Proceedings of 20th International Congress on Acoustics, ICA 2010

23–27 August 2010, Sydney, Australia

Behavior of precedence effect generated by two sound sources at the front and on the mid-coronal plane

Abe, Koji (1) Kato, Sakie (1) Watanabe, Kanji (1) Takane, Shouichi (1) Sato, Sojun (1)

(1) Faculty of Systems Science and Technology, Akita Prefectural University, Akita, Japan

PACS: 43.66.Lj, 43.66.Qp

ABSTRACT

While many researches on this phenomenon exist in the case of the sound sources located on the horizontal plane, little is known about the behavior of the precedence effect with the location of sound sources located not on the horizontal plane. In order to investigate the behavior of the precedence effect for the various location of the sound sources, an hearing experiment was carried out with one of the sound sources located at the front, and the other one located on the mid-coronal plane. The directions of the sound source arranged in the mid-coronal plane are seven (0°, ±30°, ±60°, ±90°, 0° defined as the vertex of the subjects' head). As a result, it was found that the behavior of the precedence effect is clearly different due to the position of the sound source on the mid-coronal plane, i.e. the shift of a fused sound image toward the direction of the that sound source becomes small as its directional angle decreases.

INTRODUCTION

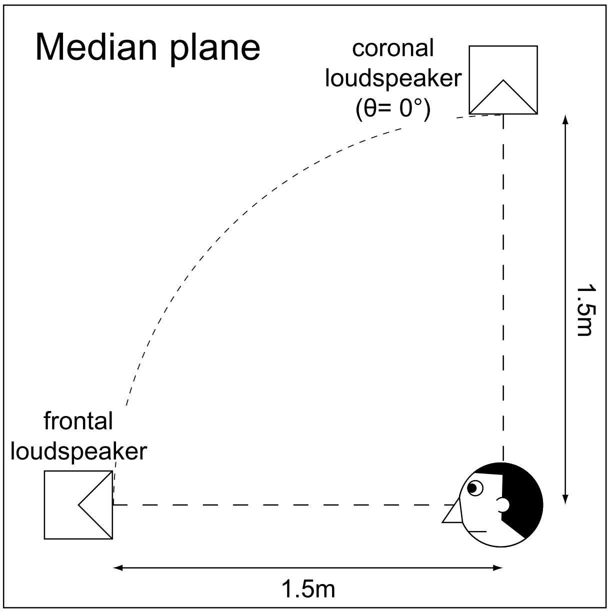
Perception of sound image(s) produced by multiple sound sources is more complicated than perception of image(s) generated by a single sound source. As a simple example, the case of two sound sources producing similar sound stimuli is considered. In this case, three types of sound images can be perceived, according to the time lag between the sound sources. If the time lag is long enough, the sound stimuli from the two sound sources are individually perceived. This phenomenon is known as 'echo'. The echo threshold changes greatly from 2 ms to 100 ms, according not only to the type of sound stimulus (e.g., click, broadband noise and or speech), but also to the definition adopted as the echo threshold [1–3]. In the case of the time lag shorter than the echo threshold, the sound stimuli from two sound sources generate a single sound image, refered to as a "fused image" [4, 5]. When the time lag is very small, the perceived direction of a fused image is decided depending on a weighted averaging of the information from both sound sources. This phenomenon is called 'summing localization.' As the time lag increases, a fused image gradually shifts toward the direction of preceding sound source. The shift to the direction of preceding sound source is completed at a lag of 0.63 - 1 ms [6, 7]. For time lags between this value and the echo threshold, the perceived direction of the fused image depends only on information from the preceding sound source. This specific localization phenomenon is called the 'precedence effect' [8–10].

This effect is also referred to as the law of the first wave front, which gives the human sound localization at the position of the original sound source located in the ordinary room with many reflections. Because of its property, the precedence effect is often used for the public-address system [11, 12]. In ordinary space, the loudspeakers used for public-address system is arranged on the ceiling or wall. In particular, the ceiling installation of loudspeaker is often used for sound reinforcement in a wide space. Nevertheless, the studies on the behavior of the precedence effect with the location of sound sources located not on the horizontal plane is a little [13, 14]. As a particular three-dimensional arrangement, there is a case where the sound sources is arranged in a median plane. From our preliminary investigation, the precedence effect in the median plane was slightly different from that in the horizontal plane. One of the differences is to generate the precedence effect only when a sound from a loudspeaker in front preceeds that from another. Moreover, when one of the two sound sources was arranged rear side, the localization of the sound image became unstable. In this report, it is examined how the behavior of the precedence effect changes in the space between the horizontal and the median plane. Therefore, we arranged a loudspeaker in front of the subject, and the other one on the mid-coronal plane. The finding obtained for this examination might usefully contribute to the development of effective public-address systems.

