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VISUO-ACOUSTIC INTERACTION IN THE IMAGE SPACE OF BINAURAL SOUNDS

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Summary

The effects of eye position on the lateralization of binaural stimuli were observed to study visuo-acoustic interaction in egocentric perceptual space. The stimuli included clicks with interaural time and intensity differences, as well as pure tones of low frequencies with interaural phase differences. These were presented under four eye position conditions, i.e., eyes closed, gazing at center, at left and at right. Subjects showed dominancy for space occupied by lateralized sound images under center condition, as well as with their eyes closed. The image space changed to symmetry when subjects gazed at the side contralateral to the dominant side, although the space dominancy was unchanged when subjects gazed at the ipsilateral side. These results were discussed in terms of the bilateral nervous system for spacial perception.

1. Introduction

In human communication, intra- as well as intermodal coordination is important for establishing an egocentric perceptual space 1). Such intramodal interaction in the auditory system emerges from binaural phenomena, e.g., sound localization and lateralization 2), binaural unmasking 3), etc., which play a role in "cocktail party" effects 4).

In a previous paper 5), we presented evidence on the asymmetrical image space of binaural sustained tones with interaural phase differences. The dominant hemispace varied even in dextrals, but the dominancy was rather consistent in each subject.

In the present paper, we try to confirm this fact in the case of the dominant spaces of binaural images for clicks with interaural intensity and time differences (IID and ITD), as well as sustained tones with interaural phase differences (IPD), while controlling the subjects' eye position to analyze the mechanism of visuo-acoustic interactions in egocentric space perception within a bilateral nervous system.

2. Method

The stimuli, clicks or sustained tones of 250Hz-4sec synthesized by a laboratory computer, were presented through dual D/A convertes (20k sample points/s) and low-pass filters (fc= 1kHz, -48dB/oct) to both ears of the subjects through headphone.

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Twenty types of clicks with IIDs from -36dB to +40dB (4dB step) or ITDs from -1.8ms to 2.0ms (0.2ms step), or of sustained tones with IPDs from -162° to 180° (18° step), were generated randomly at a rate of 8/min in one session.

Each subject sitting with head fixed in a sound-proof room was instructed to indicate the image position of the binaural stimuli by use of a pointer with a short handle attatched to a potentiometer which was read by the computer. Prior to presentation of the series of stimuli, subjects were asked to center the images of stimuli with no ITD or IPD by controlling the pointer, which worked in real time to adjust the balance in intensity of the binaural stimuli generated by the computer.

Four sessions in one experiment were conducted under each of the eye conditions (eyes closed, gazing at center, left and right) under the guidance of a concentric circles mobable within 18° to the right or left of the visual center 2m in front of a subject's face.

Three dextrals with normal histories served as subjects. Subjects TA (female, 22 years old) and SK (male, 40 years old) had some previous experience with binaural tasks. Subject KA (female, 21 years old) was naive for psychoacoustic tasks. The tasks with the click stimuli were performed by all subjects, but the task with the sustained tone stimuli was only done by subject TA. In each session, the subject was presented four dummy stimuli for pre-test trials, followed by the test stimuli.

The angle of the image position corresponding to each stimulus was stored in a disk file, and the values of the angles for twenty stimuli were drawn as connected lines by a X-Y plotter. As positive angle values were adopted for rightward shifts in image positions, the laterality index l was as follows,

$$l = (R - L) / (R + L) \tag{1}$$

where R and L were the absolute values of the sums of the positive and negative angles, respectively.

The mean and SD were calculated for the data under the same conditions for each subject. The group differences in the laterality indices for the four eye conditions were analyzed by a modified t-test.

3. Results

Data on the means and SD's of the responses to binaural with ITDs for several trials from each subject are shown in Fig.1. Data on three types of stimuli under the eyes closed condition from subject TA are shown in Fig.2.

Subjects KA and SK had a left hemisace dominancy, but subject TA had a right hemispace dominancy even under the eyes closed condition, i.e., with no visual load.

Figure 3 shows an example of TA's space with shifted dominancy for clicks with IIDs under three eye conditions. Figure 4 shows an example for clicks with ITDs from TA. Figure 5 shows an example for sustained tones with IPDs from TA.

