Proceedings of 20th International Congress on Acoustics, ICA 2010

23–27 August 2010, Sydney, Australia

Simultaneity perception characteristics in contralateral ear considering attention

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PACS: 43.66.Mk, 43.66.Lj

ABSTRACT

To investigate simultaneity perception characteristics of auditory stimuli taking into account for attention, experiments of simultaneity perception between left and right ear (contralateral ear) were performed. In the experiment, a set of inducing sounds for taking an attention to one side of the contralateral ear and a pair of instantaneous sounds having various interstimulus interval were reproduced for investigating simultaneous perception characteristics. Results indicate that experimental subjects percept the sound presented to attentive ear comes first than the other sound presented to no attentive ear even if these sounds were presented almost simultaneously. Also, the subjects percept simultaneously when the sound presented to no attentive ear precedes the other sound at attentive ear by about 30 ms. From these results, it was clarified that the attention in the contralateral ear changes the simultaneous perception characteristics of auditory stimulus.

INTRODUCTION

Human beings obtain much information by combining various sensations. The simultaneity perception characteristics of these sensations play an essential role to understand the information. Therefore, a lot of previous studies concerning with the simultaneity perception characteristics were performed, and the characteristics between auditory and visual stimuli were investigated many times [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. In these studies, human beings are reported to perceive simultaneously when a visual stimulus precedes an auditory stimulus by a few ten milliseconds because of processing duration difference from the sensor organ to the brain between visual and auditory stimuli [1, 2, 3, 4]. The processing duration of visual stimulus is reported longer than that of auditory stimulus [2, 12]. Also, the simultaneity perception characteristics is reported to be changed by adaptation and attention in these days [8, 10, 11].

In addition to simultaneously perception characteristics between different sensations, the simultaneity perception or timing perception characteristics in one sensation are important. In the auditory sensation, we can obtain various sound source information by the perception timing of each sound, and localize sound source by the timing difference of the sounds percept at left and right ear. Also, when we perceive some sounds, we sometimes pay attention to one of the sound sources or a frequency or one side of contralateral ear according to the listening situation. However, studies concerning with the auditory simultaneously perception characteristics taking into account for attention are rarely seen. In this study, we investigated the simultaneity perception characteristics of auditory stimuli considering attention.

EXPERIMENT

Apparatus and Stimulus

In the experiment, we presented two instantaneous auditory stimuli at contralateral ear for evaluating the simultaneity. As the instantaneous auditory stimulus for evaluating the simultaneity at contralateral ear, we used two pure tones having a 80 dB sound pressure level (SPL) at a frequency of 1 kHz and a duration of 10 ms. To eliminate the click sound at the onset and offset of the test sounds, we performed 2.5 ms liner fade-in and fade-out processes. Also, in this study, we investigate the simultaneity in the contralateral ear considering attention, therefore, we prepared inducing sounds for paying attention to one side of the contralateral ear (left/right ear). The inducing sounds were presented before presenting the test sound. The characteristics of the inducing sound (frequency, SPL, duration, fade) were identical with those of the test sound. These inducing and test sounds were recorded at 44.1 kHz sampling frequency and recorded on two channels. The sounds presented to left ear were recorded on the first channel, and the sounds to right ear were recorded on the second channel. The presentation timing of these inducing and test sounds were set according to the experimental procedure described in the next section. These sounds were presented from personal computer (PC) via headphones (SONY MDR-Z600). And the experimental subject evaluated the presentation timing of the test sounds by two alternative forced choice method (2-AFC) using original software. In addition, the software can reproduce inducing and test sounds and save the evaluation result.

