PSYCHO–ACOUSTIC EXPERIMENTS OF THE MISSING FUNDAMENTAL AND CONSIDERATIONS BY USE OF COCHLEAR MODELS – ANTEROVENTRAL COCHLEAR NUCLEUS MODELS

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Abstract: Some phenomena, which were made clear by psycho-acoustic experiments, have no evidence data of electrophysiology. The missing fundamental phenomenon is one of the phenomena. We try making clear the mechanism how the missing fundamental is produced. We showed how the information of the missing fundamental f_0 explicitly appears on the aggregated autocorrelogram of output pulse trains from cochlear models for input signals f_1 and f_2 in the frequency range (250Hz<f_0, and f_1, f_2<1000Hz) where the influence of spontaneous discharge of primary auditory nerves and the influence of refractory period of primary auditory nerves can be ignored[3]. In this report, we mention the results of psycho-acoustic experiments in the frequency range where we can not ignore those influences. We discuss the results by use of cochlear models - Anteroventral Cochlear Nucleus models(AVCN models) , where f_1 =n f_0 and f_2=(n+k)f_0.

Introduction

We have research results of fundamental characteristics of an integrate and fire unit with refractory period[1]. It is known that a primary auditory nerve is an integrate and fire unit with refractory period[2]. We have the results of model experiments which show the relation between the characteristics of an integrate and fire unit and the missing fundamental[3]. The missing fundamental is not in the frequency band (300Hz to 3400Hz) of one channel of a telephone line, but we can perceive it over the telephone. (1) We confirmed by psycho-acoustic experiments that subjects can perceive the missing fundamental (f_0) for input signals f_1 and f_2 in the frequency range (250Hz<f_0, and f_1, f_2<1000Hz) where the influence of spontaneous discharge of primary auditory nerves and the influence of refractory period of primary auditory nerves can be ignored[3]. (2) We investigated the fundamental characteristics of the missing fundamental by psycho-acoustic experiments and by two cochlea models (the right ear model and the left ear model) shown in Figure 1. In this report, we mention the results of psycho-acoustic experiments in the frequency range where we can not ignore those influences. We discuss the results by use of cochlear models - Anteroventral Cochlear Nucleus models (AVCN models) , where f_1 =n f_0 and f_2=(n+k)f_0.

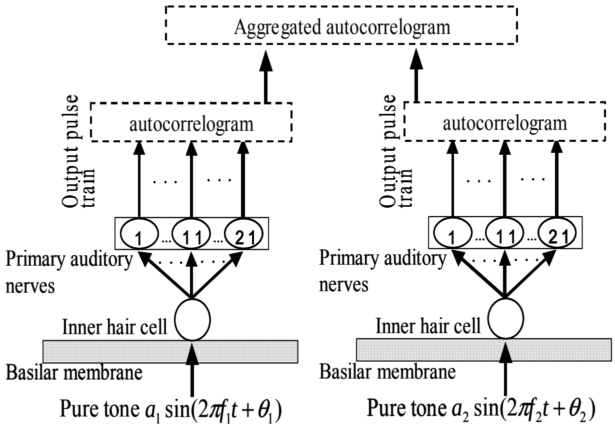

Figure 1: Cochlear models, autocorrelograms, and aggregated autocorrelogram

Methods

The procedure of the psycho-acoustic experiments is shown in Figure 2. At stimulus #1, a subject listens to the tone of f_0 to each ear through a head phone. At stimulus #2, a subject simultaneously listens to a tone of f_1 to his/her one ear and a tone of f_2 to his/her another ear. It is for avoiding listening to a combination tone.

