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THE THRESHOLD OF THE RESIDUAL PITCH IN THREE-COMPONENT INHARMONIC STIMULI

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The paper presents the research results of the first effect of pitch shift in three-component inharmonic complexes. The appearance of this effect is the most important evidence that the difference tone introduced by the nonlinearity of a hearing system does not influence residual pitch perception in three-component complexes. The subjects in the adjustment procedure matched the three-component complexes pitch to the same sensation produced by pure tone. The subjects listened to three components, the harmonics of 200 Hz, which were equally shifted in the frequency domain. A 30 Hz shift was applied. The frequency range was 630–4430. The hearing experiments reveal the existence of the threshold of the appearance of the virtual pitch corresponding near to $F_1 = 200$ Hz. These results are explained using the pitch perception models based on the Licklider duplex theory and Terhardt's pitch algorithm.

Key words: pitch perception, residual pitch, residue phenomenon threshold.

1. Introduction

Previous research [3] regarding the threshold of the residue phenomenon in two-component stimuli with the fundamental frequency $F_1 = 200$ Hz defined the conditions in which the residual pitch can be clearly perceived. Another research on the residue [2], for the three-component harmonic stimuli, defined the threshold of appearance of the virtual pitch corresponding to $F_1 = 200$ Hz. It gave the opportunity to compare the behaviour of the threshold obtained in [3]. The research described in [2] also provided the possibility of creating a thesis for the existence of two kinds of three-frequency stimuli (with the odd and with the even number of central component), in which the pitch sensation depends strongly on the level of the central component representing the threshold of appearance the pitch sensation corresponding to the missing fundamental $F_1 = 200$ Hz. The pitch sensation also depends strongly on the spectral region in which the stimuli occur: resolved (< 8), middle (8–12) or unresolved (> 12). To check the thesis mentioned above for the inharmonic stimuli, the first effect of pitch shift is examined in this article. Another reason is to show the lack of influence of the difference tone on the pitch sensation evoked by these two kinds of three-component stimuli. The two thresholds of the virtual pitch appearance corresponding to $F_1 = 200$ Hz, another for each kind of stimuli, are expected to be obtained on the basis of the experiment results.

2. The hearing experiments

Twenty people with normal hearing took part in the experiments. The three-component complexes were generated by a computer and passed through the headphone amplifier to the headphones. The stimuli were composed of 200 Hz harmonics, which were equally shifted up in the frequency domain for 30 Hz. The frequency range was 630–4430 Hz. All three-frequency complexes contained successive components: from h_3, h_4, h_5 up to h_{20}, h_{21}, h_{22}. The first and third component in each stimuli had a constant level of 50 dB SPL, the level of the central (second) component was changed in the range of 5–50 dB SPL in 5 dB steps. Only the changes of the level of the central component give the possibility of defining the threshold of appearance of virtual pitch corresponding near to $F_1 = 200$ Hz (the influence of the firs effect of pitch shift). Twenty measurement series were made, one for each central component number. Four pitch matches were made in each series for one subject. The presentation time was 4 sec., followed by a 0.5 sec. break, and after that, the listeners had to match the pitch of stimuli to the same sensation produced by pure tone. The goal of the research is to define the level of the central component, which allowed the perception of the residual pitch corresponding to the missing fundamental near the $F_1 = 200$ Hz (the influence of the frequency shift [5, 6]). That level is thought to be the threshold of the residual pitch in this paper. The presented results were averaged through twenty subjects.

3. Results and discussion

It can be concluded that the two kinds of three-component complexes can be observed on the basis of the hearing research. Although they have a similar fundamental frequency of about $F_1 = 200$ Hz (depending on the number of the dominant component), the perceived pitch depends strongly on the level of the central component and the spectral region in which they occur. The first group of the three-component complexes has the odd number of central component e.g. $h_4 = 830$ Hz, $h_5 = 1030$ Hz, $h_6 = 1230$ Hz. When the level of the central component does not reach the F_1 residual pitch threshold, another residual pitch sensation corresponding to the new fundamental frequency near $F_2 = 400$ Hz (the influence of the frequency shift) is perceived. That pitch sensation is independent of the components un- and resolvability. It is a result of frequencies of edge components, which are successive harmonic (shifted for 30 Hz) of F_2. When the level of the central component crosses the particular level, the pitch sensation corresponds to the fundamental near $F_1 = 200$ Hz (the influence of the frequency shift). That level represents the residual pitch threshold and is presented in Fig. 1.

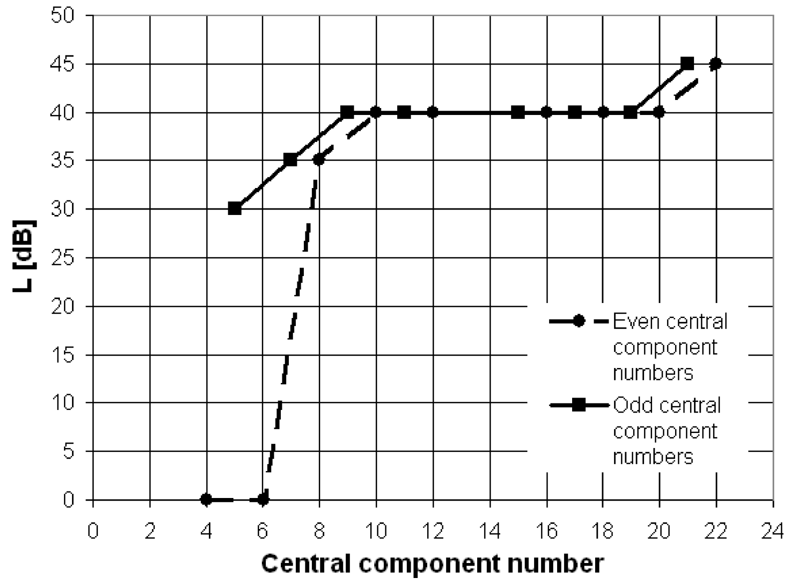

Fig. 1. Relationship between the central component level that causes the virtual pitch sensation corresponding near to $F_1 = 200$ Hz and the three presented components number.