Procedure

We presented one of the two test sound to left or right ear and presented the other sound to the opposite side of the ear to evaluate the simultaneity characteristics. We prepared eight kinds of interstimulus intervals to perform the simultaneity evaluation in the contralateral ear. The interstimulus interval was set at -80, -40, -20, -10, $+10$, $+20$, $+40$ or $+80$ ms. The negative value denotes the sound to right ear precedes the sound to left ear and the positive value denotes the sound to left ear precedes the sound to right ear. Also, for evaluating the characteristics considering attention, we prepared two kinds of test pattern (attention test pattern and no attention test pattern).

In the attention test pattern, we tried the subject to pay attention to one side of the contralateral ear. In the no attention test pattern, we tried the subject not to pay attention to one side of the ear. In the attention test, to induce attention to one side ear (left/right), inducing sound was presented 20 times to one

side ear continuously as shown in Fig. 1(a),(b). The interval of the 20 inducing sounds was set at 50 ms and the interval between the last inducing sound and the first test sound was set at 200 ms [13]. We called the test pattern, in which the inducing sounds were presented to left ear, as left ear attention test (Fig. 1(a)), and called the test pattern, in which the inducing sounds were presented to right ear, as right ear attention test (Fig. 1(b)). Therefore, there are three test patterns in all (left ear attention test, right ear attention test, no attention test). In the no attention test, the inducing sound was presented left or right ear randomly 20 times as shown in Fig. 1(c) not to pay attention to one side of the ear. After presenting the inducing

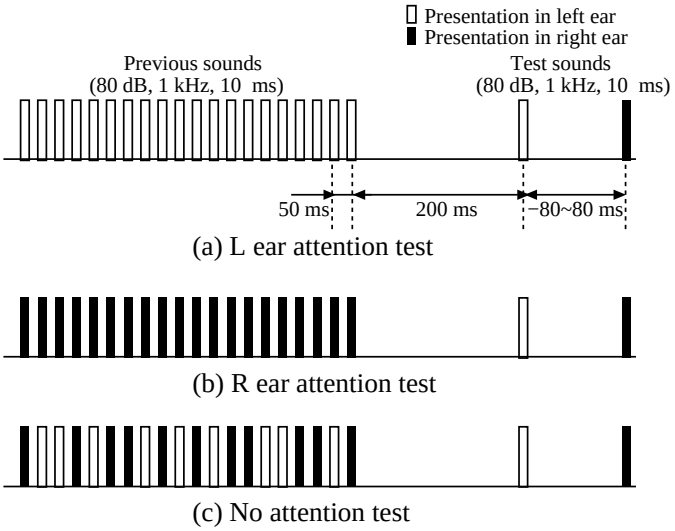

Figure 1: Presentation pattern of inducing and test sounds for simultaneity perception test considering attention. There are three test patterns: (a) is left ear attention test, (b) is right ear attention test, (c) is no attention test. Eight intervals (-80, -40, -20, -10, $+10$, $+20$, $+40$, $+80$ ms) were used for evaluation of the simultaneity.

and test sounds in each pattern, we asked the subject to answer the following question: "Which sound at left ear or right ear comes firstly?" These test patterns were performed separately in each session. In one session, the eight interval kinds of test sound pair (-80, -40, -20, -10, $+10$, $+20$, $+40$ and $+80$ ms) were presented 10 times randomly, therefore, there are 80 trials in one session. And we made four sessions (1. left ear attention test, 2. no attention test, 3. right ear attention test, 4. no attention test) as a set and performed the set continuously in one time. The experimental subject took about 30 minutes to perform one test set. Each subject performed eight test sets in all. There are, therefore, a subject performed 2,560 trails in all (80 trials $\times$ 4 sessions $\times$ 8 test sets). Six male subjects from 20 to 22 years old having normal hearing acuity participated in this experiment. Hence, 15,360 trials were performed in all subjects (2,560 trials $\times$ 6 subjects). In addition, to reduce the effect of experimental session order, we prepared four kinds of session order (1[left ear attention test]$-$2[no attention test]$-$3[right ear attention test]$-$4[no attention test], $3-4-1-2$, $4-3-2-1$, $2-1-4-3$), and each subject performed each session order two times in all eight test sets.

