2010 International Workshop on Nonlinear Circuits,
Communication and Signal Processing
NCSP'10, Waikiki, Hawaii, March 3-5, 2010

Pitch perception of complex sounds with varied fundamental frequency and spectral tilt

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1. INTORODUCTION

Generally pitch is strongly related to fundamental frequency. However, we experience the different pitch when we listen to the sound , produced by different musical instruments, which has same fundamental frequency. It is conceivable that the height is not only determined by fundamental frequency.

It was reported that the second harmonic influences the pitch perception by E. Zwicker and H. Fastl (1999) [1] . Roelf J. Ritsma (1967) showed that the lower harmonics had an influence on pitch [2] . These studies showed that pitch of harmonic complex sounds was affected by the higher harmonics. However, these researches do not show the relation between the strength of harmonics (spectral tilt) and pitch in detail. Therefore, we investigate pitch perception of complex sounds with spectral tilt.

We confirm that pitch is different depending on change of spectral tilt. We investigate the physical correlates of pitch perception in addition to the fundamental frequency.

We used two groups of stimuli to investigate existence of pitch perception change depending on spectral tilt, and to investigate the factor of pitch perception. In experiment 1, we presented stimuli according to the pitch with stimuli consisting of same spectral tilt and different fundamental frequency. In experiment 2, we presented stimuli according to the pitch with stimuli consisting of different spectral tilt and same fundamental frequency.

We did a comparison experiment of the pitch perception with all stimuli. It was difficult to compare stimuli of two groups varied under different conditions. Therefore, we measured psychological distance of all stimuli.

We constructed a perceptual space using by Multi-Dimensional Scaling (MDS) (Experiment 3). We applied results of experiment 1 and 2 to the perceptual space with a multiple regression analysis. Based on this investigation, we consider whether the pitch perception factors in each condition are different. Based on the perceptual space, we consider the physical correlates which are strongly related to the pitch perception of the stimuli in which spectral tilt is different.

2. EXPERIMENT 1

We investigate the pitch perception varying with fundamental frequency. Our purpose is to arrange stimuli which are seven complex sounds having flat spectral tilt and varied F0s in pitch.

2.1. Stimuli

We used seven complex sounds having flat spectral envelope and varied F0s from 144 to 156 Hz at 2-Hz steps. We named the stimuli from A (F0=144 Hz) to G (F0=156 Hz). These stimuli are the harmonic complex sounds having seven harmonics from the fundamental frequency.

2.2. Method

Listening tests were conducted in the soundproof chamber with nine subjects. Figure 1 is the equipments which we used in the experiment.

In this experiment, we considered the transmission characteristics from a equipment to an ear because spectral tilt was important. The stimuli was corrected by the frequency characteristic that we found by Time Stretched Pulse. The stimuli were corrected in every experiment. The length of the stimuli is one second. Sound level of stimuli was 65 dB SPL.

We adopted Scheffefs Paired Comparison for the tests the subjects heard a pair of stimuli, and compared their pitch. The subjects were asked to answer which stimulus of the paired complex sounds is lower than the other in five grades, the former is low, the former is slightly low, same, the latter is slightly low, or the latter is low.

2.3. Results

Figure 2 is the result by Scheffe's Paired Comparison. The stimuli were presented according to fundamental frequency. This result showed that pitch perception of these stimuli was strongly related to fundamental frequency.

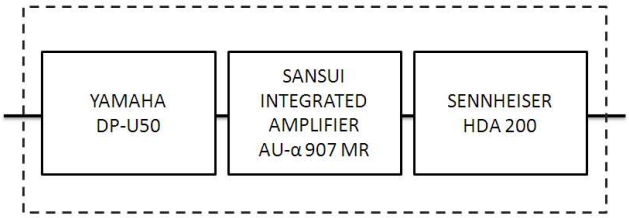

Figure 1: Experiment equipments

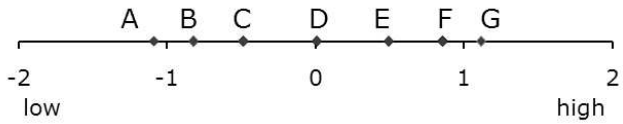

Figure 2: The result of experiment 1 by Scheffe's Paired Comparison. A-G are the stimuli name. As values increase to 2, the pitch is higher. As values decrease to -2, the pitch is lower.