The laterality index for each condition was analyzed by a

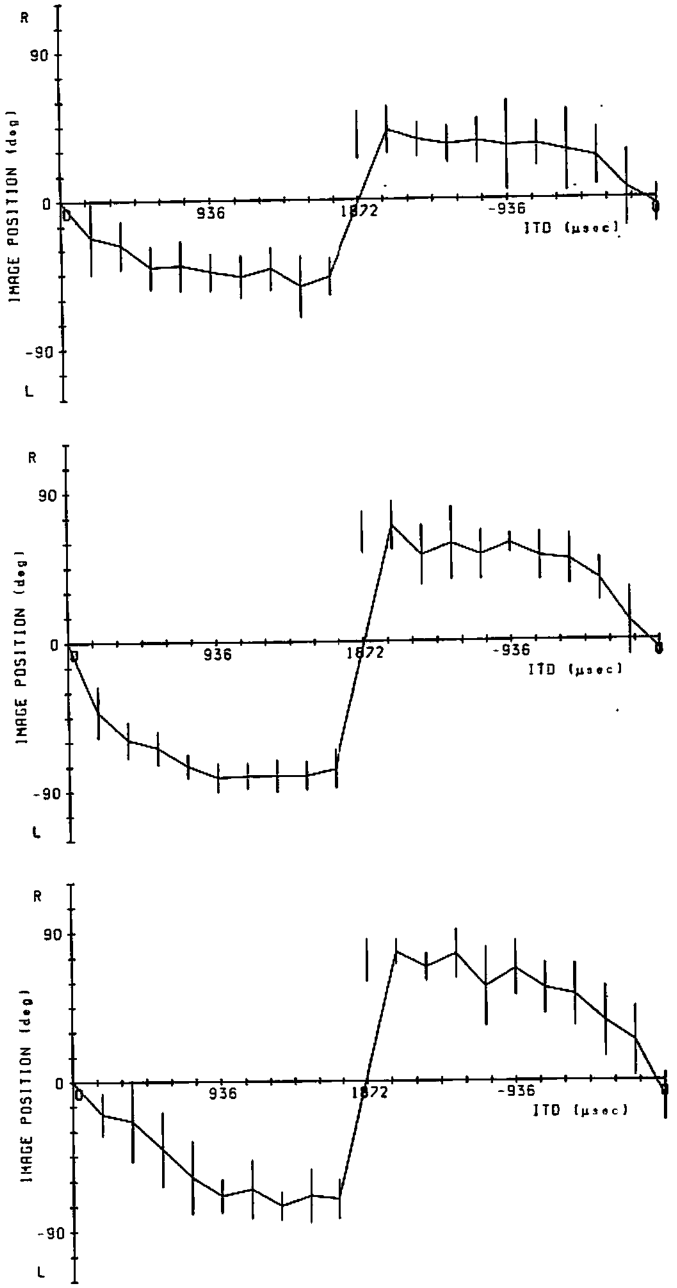

Fig.1. Averaged data for responses to binaural clicks with ITDs for three subjects with eyes closed. Vertical bars: SD's. (a): sub. KA (N=14); (b): sub. SK (N=6); (c): sub. TA (N=11).

