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AN ASPECT OF THE PROBLEM OF PITCH DEPENDENCE ON THE DURATION OF SHORT SINUSOIDAL SIGNALS

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The influence of the duration on the pitch of short tone pulses with rectangular envelopes and integral numbers of periods in the pulses was investigated. The part of the period in which the pulse started, i. e. its initial phase angle was either 0° or 80°. Experiments have shown that the initial phase influences the estimation of the pitch of a tone pulse especially at the duration near the duration threshold for the tone pitch.

I. INTRODUCTION

Investigation of the hearing properties within the field of short acoustic signals was directed from the beginning first of all towards the study of the influence of those parameters which generally characterize the stationary signals. Thus for example Békésy [1] studying the difference limen for frequency as the function of signal duration defined, in addition to duration, the frequency and intensity of the signals used. Similarly Bürck, Kotowsky and Lichte [2] ascertaining the minimum duration of the sinusoidal signal at which it reaches a tonal character characterize the signals by means of the same parameters. Although the authors of relatively later works, e. g. Doughty and Garner [3], when measuring the duration threshold for the tone-pitch, and the click-pitch Lian Czi-an and Chistovich [4] when measuring the difference limen for frequency, refer to a part of the period in which tone pulses begin, i. e. to their initial phase angle — utilize in experiments the pulses with a random initial phase. Cardozo [5] actually mentions the initial phase effect in perceiving short tone pulses when he states that the difference limen for frequency is the smalles „by gating the sinusoid in the axis crossing". Therefore he utilized in experiments the pulses with a zero initial phase, the same as Krútel [6] when measuring the difference limen for intensity. In a previous study [7] it was shown that in the estimation of the pitch of tone pulses with a rectangular

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envelope, an integral number of periods, a duration approximately equal to the duration threshold for the tone-pitch (defined in [3]), a role is played also by their initial phase. According to the experiments in [7] the pitch of tone pulses with a zero initial phase does not deviate significantly from the pitch corresponding to the frequency of the signal and also the pitch of the pulse is proportional to the initial phase in the investigated interval of initial phases (0°—80°). This behaviour has been to be in accordance with the general tendency of the spectrum of the pulses.

The significance of the initial phase of the short sinusoidal pulse from the standpoint of the spectrum as well as the time pattern falls at its prolongation. It could be interesting to observe how the influence of the initial phase upon the estimation of the tone pulse pitch becomes relevant in dependence on their duration near the duration threshold for the tone-pitch. The suggested problem may be solved at least partially by finding the points of subjective equality for frequency (PSEf) of the tone pulses with concrete values of the initial phase at various durations of the pulses.

The results of experimental research into the effect of the duration of tone pulses with a rectangular envelope, an integral number of periods in relation to their pitch at two values of the initial phase—are reported in this work.

II. EXPERIMENTS

Experiments were done with tested tone pulses of three different frequencies (250, 1000, 4000 Hz), an integral number of periods in the pulse and with two values of the initial phase (0°; 80°). The sound pressure level (SPL) of the used pulses was 60 dB re 2×10^{-5} N/m^2 and was determined as the SPL of steady tones from which the pulses were cut out. The envelope of the pulses was rectangular. The experiments were carried out monaurally with four normally hearing subjects.

1. Method

The method of constant stimuli was used to find the PSEf of the signals tested. The subject in an anechoic chamber got a pair of pulses through an earphone at one trial. The first-tested-pulse had its duration within the range of 4—32 ms. Its initial phase was either 0° or 80° in the particular series. Within the range of one series of measurements all its parameters were kept constant. The second-comparative-pulse lasted always 250 ms, it had always the initial phase of 0° and followed the first one after a 500 ms lasting inter-stimulative interval. The frequency of the comparative pulse had one of the

nine values determined in pilot experiments and varied in a random order. The time interval between the particular trials was long. The subjects' task was to determine whether the pitch of the two presented pulses was the same (positive answer) or not the same (negative answer). When the subject was not able to determine whether the pitch of the presented pair of pulses was the same or not, he did not answer. The subject was given every pair of pulses within one series of measurements at least eight times — so as to give eight answers. The shortest duration of a tested pulse at the frequency of 250 Hz was 8 ms, at frequencies of 1000 and 4000 Hz it was 4 ms. At any frequency the tested pulse was lengthened by 4 ms up to the duration of 24 ms at the frequency of 250 Hz, and 16 ms, respectively, at frequencies of 1000 and 4000 Hz. Moreover a series of measurements with a 32 ms duration of the tested pulse was carried out at all frequencies.

2. Apparatus

Figure 1 represents a block diagram of the apparatus used. Two tone generators (Brüel-Kjaer 1022) were used as sources of the particular pulses. The signals from the generators were led to two electronic switches controlled by a timer (ES-1). The last was constructed in such a way as to transmit a pair of pulses with a selective initial phase and interstimulating interval, after a pushbutton had been pressed down. Both pulses after being transmitted through matching networks (attenuators, amplifier) were led to an earphone (Beyer DT 48). A two-way communication system was installed between the experimenter and the subject by means of optical signals. Before each trial the experimenter warned the subject of his transmitting a pair of pulses. The subject could select a positive or negative answer.