3. EXPERIMENT 2

The purpose of this experiment is to investigate pitch sensation of stimuli which have different spectral tilts. We confirm that pitch is different depending on change of spectral tilt. We present stimuli consisting of spectral tilt according to pitch.

3.1. Stimuli

Fundamental frequency of the stimuli is 150Hz. These stimuli are the harmonic complex sounds including seven harmonics from the fundamental frequency. Figure 3 shows the details of spectral tilt of the stimuli. We assigned the alphabet (H to N) to name these stimuli shown in Figure 3.

3.2. Method

Listening tests were conducted in the soundproof chamber with ten subjects (nine participated in experiment 1 and one additional subject). All other experimental procedures were the same as experiment 1.

3.3. Results and discussion

Figure 4 is the result by Scheffe's Paired Comparison. The stimuli with the different spectral tilts were presented according to pitch. As for this pitch perception, there probably are strong relationships among the peak, the slope or the center of gravity of spectral tilt.

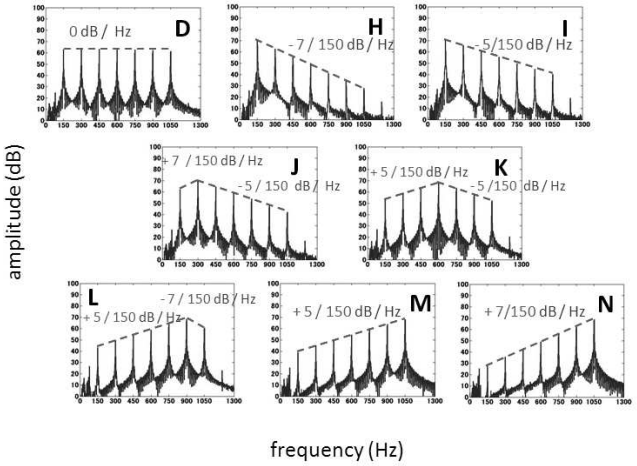

Figure 3: The stimuli in experimentII

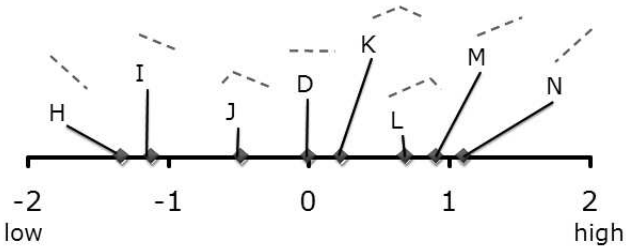

Figure 4: The result of experiment 2 by Scheffe's Paired Comparison. H-N and D are the stimuli name. The dashed line shows spectral tilts. As values increase to 2, the pitch is higher. As values decrease to -2, the pitch is lower.

4. EXPERIMENT TO COMPARE PITCH USING ALL STIMULI

Each of two group stimuli were presented depending on pitch in experiments 1 and 2. Therefore we tried an experiment to compare pitch, using the all stimuli. However, it was very difficult to compare the pitch of all stimuli. This shows the possibility that the pitch perception factors of each stimulus group are different.

The proof of this supposition is important. So we investigate it whether pitch perception factors of each stimuli group is different. We examine physical correlates of pitch in stimuli of experiment 2 if each pitch perception factors is different. We built perceptual space of the stimuli based on psychological distance of all the stimuli to conduct these investigations.

5. EXPERIMENT 3

We investigate possibility that the pitch perception factor in experiment 1 is different from that in experiment 2. In addition, we examine physical correlates of pitch perception varying with spectral tilt. We build perceptual space based on psychological distance of the stimuli to conduct this investigation.