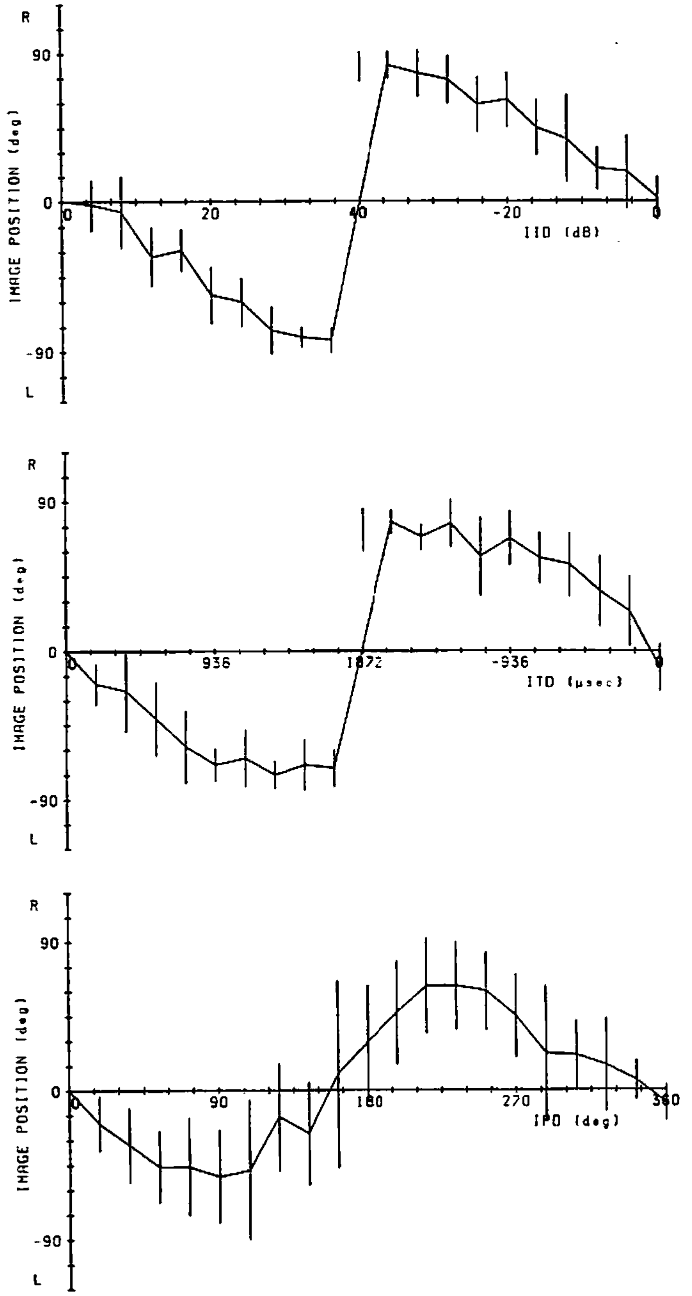

Fig.2. Averaged data for responses

Fig.2. Averaged data for responses to binaural stimuli for sub. TA with eyes closed. Vertical bars: SD's. (a): IIDs (N=12); (b): ITDs (N=11); (c): IPDs (N=11).

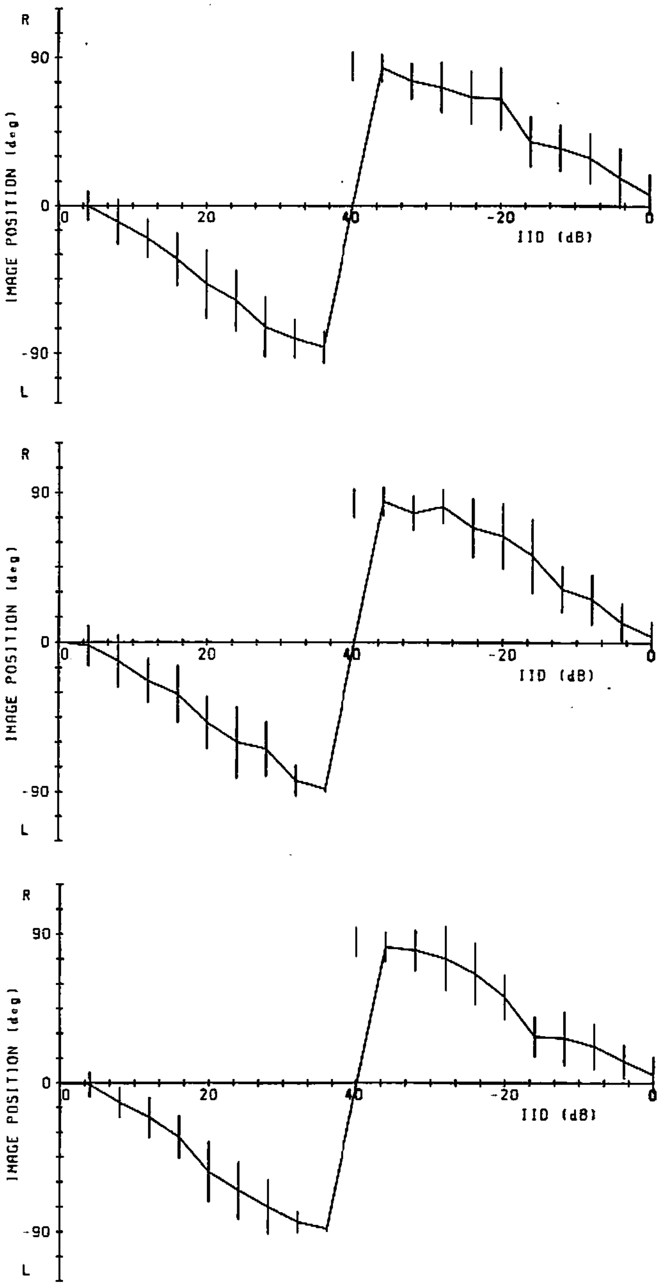

Fig.3. Averaged data for responses to binaural clicks with IIDs under three conditions: gazing at center (a), right (b) and left (c). Vertical bars: SD's; sub. TA.