RESULT

Figure 2 shows the selection probabilities of the two response types in all tests. White bars indicate the probabilities in which subjects percept the sound presented in left ear comes first and black bars indicate the probabilities in which subjects percept the sound presented in right ear comes first. Figure 2(a) shows the experimental result at no attention test, and Figure 2(b) shows the result at left ear attention test, and Figure 2(c) shows the result at right ear attention test. The horizontal axis in each graph shows the presentation timing difference between the sound presented at left ear and the sound presented at right ear. A negative value of the timing difference denotes that the test sound at right ear preceded the sound at left ear and a positive value denotes that the test sound at left ear preceded the sound at right ear. The vertical axis shows the selection probability of each response type. At the no attention test (Fig. 2(a)), the experimental subjects could select the first presented sound correctly at high probability at an interval of $+80$ and -80 ms. But the difference of selection probability between left ear advance and right ear advance becomes small as the presentation interval becomes small, and the selection probabilities of left ear advance and right ear advance become almost 50% when the interval was under 20 ms. From these experimental result, it is found that when the interstimulus interval was under 20 ms, the subjects has difficulty to response correctly the presentation order in contralateral ear, and they can response correctly the order at high probability (over 60%) when the interval is over 40 ms. In addition, the distribution of the response probability is almost symmetrical on center of 0 ms in no attention test (Fig. 2(a)). This result shows the subjects have a tendency to perceive simultaneously when the sound at left ear and the sound at right ear are presented at the same timing in no attention test.

On the other hand, at left ear attention test (Fig. 2(b)), the selection probabilities of left ear advance are higher than those of right ear advance when the interstimulus interval was under 20 ms. This result indicates the subjects have a tendency to perceive the sound at left ear comes firstly than the sound at right ear by giving their attention to left ear even if these sounds presented at about same timing. Also, when the interval was about -30 ms, the selection probability of left ear advance is estimated as almost same (50%) as that of right ear. This means that when the sound at right ear precedes the sound at left ear by 30 ms, the subjects perceive these sounds come simultaneously. Therefore, these results clarified the point of subjective simultaneity (PSS) is different at the point of objective simultaneity (POS). In the right ear attention test (Fig. 2(c)), the tendency is opposite of that in the left ear attention test (Fig. 2(b)). When the interval is under 20 ms, the selection probabilities of right ear advance are higher than those of left ear advance and when the sound at left ear precedes the sound at right ear by about 30 ms, the subjects perceive simultaneously. From these results, it is clarified that the subjects perceive the sound presented to the attentive side ear comes firstly even if these sound (sound at left ear and sound at right ear) are presented at the same timing.

Then, we calculate the PSS in the contralateral ear at each test pattern (no attention test, left ear attention test, right ear attention test). For obtaining the PSS, the cumulative Gaussian distribution curves were fitted to distribution curves of left ear advance and right ear advance at each test pattern by employing Least Square Method, and the cross point of the fitted distribution curves between left ear advance and right ear advance becomes PSS (then, the selection probabilities at left ear advance and right ear advance become same at 50%). Figure 3 shows the analytical results. The positive value means the PSS shifted to left ear advance, and the negative value means PSS shifted to right ear advance. The PSS at no attention test was -7 ms, this means when the subject does not pay attention to one side of the contralateral ear, there is little deviation between PSS and POS. But the PSS at left ear attention test was -25 ms and the PSS at right ear attention test was $+32$ ms. These result indicates that the PSS changes depending on the attention and the PSS moves toward advance presentation timing at no attentive side of the contralateral ear.