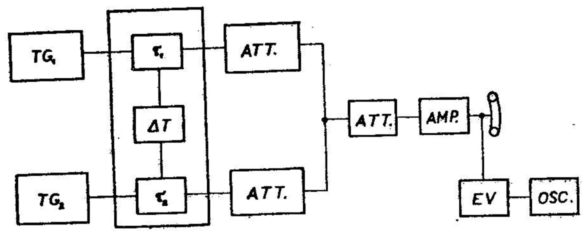

Fig. 1. Block diagram of the apparatus. The apparatus consisted of: TG 1, TG 2 — tone generators, electronic switches and timer, ATT — attenuators, AMP — amplifier, EV — electronic voltmeter, OSC — oscillator and earphone.

3. Results

The distribution of positive answers of the four subjects for one series of measurements is shown in Fig. 2. From the histogram we can see that the maximum of positive answers at a given duration of the tested pulse and the initial phase 80° is, with respect to its frequency, shifted towards higher frequencies.

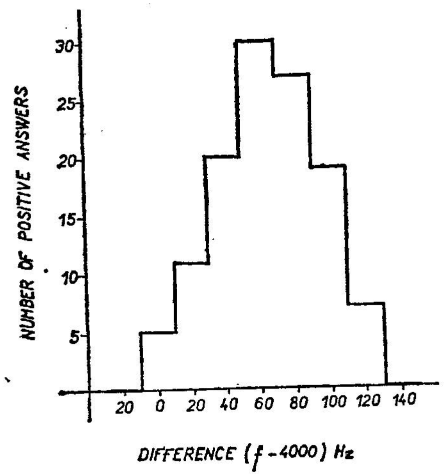

Fig. 2. The histogram of positive answers of the four subjects at the frequency of 4000 Hz, the duration of 8 ms and the initial phase of 80°. *f* denotes the frequency of the comparative tone pulse.

First tests of the significance of differences in the answers of the individual subjects during one series of measurements were carried out according to Fischer [8] for the statistical processing of the measured results. Those tests showed that no significant differences were between the answers of the individual subjects about a tested pulse. Therefore the answers of all the subjects together were taken for the calculus of statistics and they were considered as one sample. The calculus of PSEf was performed by using formulas for the normal distribution of positive answers. The results are given in Tab. 1. In the first line there are the results for the initial phase of 0° for each frequency, in the second line for the initial phase of 80°. The columns show the PSEf and their standard deviations for the marked durations.

The PSEf as functions of duration for all frequencies are shown in Fig. 3. The initial phase was utilized as a parameter. It is seen from the figure that the case of the initial phase of 0° the PSEf does not deviate significantly from the tested pulse frequency in any direction and at any duration of pulses. The situation

Table 1

f [Hz]		duration [ms]	4	8	12	16	20	24	32
250	init. phase	0°	–	249.8 ± 0.3	250.3 ± 0.2	249.7 ± 0.2	250.3 ± 0.2	249.9 ± 0.2	250.0 ± 0.2
		80°	–	252.8 ± 0.3	252.8 ± 0.3	254.9 ± 0.3	253.6 ± 0.3	252.5 ± 0.3	249.8 ± 0.3
1000	init. phase	0°	999.8 ± 0.6	999.9 ± 0.6	999.5 ± 0.5	1000.5 ± 0.5	–	–	999.7 ± 0.5
		80°	1000.8 ± 0.6	1013.0 ± 0.6	1006.5 ± 0.6	1004.8 ± 0.6	–	–	1002.4 ± 0.6
4000	init. phase	0°	4000.8 ± 2.8	4001.3 ± 3.2	4003.2 ± 2.6	3997.1 ± 2.2	–	–	4001.8 ± 2.3
		80°	3999.8 ± 2.8	4064.9 ± 2.8	4040.0 ± 2.9	4005.7 ± 2.9	–	–	4001.7 ± 2.9

is different in the case of the initial phase of 80°. It is seen that the PSEf is increasing with the pulse shortening under the value of 32 ms when compared with the pulse frequency. The deviation reaches its maximum near the duration threshold of the tone-pitch, i. e. the minimum duration at which a signal just gets a tonal character. At a further pulse shortening this deviation decreases again. At an equal shortening expressed in ms the decrease is the more intensive,