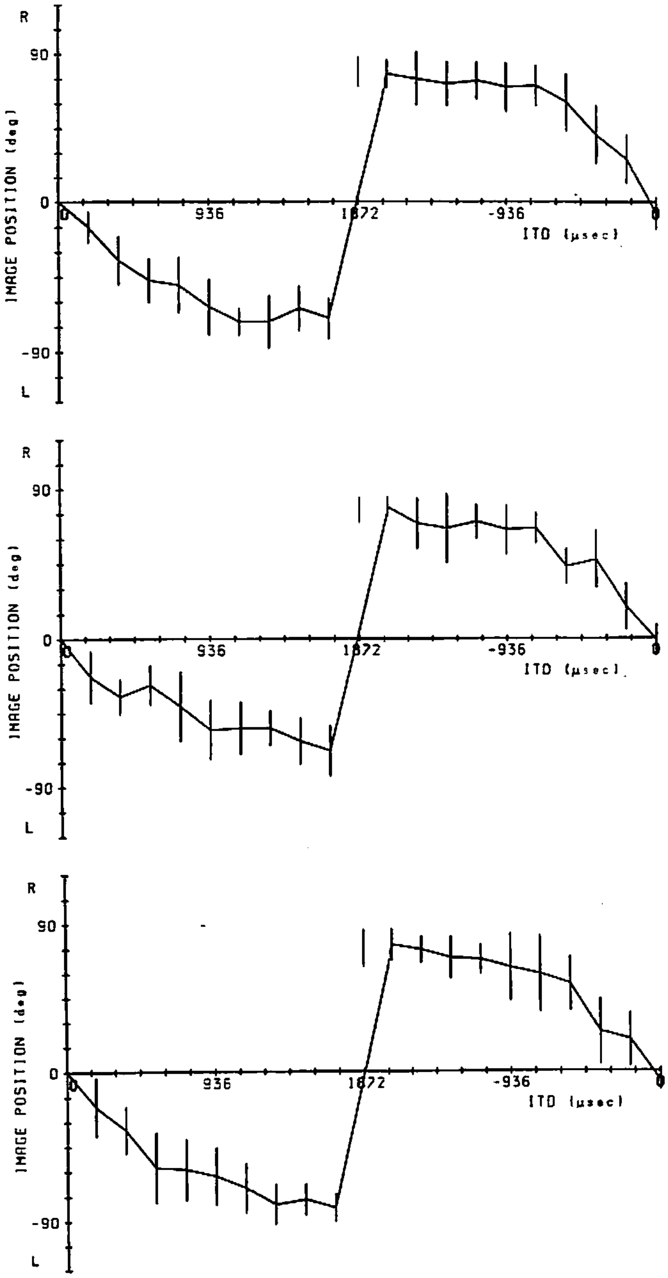

Fig.4. Averaged data for responses to binaural clicks with ITDs under the same conditions as in Fig.3. Vertical bars: SD's; sub. TA.