DISCUSSION

In this study, we performed simultaneity perception test in the contralateral ear to investigate the auditory simultaneity perception characteristics considering attention. As results, the sound presented to attentive ear is found to be percept as coming firstly by the attention. In the previous auditory-visual si-

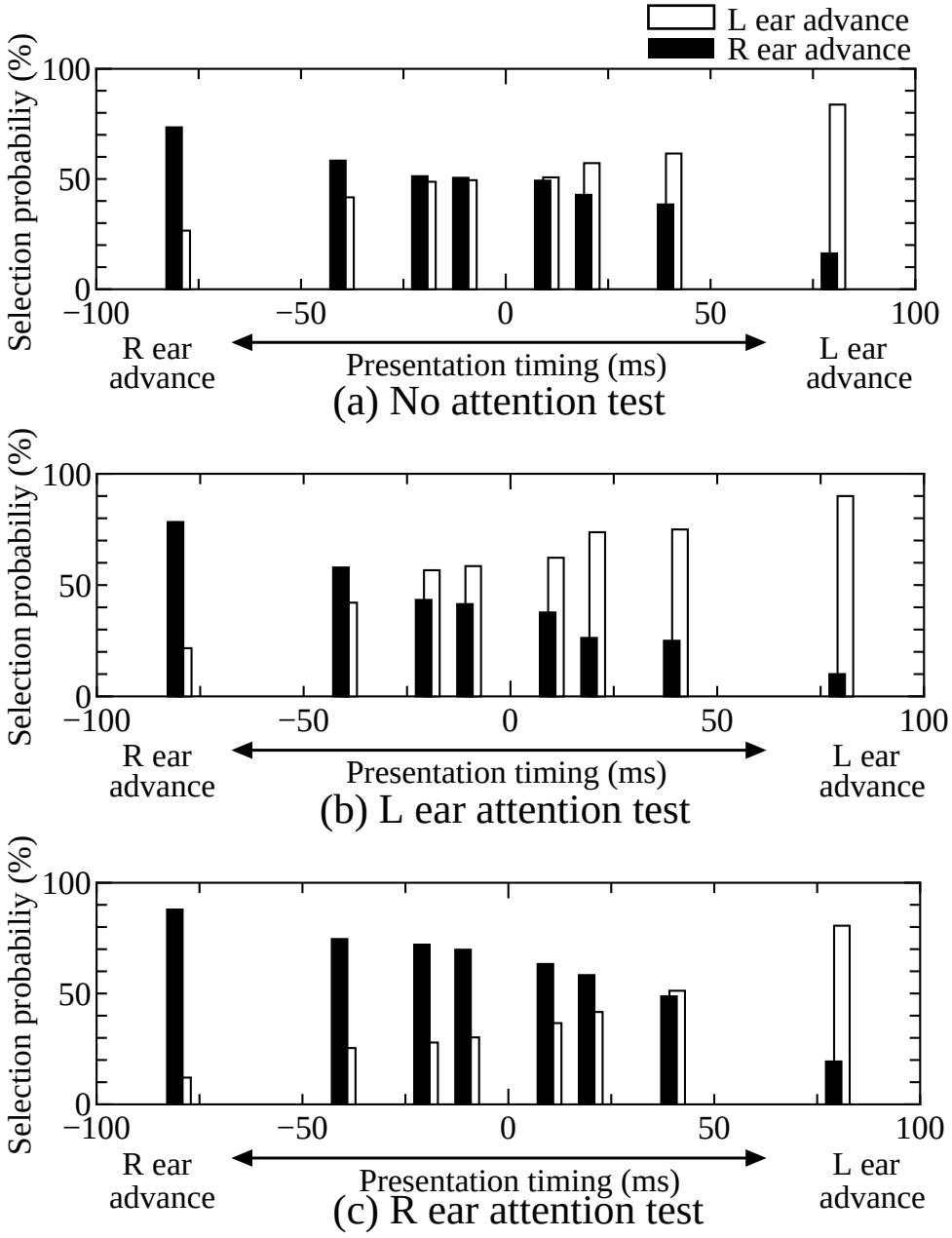

Figure 2: Selection probabilities of two response types. White bars indicate the probabilities in which subjects percept the sound presented in left ear comes first and black bars indicate the probabilities in which subjects percept the sound presented in right ear comes first. The horizontal axis shows the presentation timing. The vertical axis shows the selection probability of each response type.