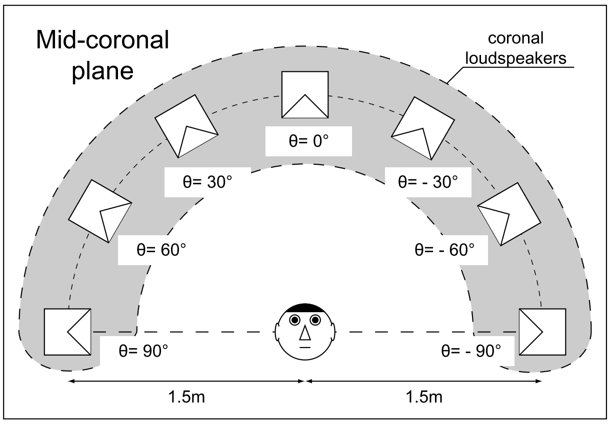
EXPERIMENTAL CONDITION

The purpose of this experiment is to clear the behavior of precedence effect generated by two sound source with three-dimensional arrangement. For this purpose, we adopted an experiment to answer the perceived direction of a fused image produced by two sound source. This experiment was conducted in an anechoic room with dimensions as follows: W: 7.5 m×D: 6.0 m×H: 4.5m. Each subject sat on a chair at the center of the room. Eight loudspeakers (Bose 101MM) were 1.5 m from the subject (See Figure 1). One loudspeaker was fixed in front of subject. (Figure 1 (a)). This loudspeaker is called a 'frontal loudspeaker'. Other seven loudspeakers were arranged on the mid-coronal plane of a subject (Figure 1 (b)). An interval between adjacent loudspeakers was 30 degrees. The angles of each loudspeaker were $\theta = 0^\circ$, $\pm 30^\circ$, $\pm 60^\circ$ and $\pm 90^\circ$ (0 degree corresponds to the right above direction of a subject). These loudspeakers are called 'coronal loudspeakers'.

A white noise with duration of 200 ms was used for the sound stimulus. In each trial, the sound stimulus was presented from the frontal loudspeaker and one of a set of coronal loudspeakers. A time pattern of sound stimuli is shown on Figure 2. The time delay set between these sound sources was defined as the time lag. The time lag was defined positive when a sound from the coronal loudspeakers precedes that from the frontal one. The time lags set are shown in Table 1, along with



(a) Setup of sound sources on median plane



(b) Setup of sound sources on mid-coronal plane

Figure 1: Arrangement of sound sources

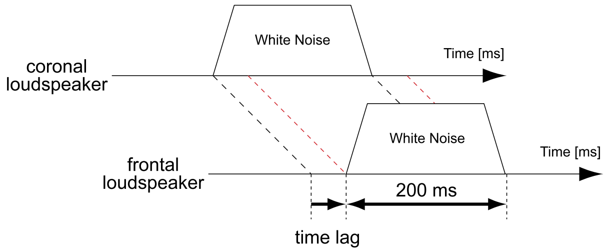


Figure 2: Time pattern of experimental sound stimuli

Table 1: Time lag between two loudspeakers

Time lag [ms]	Number of trials
0.0	5
$\pm$0.5	5
$\pm$1.0	5
$\pm$1.5	5
$\pm$2.0	5
$\pm$3.0	5
$\pm$4.0	5

the corresponding number of trials. In a certain trial, sound stimulus were repeated five times with 200 ms interval. The order of selection of time lags and coronal loudspeaker used to present the sound stimulus was randomized. Subjects were asked to answer the perceived direction of the fused image produced by sound stimulus. A handmade answer device was used to acquire the subject's answer of the perceived direction. A laser pointer and three dimensional sensor module are built into this answer device. Subjects were asked to point laser to the perceived direction. The elevation and azimuthal angle of perceive direction were obtained from the three dimensional sensor module (Vitec TDS01V) built in answer device. The data of perceived direction were compensated, since the position of the answer device was not a center of the subject's head. The subjects were four males and one female, with normal hearing.