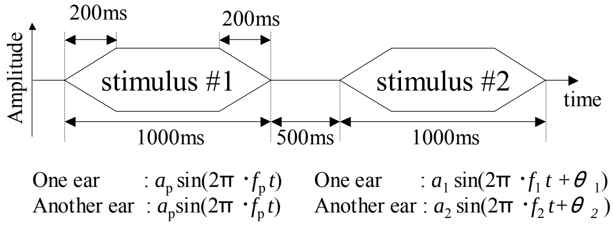

Figure 2: A stimulus tone series for psycho-acoustic experiments
stimulus#1: $f_p = f_0$ or $f_p \neq f_0$
stimulus#2:a complex tone

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Each subject listens to a stimulus tone series and says whether stimulus #2 includes the same frequency component as stimulus #1 or does not include. To discuss the results of psycho-acoustic experiments, we have made cochlear models - AVCN models. In the case that the influence of spontaneous discharge of primary auditory nerves and the influence of refractory period of primary auditory nerves can be ignored [3], each of 21 pathways in Figure 1 has the same pulse train. So, we can consider the characteristics by use of one pathway. In the case that the influence of spontaneous discharge and the influence of refractory period of primary auditory nerves cannot be ignored, each pulse train in 21 pathways in Figure 1 is different. But it is suggested that an Anteroventral Cochlear Nucleus has the function of an agreement detector [4]. So, we add an Anteroventral Cochlear Nucleus model (AVCN model) to a cochlear model. Cochlear model - AVCN model is shown in Figure 3. The value of parameter of AVCN model is determined by computer simulation and physiological data. An Anteroventral Cochlear Nucleus model works as an agreement detector of output pulse trains from AN_1(a primary auditory nerve) ~ AN_{21} (a primary auditory nerve) shown in Figure 4 and generates a pulse train for 21 input pulse trains. The value of parameter of AVCN model is determined such that the synchronization index and the entrainment index of the pulse train from the model agree with those indexes of the pulse trains (physiological data) from Anteroventral Cochlear Nucleuses [4]. The synchronization index is the followings. When an output pulse is generated at the particular phase in every cycle of the input signal, the value of the index is 1. When an output pulse is generated at the random phase in the input signal, the value of the index is 0. The entrainment index is the followings. When an output pulse is generated in every cycle of the input signal, the value of the index is 1. When an output pulse is not generated in any cycles of the input signal, the value of the index is 0. The values of both indexes are between 0 and 1.

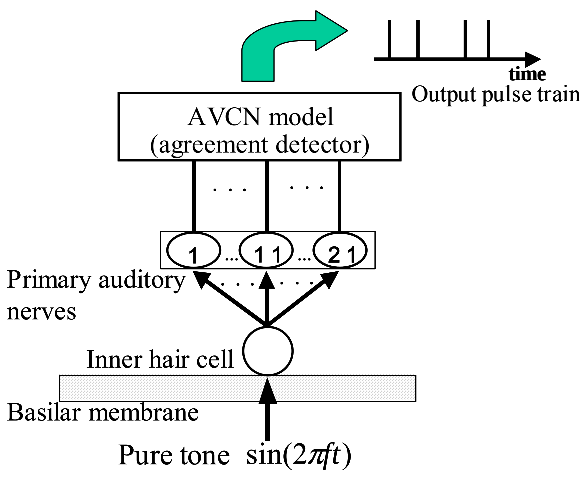

Figure 3: Cochlear model - Anteroventral cochlear nucleus model (AVCN model)

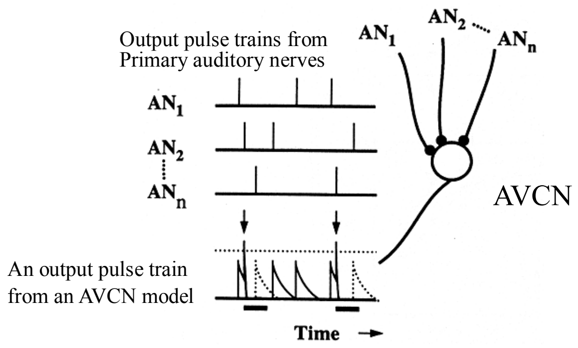

Figure 4: An output pulse train from an agreement detector (an AVCN model) where n = 21

Finally, we discuss the results of above-mentioned psycho-acoustic experiments by use of cochlear models - Anteroventral Cochlear Nucleus models (AVCN models).