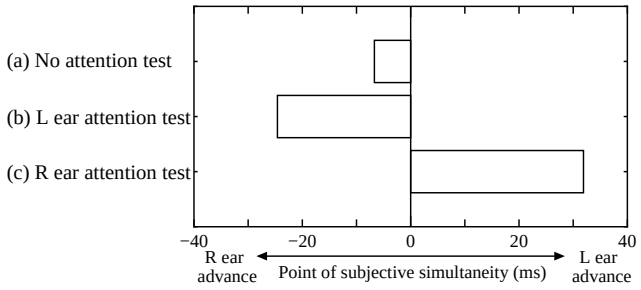

Figure 3: Point of subjective simultaneity at each test pattern (no attention test, left ear attention test, right ear attention test). The horizontal axis shows the PSS. Positive value means PSS shifted to left ear advance, and negative value means PSS shifted to right ear advance.

multaneity study, the PSS change by attention is reported [10, 11]. Zampini *et al.* performed an auditory-visual simultaneity perception experiment considering attention [11]. As results, the PSS was obtained as about 40 ms visual advance when the subjects divided their attention to both auditory and visual stimuli (that is almost same experimental condition in our no attention test in which the subject does not pay attention to one side ear). But the PSS at auditory attention test became at about 45 ms visual advance (PSS shifted to visual advance in comparison to both attention test) and the PSS at visual attention test was at about 30 ms visual advance (PSS shifted to auditory advance in comparison to both attention test). These results illustrate the PSS shifted toward the presentation timing of the stimulus that was not paid attention. In our experiment, when the subject paid attention to left side ear, the PSS changed to right ear advance at 25 ms and when the subject paid attention to right side ear, the PSS changed to left ear advance at 32 ms. These results are similar with that of Zampini's auditory-visual experimental results. The reason why PSS changed to the advance presentation timing of no attentive side is considered as follows.

As shown in Figure 4, when the processing duration of a stimulus (Stimulus 1) from the sensor organ to the brain is shorter than that of the other stimulus (Stimulus 2), the PSS shifts to the stimulus (Stimulus 2), that has longer processing duration, preceding the other stimulus (Stimulus 1) having shorter processing duration. Hence, the PSS change to advance presentation of no attentive stimulus indicates the response to the attentive stimulus becomes faster relatively than that of no attentive stimulus.

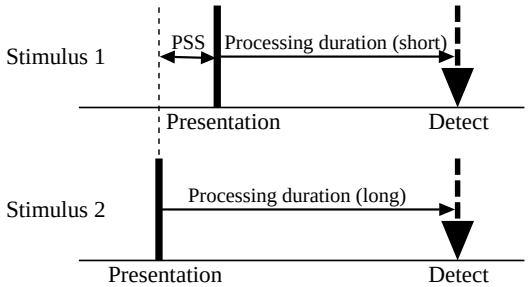

Figure 4: Relationship PSS and response time. When the response time of Stimulus 1 is shorter than that of Stimulus 2, the PSS shifted to Stimulus 2 advance.

The fact that the response to attentive stimulus becomes faster suggest a few possibility as follows. The first one is that the transfer speed of auditory signal from the auditory peripheral system to the central system at brain becomes faster. Another one is that the transfer speed does not change but the subjective presentation order changes by post process at the central system. To clarify which possibility occurs in our experiment is difficult at present. However, if the transfer speed becomes faster, the sound localization, that is carrying out by using a very small timing difference between left and right ear, could be changed depending on the attention. But in practical, the subjective location of the sound is not changed widely depending on the attention. Therefore, the PSS is considered to be changed by post process mainly. By performing additional experiments, we would like to clarify the factor.

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