RESULTS AND DISCUSSION

To visually show the behavior of the precedence effect in two sound sources of three-dimensional arrangement, evaluation planes were defined. The evaluation plane was a plane where the frontal loudspeaker, one of the coronal loudspeaker and subject's head were all included. Therefore, the number of the evaluation planes was seven. In this report, each evaluation plane was identified by the angle θ. When the angle θ is 0 degree, the evaluation plane is identical with the median plane. The evaluation plane is equivalent to the horizontal plane when the angle θ is ± 90 degrees. For each evaluation plane, angles ϕ and ψ were respectively calculated from the percived direction. As an example, the relationship between the angles ϕ, ψ and the perceived direction was shown in Figure 3, when θ is $60°$. As shown in Figure 3, the angle ϕ shows what degree the fused image shifts toward the coronal loudspeaker side, and the angle ψ shows the amount that the perceived direction deviates from the evaluation plane.

The obtained angles ϕ and ψ are plotted against time lag as shown in Figure 4 - 8. However, note that angle ϕ was transformed into $-\phi$ when the angle θ was positive. The reason for this transformation is to confirm whether the behavior of the precedence effect is bilaterally symmetric. The upper four panels show the relationship between the angle ϕ and the time lags, and the lower three panels show the change of the angle ψ. The rows in each figure indicate the evaluative plane ($\theta = 0°$ or $\pm 30°$ or $\pm 60°$ or $\pm 90°$).

When θ is 0 degree, angle ϕ of almost subjects was comparatively small regardless of the time lag condition. This means that a fused image was perceived near the frontal loudspeaker irrespective of the time lags. And, the angle ϕ has been a little biased to a positive direction. This means the fused sound image is generated above the position of the frontal loudspeaker even though a sound from the frontal loudspeaker. Moreover, when the time lag is positive, the localization tend to become vague (Subs. A and C).

When θ is ± 90 degrees, all loudspeakers used to present the sound stimulus are arranged on a horizontal plane. If the precedence effect was clearly occured, ϕ was almost ± 90 degrees when the time lag is positive, and ϕ was about 0 degree when the time lag is negative. As shown in Figures 4, 5 and 6, the precedence effect was observed for subjects A, B and C, though it was a little unstable. The angle ψ falls within the range from 0 to 30 degrees. Therefore, the fused sound image has been perceived above the plane where the sound source was arranged (horizontal plane). However, the precedence effect was not observed for subjects D and E, and the reason is unknown. There is room for argument on this cause, but it is not my present pur-

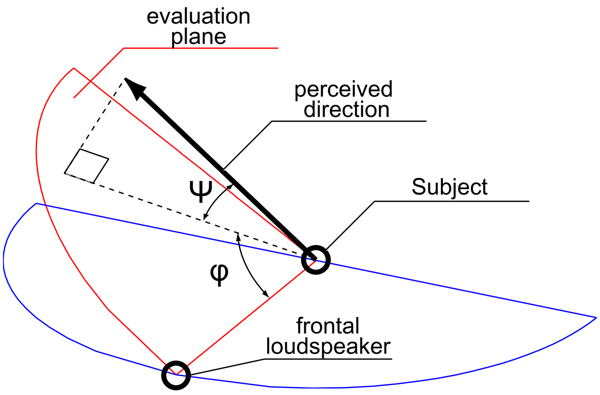


Figure 3: Relationship between angles ϕ, ψ and the perceived direction on the evaluative plane ($\theta = 0°$)

pose to explore this problem because the purpose of this report is to clarify how behavior of the precedence effect changes by angle θ.