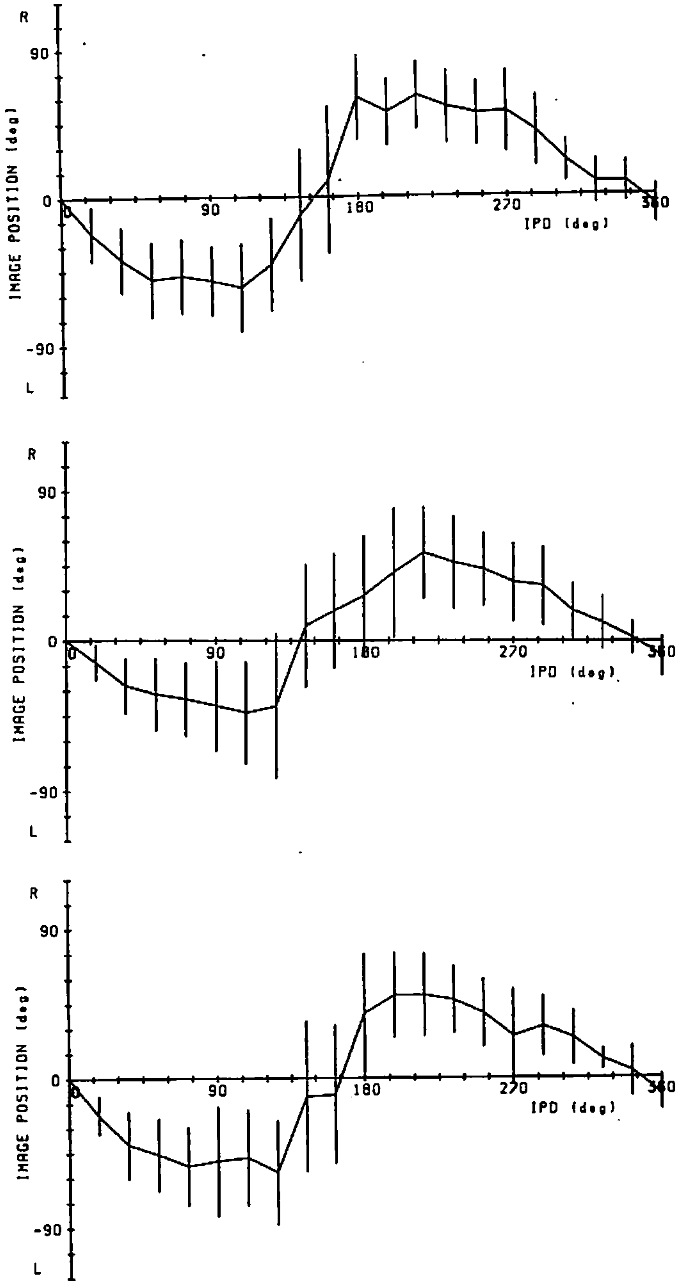

Fig.5. Averaged data for responses to binaural sustained tones with IPDs under the same conditions as in Fig.3. Vertical bars: SD's; sub. TA.

Tab.1. Results of significance tests on the group laterality indices for each eye position: (a) clicks with IIDs; (b) clicks with ITDs; (c) sustained tones with IPDs.

(a)

	Gazing at			
Sub.	Closed	Center	Right	Left
KA	L ***	L ***	N	L *
TA	N	R ***	R ***	N

(b)

	Gazing at			
Sub.	Closed	Center	Right	Left
KA	L **	L **	N	L ***
SK	L ***	L ***	L **	L ***
TA	N	R ***	R ***	N

(c)

	Gazing at			
Sub.	Closed	Center	Right	Left
TA	R **	N	R **	N

L: left hemispace dominant
R: right hemispace dominant
N: no difference
* p <.1 / ** p <.05 / *** p < .01

modified t-test. The statistical significance of the data are shown in Table 1.

Data on the differences between the responses to binaural clicks with ITDs under the conditions of gazing at right and at left from each subjects are shown in Fig.6. Data on such differences for three types of stimuli from subject TA are shown in Fig.7.

4. Discussion

The data on dominancy in image space were analyzed for three types of binaural sounds, i.e., clicks with IID or ITD and tones with IPD, under the control of eye position in order to investigate effects of visuo-acoustic interaction on image space.

As seen in Fig.1, subjects showed a dominancy in image space under the eyes closed condition. A stimulus-specific pattern in the dominancy was not observed 6). The patterns in the binaural image space were rather consistent for the three types of stimuli within a subject, but the dominant hemispace varied among the dextral subjects. The result for dominancy in the image space of sustained tones with IPD agrees with our previous report.

Under the condition of gazing at center, the subjects still persisted in their own dominancies as seen in Table 1. The visual load of gazing at the side ipsilatral to the dominant hemispace also could not change the dominancy. However, the visual load of gazing at the side contralateral to the dominant hemispace cancelled the dominancy.

The SD values showed a stimulus-spacific pattern. The values had maxima at the image positions of about ±45°, ±45° and ±90°, and minima at the image positions of ±90°, ±90° and 0°, in the IID, ITD and IPD conditions, respectively. These data suggest that the consistency of a image positions depends on the probability fusion of the binaural image 7).

Data on the differences in the responses to binaural clicks with ITDs indicates that the effect of eye position had a maximum in the nondominant hemispace for each subject as seen in Fig.6. However, the differences for clicks with IIDs had a maximum in her dominant hemispace although the differences for sustained tones with IPDs had a maximum in the same hemispace as for clicks with ITDs.

