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A Research of Timbre Perception Mechanism for Phase variation

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1 Introduction

Phase information was seldom referred in research of timbre perception, because it has not been regarded as importance in the auditory system. However, there has been a few reports which has stated about effects on timbre perception by phase variation. Relationship between phase variation and timbre perception is very important in examining about timbre perception mechanisms and time information processes in the auditory system.

The first experiment about influence of phase on timbre of complex tones was performed by von Helmholtz[1]. von Helmholtz concluded that “the changes in timbre are too small to transform one vowel in another”. Later, this conclusion has oversimplified as “effect of phase on timbre can be regarded as negligible”.

However, afterwards, experiments using complex tone were performed by Licklider[2], Shroeder[3], Plomp[4],etc. These reported that timbre change by phase variation can be perceived under some circumstances.Patterson[5] proposed a pulse ribbon model to simulate neural firing patterns in single auditory nerve-fiber and tried to explain quality of phase influence on timbre.

Previous reports have not referred to phase distortion in experimental systems. However, Yasutake et al[7] tried to improve experimental accuracy by removing phase distortion in experimental equipment as possible, and they performed experiments using complex tone with harmonics whose F0s are 125Hz and 250Hz.

This paper, first improves on the phase compensation method proposed by Yastake et al to remove phase distortion in experimental equipment. Next, three experiments were carried out. The first experiment was to reexaminate Yastake et al’s experiment (Experiment 1). The second experiment was to be clear influence of the total number of

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harmonics in complex tone on phase perception (Experiment 2). The third experiment was to study F0 influence of complex tone on phase perception (Experiment 3). Moreover, this paper examines quality of timbre perception in the auditory system by Auditory Image Model(AIM)[6].

2 Experimental Systems

When performing psychophysical experiment with phase information, we have to pay attention to characteristics of experimental equipment. In experiments, stabilized power supply was used for head phone amplifier. The head phone whose amplitude characteristics and group delay characteristics were relatively stable was used for the experiments. Other analog experimental systems were battery-operated to remove effects of electric source.

3 Phase Compensation

Characteristics of experimental systems were measured by Time-stretched pulses (TSP) method. The time-stretched pulse has good characteristic to measure impulse responses of acoustic systems. Amplitude and group delay characteristics of experimental systems were calculated from impulse responses measured by the TSP. The results show that positions of peaks and dips in group delay functions of experimental systems were different between measurements, especially they were unstable in low frequency. Since, it was difficult that group delay characteristics were stable all over the frequency domain, the band width of phase compensation was restricted.

Phase compensation was carried out using inverse filters. The inverse filter was calculated by inverting frequency characteristics of experimental systems. Experimental stimuli were obtained by multiplying the DFTs of complex tones and the inverse filter in the frequency domain. Then the frequency characteristics of the stimuli were added inverse frequency characteristics of experimental systems. The stimuli can reached subject's ears as original wave forms without phase distortion.

4 Experiment 1

Experiment 1 was reexamination of Yasutake et al's experiment using complex tones with 31 harmonics and F0 were 125Hz and 250Hz. The subject's task was to discriminate between timbre of complex tones whose harmonics of phase shifted π and not shifted. The result of this experiment showed that timbre change was perceived if 2 or 3 harmonics were contained in auditory filter of which center frequency was the same as that of the phase-shifted harmonic when F0 was 125Hz. Whereas, timbre change was not perceived when F0 was 250Hz. This result supported the pulse ribbon model which simulates neural firing pattern in single auditory nerve-fiber.

The result of reexamination was the same as that of Yasutake et al's report. This result verifies validity of Yasutake et al's results

5 Experiment 2

When the fundamental frequency of the complex tone is low and complex tone does not have many harmonics, influence of phase variation of harmonics in high frequency on timbre has not been examined.

Then the second experiment was performed with complex tone containing up to 31 harmonics and 60 harmonics to examine effects of the total number of harmonics on the phase perception. Results of this experiment was approximately consistent. This result indicates that phase perception is independent of the total number of harmonics.

6 Experiment 3

Experiment 3 was performed to examine effects of the fundamental frequency of complex tones on phase perception. The fundamental frequencies of complex tones were adjusted in 1/4 oct. steps from 62.5 to 250Hz. In addition, the stimuli have harmonics so far as above 5kHz.

Consequently, if the fundamental frequency was below 200Hz, timbre change was perceived when 2 or 3 harmonics were contained in auditory filter. Whereas, when the fundamental frequency was above 200Hz,timbre change by phase variation was not discriminable. Lower limit of detection of timbre change was obtained by applying least squares method, it was 2.24 harmonics in auditory filter.

When discrimination rate was high, pure tone-like sound was perceived as separate tone in the stimulus. This is the same situation reported by Duifhuis[8][9].

7 Auditory Image Model simulation

The simulations using Auditory Image Model (AIM)[6] were performed to examines quality of timbre perception in the auditory system. AIM is a model of the auditory system expanding the pulse ribbon model, and AIM simulates Neural Activity Pattern (NAP) in auditory nerve using gammatone filter bank. The output of gammatone filter is considered as Basilar Membrane Movement (BMM) at place corresponding to center frequencies of gammatone filter bank. The output is converted into Neural Activity Pattern (NAP) using Meddis's haircell model.

In this research, influence of phase variation on NAP was examined. As a result, NAP was corresponding to experimental data when fundamental frequency was below 200Hz, whereas it was not above 200Hz. More consideration was needed about this result.

8 Conclusion

- In this research, psychophysical experiments with complex tones were performed after removing phase distortion of experimental systems, examining especially about relationship between influence of phase variation on timbre and fundamental frequencies. Consequently, timbre change by phase variation was perceived when 2 or 3 harmonics were contained in auditory filter if the fundamental frequency of the complex tones was below 200Hz.

- The simulations using AIM were performed to examine relationship between NAP change and experimental data. Consequently, NAP was corresponding to experimental data when fundamental frequency is below 200Hz, whereas it was not above 200Hz. It must be more considered about this result.

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