Panels of angles $\theta = \pm 60°$ for subjects A, B and C was roughly similar to the results of angles $\theta = \pm 90°$. This means that the precedence effect is effective even if one side of two sound sources is not arranged in a horizontal plane. However, the tendency that the perceived direction of the fused sound image deviates from the evaluation plane has strengthened (See angle ψ in Figure 4, when the time lags is positive). As shown in Figure 4, 5 and 6, the precedence effect under the angle $\phi = \pm 30°$ is weak compared with that under the angles $\phi = \pm 60°$, $\pm 90°$. This shows that the precedence effect becomes weak as θ becomes small. These results suggest that spectral cue provided by the sound source arranged on the mid-coronal plane may not contribute to the precedence effect, when sound stimulus is presented without time lag.

SUMMARY

In order to clarify the behavior of the precedence effect generated by two sound source with three-dimensional arrangement, the experiment to answer the perceived direction of a fused image was carried out. Our experimental results show that the precedence effect is effective under the condition that two sound sources are arranged in three dimensions, except when both sound sources are arranged on the median plane. On the other hand, when the sound sources was arranged on the median plane, the fused sound image was located in front of the subjects regardless of the time lag. This results suggest that not spectrum cue but the interaural time difference of each sound source is necessary to generate the precedence effect.

REFERENCES

[1] M. R. Rosenzweig and W. A. Rosenblith. Some electrophysiological correlates of he perception of successive clicks. *J. Acoust. Soc. Am.*, 22:878–880, 1950.
[2] E. D. Schubert and Wernick J. Envelope versus microstructure in the fusion of dichotic signals. *J. Acoust. Soc. Am.*, 45:1525–1531, 1969.
[3] J. Blauert. *Spatial Hearing: The Psychophysics of Human Sound Localization*. The MIT Press, Massachusetts, 1983.
[4] V. L. Jordan. A system for stereophonic reproduction. *Acustica*, 4:36–38, 1954.
[5] D. M. Leakey. Some measurement of the effects of interchannel intensity and time differences in two channel soud systems. *J. Acoust. Soc. Am.*, 31:977–986, 1959.
[6] J. Blauert and W. Cobben. Some consideration of binaural crosscorrelation analysis. *Acustica*, 39:96–104, 1978.
[7] J. Blauert. Localization and the law of the first wavefront in the median plane. *J. Acoust. Soc. Am.*, 50:466–470, 1971.
[8] H. Haas. Über den Einfluss eines Einfachechos auf die Hörsamkeit von Sprache [on the influence of a single echo on the intelligibility of speech]. *Acustica*, 1:49–58, 1951.
[9] R. Y. Litovsky and B. G. Shinn-Cunningham. Investigation of the relationship among three common measures of precedence: fusion, localization dominance, and discrimination suppression. *J. Acoust. Soc. Am.*, 109:346–358, 2001.
[10] K. Saberi and J. V. Antonio. Precedence-effect thresholds for a population of untrained listeners as a function of stimulus intensity and interclick interval. *J. Acoust. Soc. Am.*, 114:420–429, 2003.
[11] Jim Brown. Systems for stereo sound reinforcement - performance criteria, design techniques, and practical examples. *AES Convention*, 113(5666):1–20, 2002.
[12] Scott Hunter Stark. *Live Sound Reinforcement: A Comprehensive Guide to P.A. and Music Reinforcement Systems and Technology*. Artistpro.Com Llc, 1996.
[13] Ruth Y. Litovsky, Brad Rakerd, Tom C. T. Yin, and William M. Hartmann. Psychophysical and physiological evidence for a precedence effect in the median sagittal plane. *J. Neurophysiol.*, 77:2223–2226, 1997.
[14] Roberto M. Dizon and Ruth Y. Litovsky. Localization dominance in the median-sagittal plane: Effect of stimulus duration. *J. Acoust. Soc. Am.*, 115(6):3142–3155, 2004.