Results

The results of psycho-acoustic experiments are shown in Table 1. 16, 8, and 15 at the bottom 3 lines (f_1 and f_2 are higher than 1000Hz) are significantly smaller than 31 at the top line (f_1 and f_2 are lower than 1000Hz).

How the value of the parameter of AVCN model is determined is the followings.When the value of parameter of AVCN model changes from 2 to 10, the synchronization index and the entrainment index of the pulse train from the model are calculated. 2 (the value of parameter) means that AVCN model generates one pulse for simultaneously (within 0.1 ms) receiving 2 input pulses. The synchronization indexes are calculated for each value of parameter. The distribution of the synchronization indexes is independent on the value of parameter and agrees with the distribution of the index from physiological data. The entertainment indexes are also calculated for each value of parameter and are plotted in Figure 5. The distribution of the entertainment

Table 1: The result of psycho-acoustic experiments of the missing fundamental
(9subjects × 5times =45(maximum numerical numbers))

stimulus#2 complex tone (One ear : f_1[Hz] , Another ear : f_2[Hz])	f_0[Hz]	The number of times of perceiving
f_1=500Hz , f_2=750Hz	250	31
f_1=600Hz , f_2=900Hz	300	33
f_1=1200Hz , f_2=1500Hz	300	16
f_1=1500Hz , f_2=2000Hz	500	8
f_1=1400Hz , f_2=2100Hz	700	15

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indexes depends on the value of parameter. The distribution of the index from physiologic data is shown by a dotted line. The distribution of the entertainment indexes at 2 (the value of parameter) agrees best with the distribution of the indexes from physiological data shown in Figure 6 [4]. So, it is determined that the value of parameter of AVCN model is 2. Thus, we have made cochlear models - Anteroventral Cochlear Nucleus models.

Finally, the experiments using cochlear models - Anteroventral Cochlear Nucleus models have been carried out. The results is shown in Figure 7. An autocorrelogram of an output pulse train from the AVCN model of right ear and an autocorrelogram from the AVCN model of left ear have been made. The frequency information of the missing fundamental of input signals lower than 900Hz has explicitly appeared

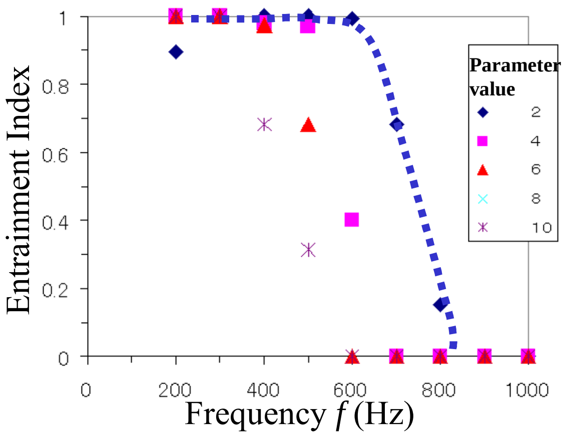


Figure 5: The entrainment index of an output pulse train from an AVCN model in case of 21 pathways

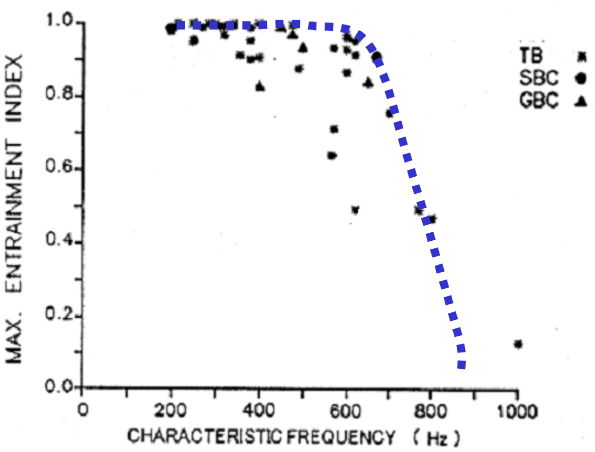
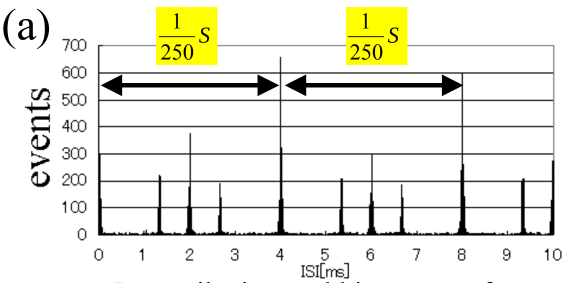