These data indicate the existence of a distorted egocentric perceptual space with an orientation bias 8) which can be partially controlled by eye position. One of the authers and Niwa et al. (1981) 9) investigated the effects of eye position on hemispheric asymmetry of event-related potentials to verbal and nonverbal stimuli. The left-hemisphere dominancy for verbal stimuli and the right hemisphere dominancy for nonverval stimuli ceased with the eye position at the side ipsilateral to the dominant hemisphere. Crosby (1953) 10) investigated the orientation reflexes of eye movements to electrical stimulation in the cortex of monkeys. He showed that orientation behavior is directed away from the activity of the dominant hemisphere 11).

Kinsbourne (1977) 12) has suggested that asymmetries in auditory and visual tasks is due not to "static" differences in neu-

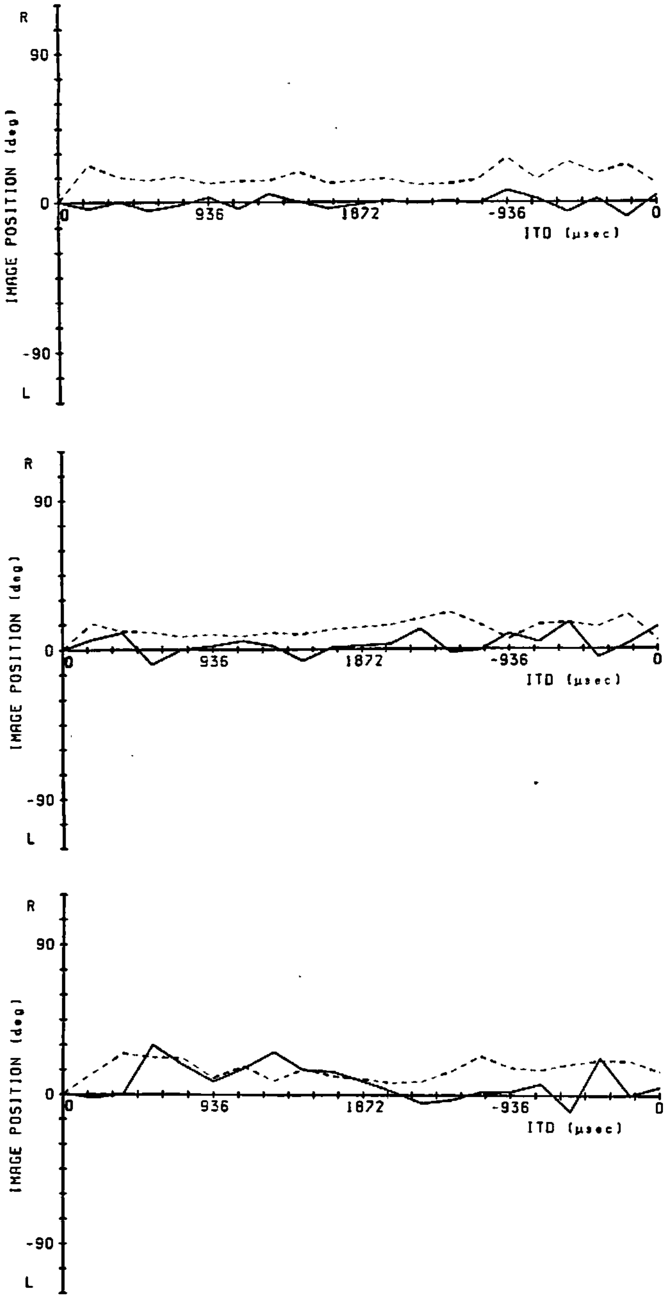

Fig.6. Differences between averaged data for responses to binaural clicks with ITDs for the same three subjects as in Fig.1 under gazing at right and left. Broken lines: SD's under eyes closed condition.