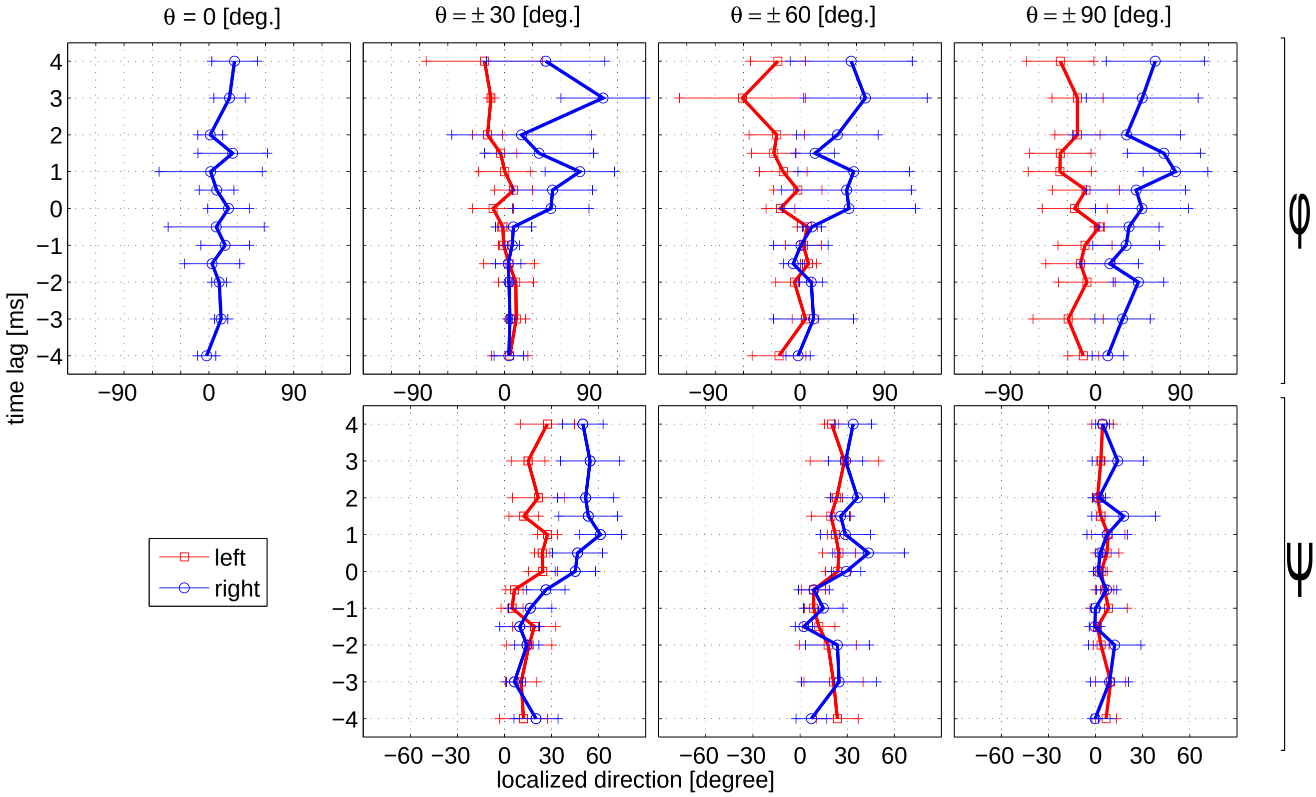


Figure 4: Relationship between time lag and localized direction (Sub. A)

