jesteadt, D.M. Green, "Frequency discrimination as a function of frequency and sensation level", *J. Acoust. Soc. Am.,* Vol. 61, pp. 178-184, 1997.

[10] A. Sek, B.C. Moore," Frequency discrimination as a function of frequency, measured in several ways", J. Acoust. Soc. Am., Vol. 97, pp. 2479- 2486, 1995.

[11] Thurlow, W.R., Jack, C.E., "Some determinants of localization adaptation effects for successive auditory stimuli", *J. Acoust. Soc. Am.*, Vol. 53, pp. 1573–1577, 1973.

[12] Canevet, G., Meunier, S., "Effect of adaptation on auditory localization and lateralization", *Acustica*, Vol. 82, pp. 149–157, 1996.

[13] Canevet, G., Meunier, S, " Auditory adaptation and localization", *Acustica*, Vol. 80, pp. 311–314, 1994

[14] Meunier, S., Bodden, M., Can_evet, G., Grabke, J., Handmann, U., "Auditory adaptation and localization: Effect of frequency and bandwidth", *Acustica 82 (Suppl. 1)*, S215, 1996.

[15] Carlile, S., Hyams, S., Delaney, S, "Systematic distortions of auditory space perception following prolonged exposure to broadband noise", *J. Acoust. Soc. Am.,* Vol. 110, pp. 416–424, 2001.

[16] Braasch, J., Hartung, K., "Localization in the presence of a distracter and reverberation in the frontal horizontal plane", *I. Psychoacoustical data. Acta Acust*. Vol. 88, pp 942–955, 2002.

[17] Getzmann, S., "A comparison of the contrast effects in sound localization in the horizontal and vertical planes", *Exp. Psychol.*, Vol.50, pp. 131–141, 2003.

[18] Kashino, M., "Adaptation in sound localization revealed by auditory after-effects", *Psychological and Physiological Advances in Hearing,* Whurr Publisher, London, pp. 322–328, 1998.

[19] G. Bekesy, "Experiments in Hearing", *New York*, pp. 454-458, 1950.

[20] C.D. Ceisler and Y. Cal, "Relationships between frequency-tuning and spatial-tuning curves in the mammalian cochlea", J. Acoust. Soc. Am., Vol. 99, pp. 1550-1555, 1996.

[21] S. Perrett and W. Noble, "The effect of head rotations on vertical plane sound localization", J Acoust. Soc. Am., Vol. 102, pp. 2325-2332, 1997.

[22] Kulkarni and H.S. Colburn, "Role of spectral detail in sound-source localization", Nature, Vol. 396, pp. 747-749, 1998.

[23] M.G. Sin, J.Y. Kuk, A.K. Park, J.U. Jin, "Anatomic physiology", Hyunmunsa, pp.129. 1999

[24] P. Dallos, "The active cochlea", J. Neurosci., pp. 4575-4585, 1992.