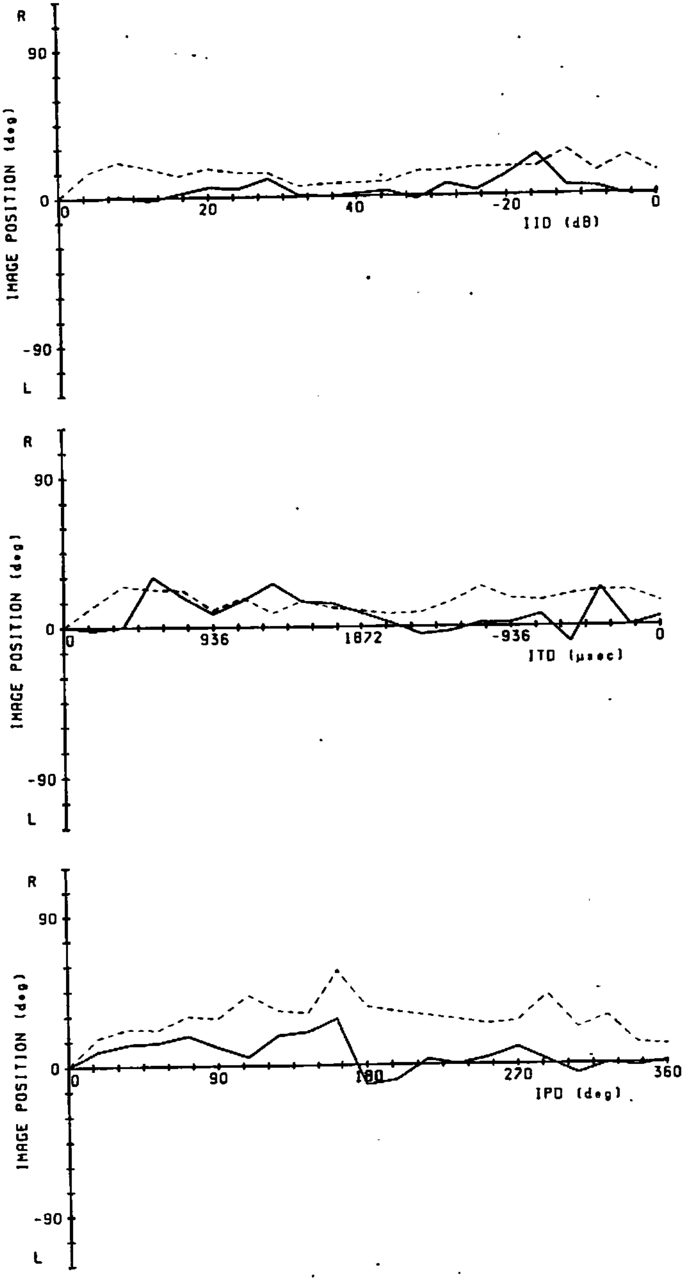

Fig.7. DIfferences between averaged data for responses to binaural stimuli for sub. TA under gazing at right and left. Broken lines: SD's under eyes closed condition. (a): IIDs; (b): ITDs; (c): IPDs.

roanatomical connections but to the "dynamic" shifting of an attentional center in the perceptual space. Nebes and Nashold (1980)[13]compared dichotic and visuo-acoustic competition in hemispherectomized patients. They found that some dichotic competition emerged as a great difficulty in reporting items presented to the ear ipsilateral to the intact hemisphere, but such ipsilateral ear decrement did not occur when a competing visual stimulus was presented in the contralateral field, which argues for no visuo-acoustic interaction in the case of monaural and hemifield stimuli.

According to previous theories of sound localization based on neurophysiological data[14][15][16], the lateral and medial superior olives[17], the deep and and intermediate layers of the superior colliculus[18], inferior colliculus[19][20], and the auditory cortex[21] play an important role in the binaural interaction which functions in spatial perception. Some neurons in these units, especially in the medial superior olive[22]and the superior colliculus[23], change activity in response to visual stimuli. Knusden (1984)[24] found neurons which respond only to the coincidence of visual and auditory direction stimuli in the owl's tectum. Knusden (1981)[25] studied the receptive fields in the inferior colliculus, external nucleus of the inferior colliculus and the optic tectum of the barn owl. He found that the optic tectum shows bimodal responses to command orientation behavior on the basis of data converging from the external nucleus, which has space-specific but unimodal responses. Jay and Sparks (1984)[26] trained monkeys, with heads fixed, to make delayed saccadic eye movements to auditory or visual targets from one of three initial fixation points. They found that the auditory receptive fields shifted with changes in eye position and concluded that such shifts allow the auditory and visual maps to remain in register.

The multi-modal interactions from the lowest center of the medial superior olive to the parieto-temporal association cortex and the binaural interaction in the bilateral auditory system share process units in the brain. Further neural modelling of the binaural interaction of complex sounds with IID, ITD and IPD, as well as of the visuo-acoustic interaction in each stage of binaural interaction, is necessary to analyze the mechanism of spatial perception related to "cocktail party" phenomena[27].

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