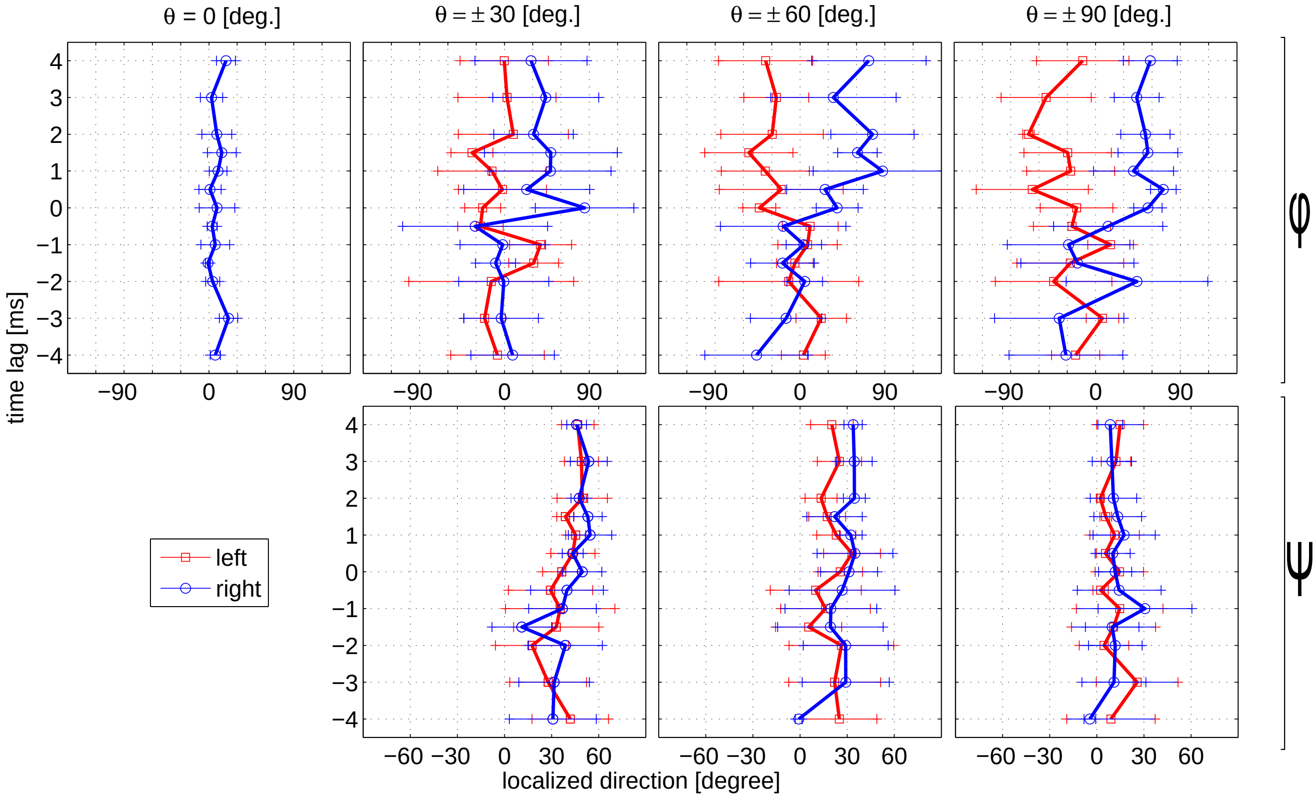


Figure 5: Relationship between time lag and localized direction (Sub. B)