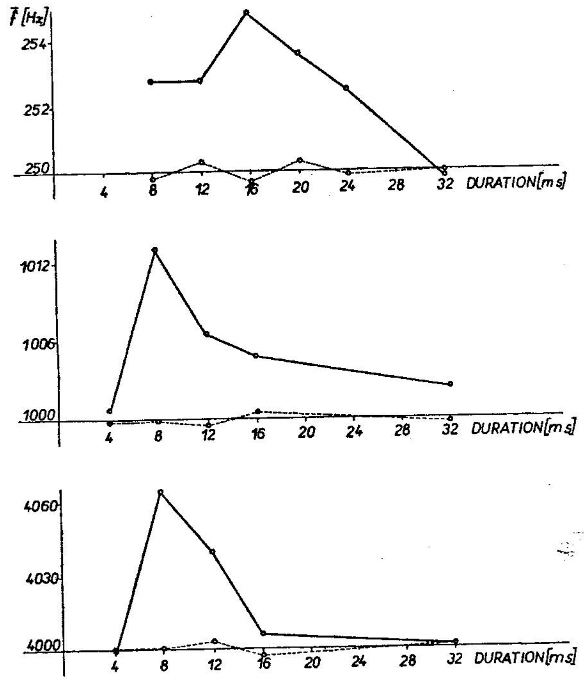

Fig. 3. Points of subjective equality for the frequency $\bar{f}$ as a function of the duration of the tone pulse with the frequency of a) 250 Hz, b) 1000 Hz, c) 4000 Hz for the initial phase of 0° (dashed line) and 80° (full line).

the higher the pulse frequency is. Significance tests of PSEf deviations from the pulse frequency in the case of the initial phase of 80° showed that the deviation is significant on the level of 0.01: a. for the 250 Hz frequency in the whole interval of the investigated durations with the exception of 32 ms; b. for the 1000 Hz frequency in the interval from 8 ms to 32 ms; c. for the 4000 Hz frequency only for two investigated durations, that is 8 and 12 ms.

III. DISCUSSION

The dependence of the pitch as a function of the tone duration has been experimentally investigated but the results of the individual authors differ considerably. For example Bürck, Kotowsky and Lichte [2] have pointed out that the consequence of shortening the higher frequency short tones is the decrease of their pitch, with lower frequency short tones there is a contrary tendency (their shortening results in the rise of the pitch). Stevens and Eckdahl [9] have concluded that the shortening of tones of all frequencies causes a decrease of pitch.

An extensive investigation of the said dependency was carried out by Doughty and Garner [10] by two different measurements. In the first measurements they used the method of constant stimuli where the subject had to determine whether the comparative tone was higher or lower than the standard one. The PSEf was taken as the 50 percent point. The measurements were performed at two SPLs. At the SPL of 70 dB there was found no change of the pitch up to the duration of 6 ms. At the SPL of 90 dB, at a 6 ms duration and 1000 Hz and 4000 Hz frequencies, the PSEf deviation from the carrier frequency was found towards lower frequencies. The deviation was greater at a 1000 Hz frequency and its value was about 0.8 percent. The experiments were then carried out by the average error method, at two SPLs again. Also in this case the greatest deviations from the carrier frequency were measured in towards lower frequencies at the SPL of 90 dB and 6 ms durations. At the SPL of 70 dB with shortening the 250 and 1000 Hz frequency tone pulses the PSEf gradually decreased by about 2 % or 1 %, respectively, at the duration of 6 ms. At the 4000 Hz frequency of the tone pulse the PSEf was slightly rising.

When comparing the mentioned results with ours it is necessary to stress the fact that the quoted authors do not specify the initial phase of the tone pulses. The results obtained at our experiment indicate a need for such a specification especially in the region of the tone-pitch threshold. Generally speaking — one of the aspects which should be specified when considering the pitch of short tone pulses with a rectangular envelope is their initial phase. Taking into consideration the aspect of the initial phase it may be stated that assuming a zero initial phase the results of our experiment agree with the results obtained by Doughty and Garner by means of the constant stimuli method (even if in [10] an other procedure was used). Our results for 0° initial phase are in agreement also with recently made measurements, e. g. by Walliser [11] and Grobben [12]. If we assume the initial phase of the tested pulses in [10] to be a random one, then the results of our experiments agree with the second measurements of Doughty and Garner at the SPL of 70 dB and the frequency of 4000 Hz.

The Fourier spectrum of short tone pulses with a rectangular envelope and an integral number of periods changes with the change of the initial phase from 0° to 90° in such a way that on the one hand the main maximum shifts towards higher frequencies and on the other the energy at lower frequencies than this maximum decreases and rises at higher frequencies — i. e. the balance point of the amplitude spectral density for the pulse with a higher initial phase (interval from 0° to 90°) is situated at a higher frequency. This effect is the greater, the shorter the pulse is and the higher the difference is between the initial phases. From a purely spectral standpoint the experimental results of the present paper agree with the general tendency of the spectrum up to the duration threshold for the tone-pitch. At shorter durations — near the duration threshold for the click-pitch — where, as it is known, the noise character of the pulse is predominant, the difference between the PSEfs for the initial phases of 0° and 80° is not significant. The appreciation of the pitch on the basis of the spectrum in this region of durations does not seem to be very probable.

IV. CONCLUSIONS

The following conclusions can be made for the pitch of short tone pulses with rectangular envelopes and integral numbers of periods:

1. In addition to other parameters also the initial phase plays its role in the estimation of the pitch of tone pulses especially at durations near the duration threshold for the tone-pitch.

2. No significant PSEf deviation from the pulse frequency occurs in shortening the tone pulse with a zero initial phase up to shortening to the click-pitch duration threshold.

3. The PSEf increases when the tone pulse with the initial phase of 80° is shortened below 32 ms. This PSEf deviation from the pulse frequency reaches its maximum near the tone-pitch duration threshold.

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