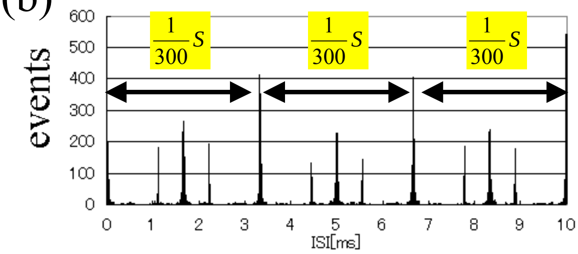
Figure 6: The entrainment index of an o0utput pulse trains (physiologic data) from anteroventral cochlear nucleus[4]

(a)



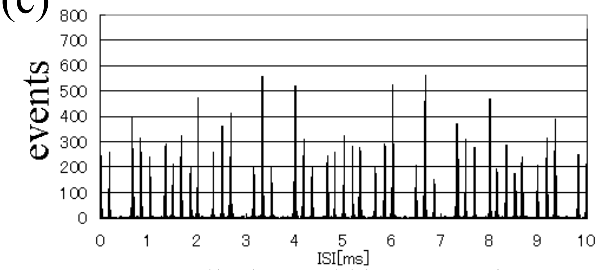
Interspike interval histogram of the aggregated autocorrelogram f_1=500Hz, f_2=750Hz, (f_0=250Hz)

(b)



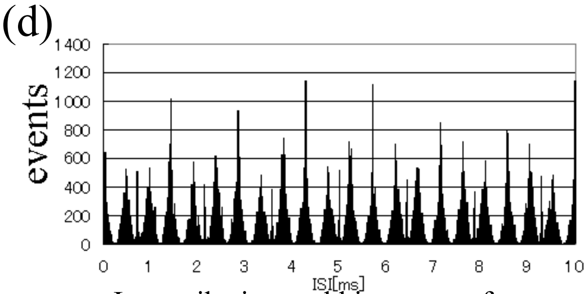
Interspike interval histogram of the aggregated autocorrelogram f_1=600Hz, f_2=900Hz, (f_0=300Hz)

(c)



Interspike interval histogram of the aggregated autocorrelogram f_1=1200Hz, f_2=1500Hz, (f_0=300Hz)

(d)



Interspike interval histogram of the aggregated autocorrelogram f_1=1400Hz, f_2=2100Hz, (f_0=700Hz)

Figure 7: The information of the missing fundamental In the aggregated autocorrelogram of the output pulse trains from AVCN models
One pulse train for pure tone f_1 (to one ear)
Another pulse train for pure tone f_2 (to another ear)

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in the interspike-interval histogram of the aggregated autocorrelogram of two autocorrelograms. The results by cochlear models – AVCN models agree with the results of psycho-acoustic experiments.

Discussion

The synchronization index and the entrainment index of output pulse train from cochlear models - Anteroventral Cochlear Nucleus models keep 0.9 until 1000Hz and 700Hz, respectively. These properties agree with those from electrophysiological data[4].

Conclusions

It has been found by psycho-acoustic experiments that we can perceive the missing fundamental of the input signals up to 900Hz and the perceptivity of the missing fundamental decreases for the input signals higher than 900Hz.

The frequency information of the missing fundamental of input signals lower than 900Hz explicitly appeared in the interspike-interval histogram of the aggregated autocorrelogram of output pulse trains from cochlear models - Anteroventral Cochlear Nucleus models. The result of psycho-acoustic experiments agrees with that of model experiments.

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