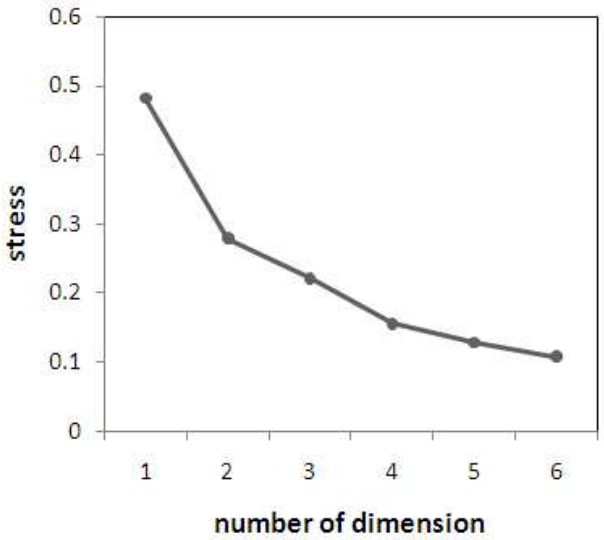

Figure 5: Stress and the relations of the dimensions

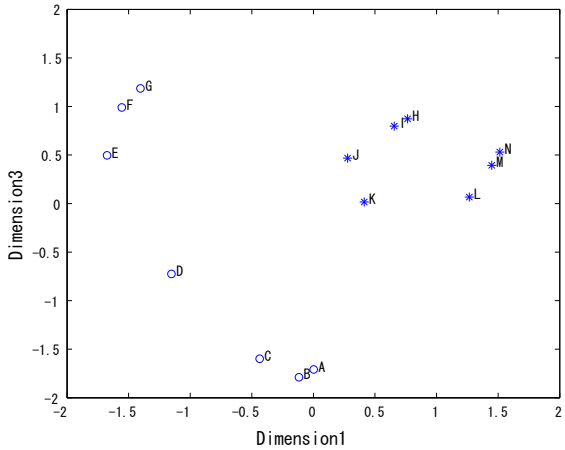

Figure 6: The result of MDS analysis (Dimension1, Dimension3)

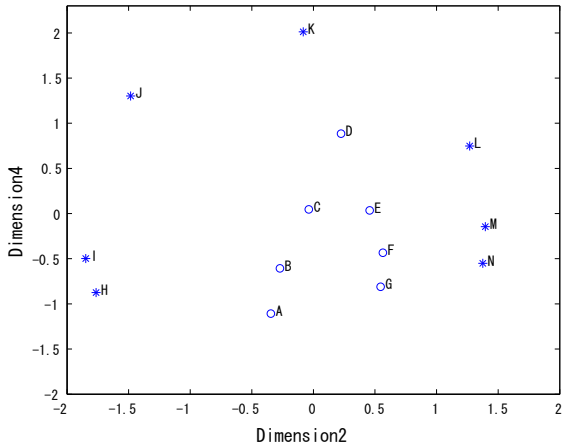

Figure 7: The result of MDS analysis (Dimension2, Dimension4)

5.1. Stimuli

We used all the stimuli of experiment 1 and experiment 2.

5.2. Method

Listening tests were conducted in the soundproof chamber with ten subjects who were the same as the participants of experiment 2. The equipments and how stimuli are heard are the same as experiment 1 and 2. In experiment 3, the subjects are asked to answer which stimulus of the paired complex sounds is similar with six grades, the former is very similar, similar, slightly similar, slightly different, different, very different.

5.3. Perceptual space based on MDS

We analyzed it in MDS based on the results of experiment 3, and we built a perceptual space. Figure 5 shows stress of the dimension in the MDS analysis. We adopt four dimensions that there become few changes of the stress. Figures 6-8 shows perceptual space which we built based on MDS. ”*” shows stimuli consisting of the different fundamental frequency having same spectral tilt. ”o” shows stimuli consisting of different spectral tilt having the same fundamental frequency. Figure 6 shows, the stimuli group of ”*” and the stimuli group of ”o” were separated. Figure 6 shows that there is psychological distance between two stimuli groups. Figure 7 shows, the stimuli that resembled a characteristic of stimulus D was distributed near D. Figure 8 shows that the distribution of ”o” resembling the results of experiment 1 and the distribution of ”*” resembled the results of experiment 2.

6. GENERAL DISCUSSION

6.1. Pitch perception factors

To prove that the pitch perception factors of stimuli H-N is different from that of stimuli A-G, we took a multiple regression analysis with a result of MDS analysis in experiment 3 and results of experiment 1 and 2. We plotted regression lines based on the results of experiment 1 and 2 in perceptual space of stimuli (Figure 8).