As it can easily be observed, the threshold increases with the frequency of the stimuli, especially for the resolved (< 8) components. It is a consequence of residual pitch timbre changes, which creates a different pitch sensation (especially octave error) from the sensation produced by pure tone [2, 7]. When the frequency increases, the listeners had to increase the central component level to be sure of F_1 residual pitch perception. This behaviour of the listeners can be explained on the basis of Tedhartd's virtual pitch algorithm [7], which respects the consonance of the stimuli components. When the frequency increases, the higher level of the central component is required to create the appropriate consonance of components that allows for the production of the residual tone sensation that is perceptually similar to the sensation created by the pure tone. Fortunately, the models using the summary autocorrelation function (SacF) to extract the pitch [1] are also able to predict the increase of the threshold of the residual pitch in the frequency domain. When the frequency of the components of the three-frequency stimuli increases, the major pick in the SacF becomes less predictive [8] and forces the listeners to increase the central component level to make the pick more significant. The threshold stabilizes for the middle and unresolved component. It seems that timbre changes are not a significant factor in pitch perception for these spectral regions. On the basis of previous research [4], the pitch is defined on the basis of the evenlope repetition of temporal excitation for that region of frequency. The clearness of the evenlope repetition is independent of the components frequency and is a reason why the threshold does not increase. However, when the number of component approaches the limit of the residue existence region (25th component), the threshold increases because the ambiguity of the residual pitch decreases.

The situation changes when we observe the second group of three-component complexes with the even number of the central component e.g. $h_3 = 630$ Hz, $h_4 = 830$ Hz, $h_5 = 1030$ Hz. For the resolved component region, the pitch is defined on the basis of the spectral information, so the pitch sensation corresponds to the fundamental near $F_1 = 200$ Hz, even without the central component. For the middle and unresolved component, the pitch corresponds to the fundamental near $F_2 = 400$ Hz until the central component does not reach the threshold value. It is a consequence of the evenlope repetition of stimuli. When the level of the central component reaches the residue threshold level, the pitch perception (Fig. 1) does not change for the resolved component (spectral information); but it changes dramatically for the middle and unresolved components since the evenlope repetition of stimuli creates the pitch sensation corresponding to fundamental near $F_1 = 200$ Hz. However, the threshold of the residual pitch is the same for both kinds of three-component complexes in that region, because the clearness of the evenlope repetition must be the same for any kind of stimuli. The increase of the threshold in the frequency domain can be explained with the aforementioned pitch perception models in the same way as the first group of three-component complexes.

The pitch matching results can be observed in Fig. 2. The obtained results confirm the Schouten theory of residual pitch shift [6], which can be expressed as:

$$\Delta p = \Delta f / n, \tag{1}$$

where Δp – is the shift of virtual pitch, [Hz]; Δf – is the shift of components of complex sound, [Hz]; n – the number of dominant component.

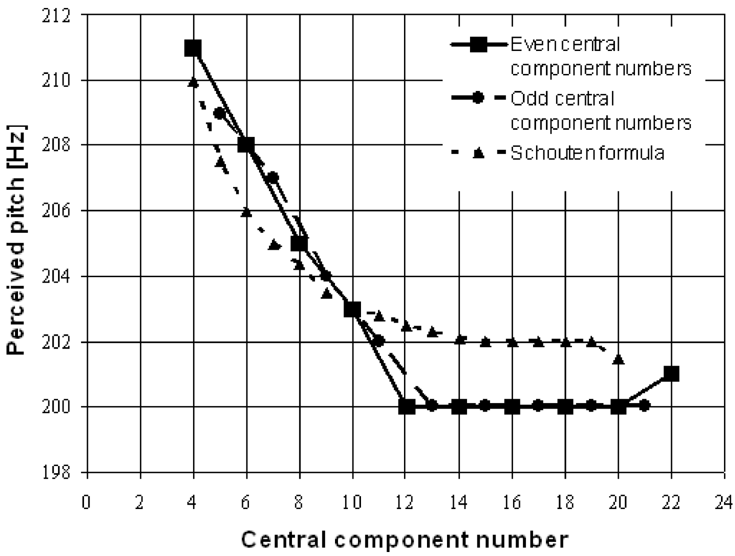

Fig. 2. The perceived pitch of three-component inharmonic stimuli in frequency domain.

The region of existence for the first pitch shift effect is also noticeable. Due to the previous research, it can be said that the pitch shift of the residual pitch disappears for unresolved components. It is a result of the lack of the influence of the excitation pattern [5, 8] in the pitch matching process using a simple tone as a matching signal. It is also a result of the small value of the frequency shift of components of three-component complex. Another result can be obtained using as a matching signal and test signal a complex sound. In that case, when the test and matching signal have the same spectral envelope, different from flat, the clear shift of virtual pitch is perceived for unresolved component [5].

4. Conclusions

• The two kinds of three-component complexes can be defined by which the pitch sensation depends on the level of the central component and the spectral region in which they occur.

• The threshold of the appearance of virtual pitch corresponding near to $F_1 = 200$ Hz increases with the frequency increase of the three-component stimuli components for both kinds of three-component complexes.

• Using the simple tone to determine a pitch of complex sound with the small frequency shift of component (< 30 Hz) allows to avoid the influence of the excitation pattern in pitch perception process.

• The obtained results confirm that the pitch perception process takes into account the component number rather than the absolute value of the component frequency.

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