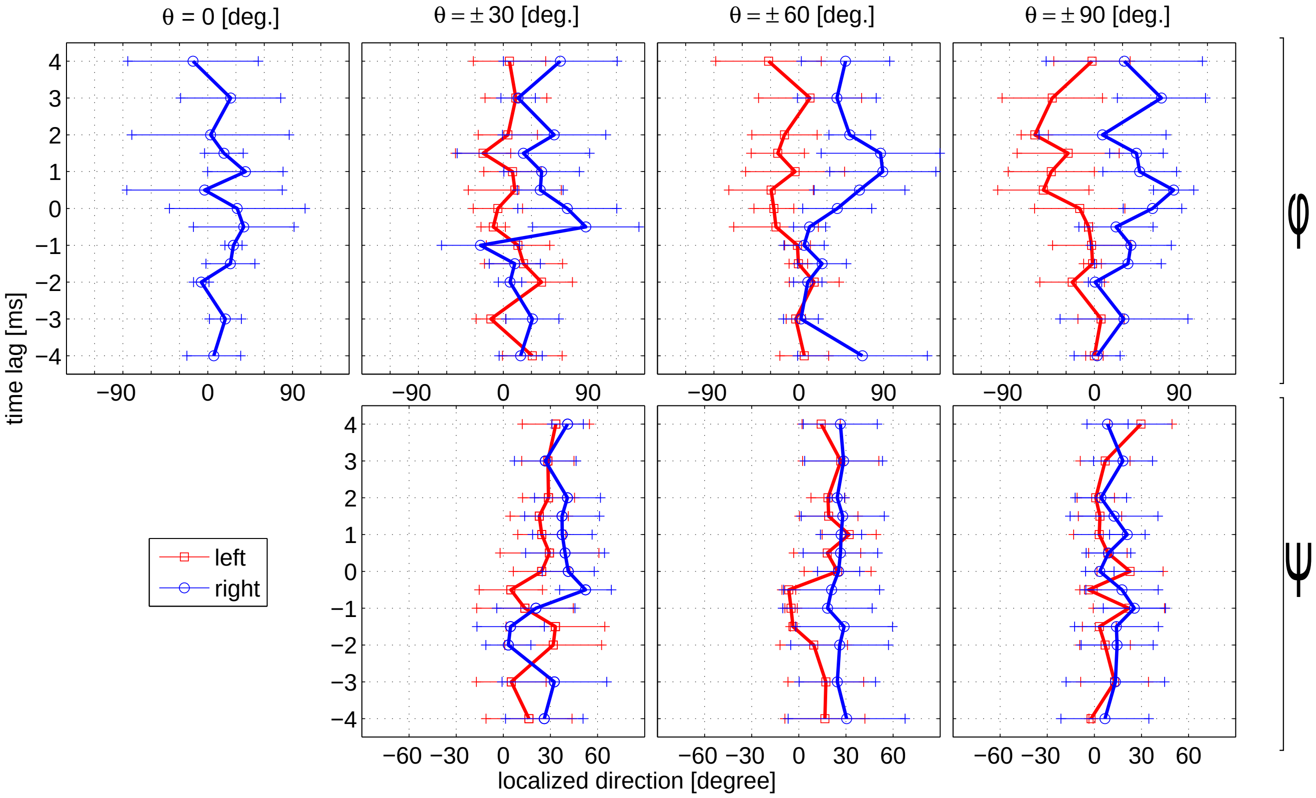


Figure 6: Relationship between time lag and localized direction (Sub. C)