If the angle of a regression line of experiment 1 and the regression line of experiment 2 are different, pitch perception factors of each stimuli group should be different. The angle of these straight lines was 60 degrees. This result shows the possibility that pitch perception factors of two stimuli groups was different. This result is regarded as the reason why it was difficult to compare all stimuli.

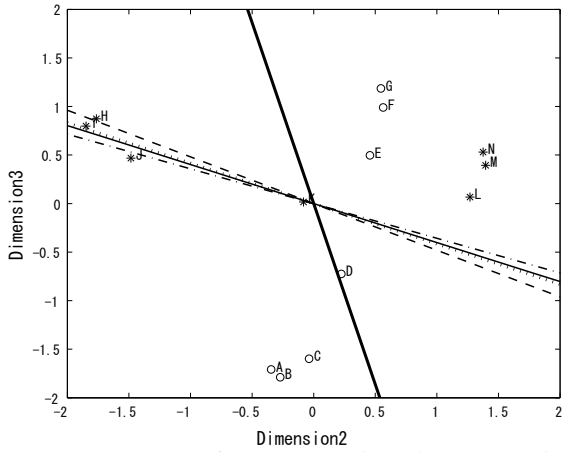

Figure 8: The result of MDS analysis and the regression line. A-N of figure 6-8 are stimuli names. ”o” shows stimuli consisting of the different fundamental frequency having same spectral tilt. ”*” shows stimuli consisting of different spectral tilt having the same fundamental frequency. The thick solid line is the regression line of experiment 1 about the stimulation of the ”o”. The dotted line is the regression line of experiment 2 about the stimulation of the ”*”. Short dashed line, dot-dashed curve, and thin solid line were regression lines which were peak of spectral tilt, slope of spectral tilt, center of gravity of spectral tilt.

6.2. Physical correlates of pitch perception

We investigated the possibility that the pitch perception factor in experiment 1 is different from that in experiment 2. In experiment 1, we considered that pitch perception factors of the stimuli was fundamental frequency. In experiment 2, we considered that the pitch perception factor of the stimuli was not fundamental frequency. In experiment 2, the possibility that relations were strong in was regarded as the peak of spectral tilt, the slope of spectral tilt and the center of gravity of spectral tilt. Using the stimuli of experiment 2, we took a multiple regression analysis about quantity of these physics. We applied the result of the multiple regression analysis to perceptual space which we built based on MDS. These physical correlates were calculated in a logarithmic frequency scale to match it with auditory perception. Figure 8 shows the regression lines of these physical correlates. The angle of a regression line of experiment 1 and the regression line of frequency of the peak of spectral tilt was about 5 degrees. The angle of a regression line of experiment 1 and the regression line of slope of spectral tilt was about 4 degrees. The angle of a regression line of experiment 1 and the regression line of center of gravity of spectral tilt was about 3 degrees. These result showed that quantity of three physics was physical correlates of pitch which changes depending on a change of spectral tilt. In this pitch perception, the center of gravity of spectral tilt was the best for physical correlates.

7. CONCLUSION

We used two groups of stimuli to investigate pitch perception changing depending on spectral tilt, and to investigate the factor of pitch perception. The first group is stimuli consisting of same spectral tilt having different fundamental frequency. The second group is stimuli consisting of the same fundamental frequency having different spectral tilt.

In each condition, we presented each stimuli according to the pitch. We built perceptual space with psychological distance of all stimuli by performing MDS analysis. We took a multiple regression analysis with the results of experiment 1 and 2. We applied these results to perceptual space built by MDS. The result showed the possibility that pitch perception factors in each two groups was different.

In the stimuli consisting of the same fundamental frequency and different spectral tilt, we took a multiple regression analysis of some physical values. It suggests that center of gravity of spectral tilt was quantity of physics that is most strongly related to this pitch perception.

8. ACKNOWLEDGEMENTS

This study was supported by the SCOPE (071705001).

References

[1] E. Zwicker, H.Fastl, *Psycho–acoustics*, Springer, 1999.

[2] Roelof J. Ritsma, “Frequencies dominant in the perception of the pitch of complex sounds,” J. Acoust. Soc. Am., **42**, 191–198, 1967.