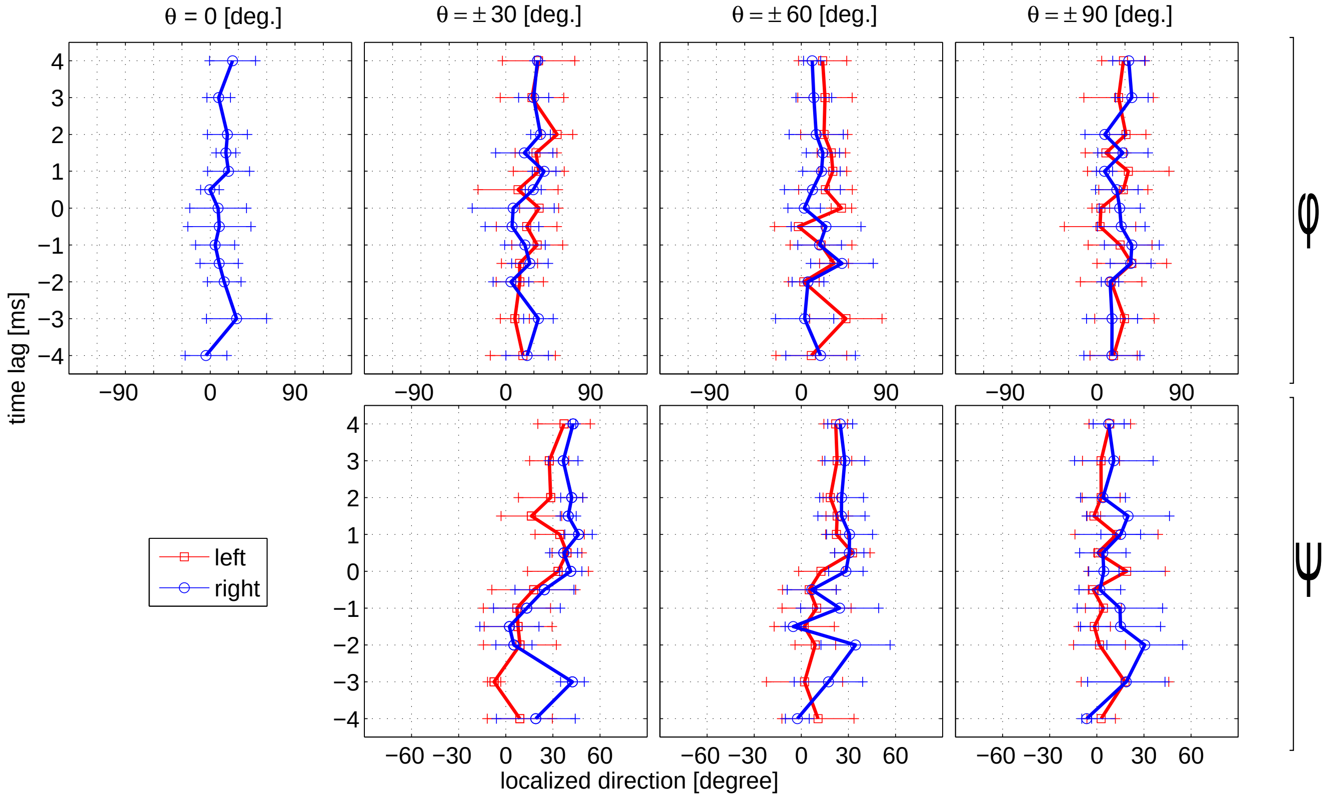


Figure 7: Relationship between time lag and localized direction (Sub. D)

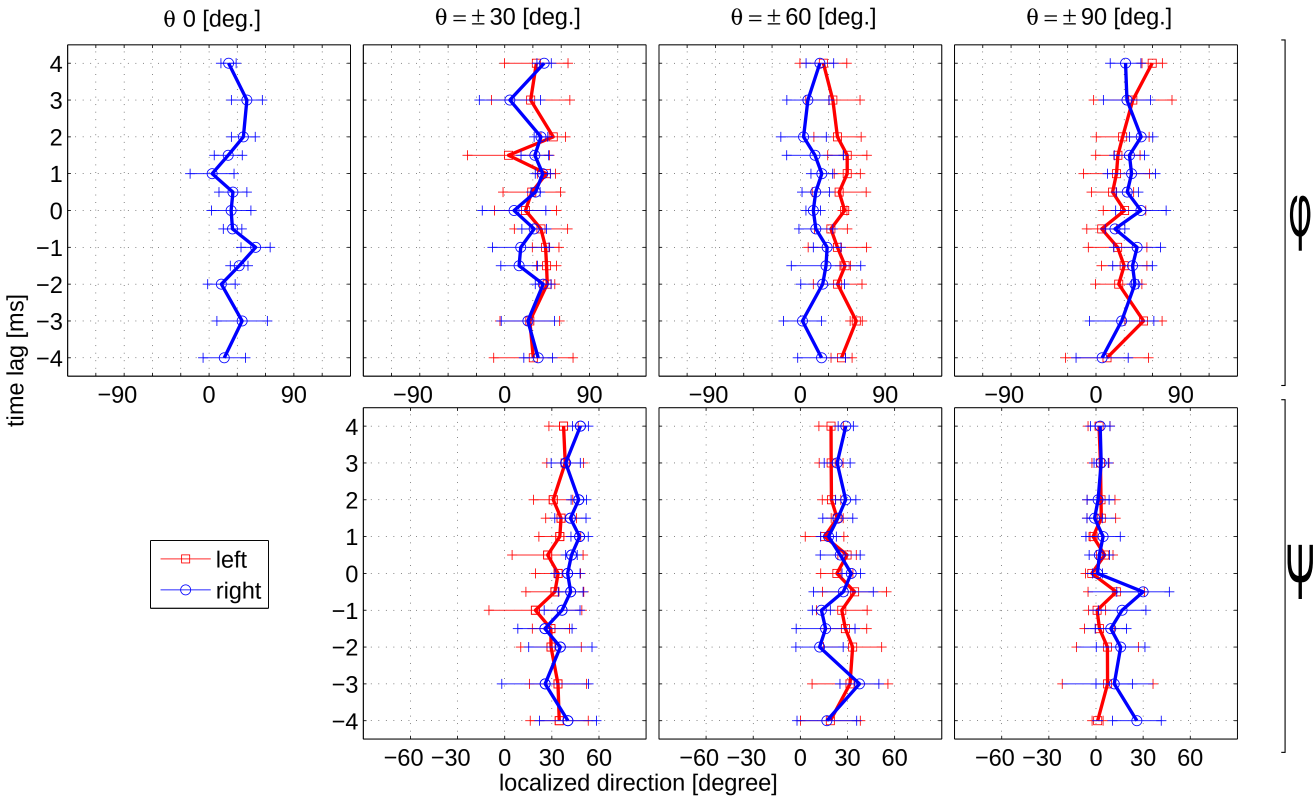


Figure 8: Relationship between time lag and localized direction (Sub. E)