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THRESHOLDS OF PERCEPTION OF JUMP FREQUENCY CHANGES FOR A DECAYING SIGNAL

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The papers devoted in the literature to the subject of the perception of frequency changes most often deal with research on the perception of frequency modulation or its changes of linear character, or the evaluation of the pitch of a signal with frequency varying in time. Within the range of these problems, an interesting question, so far not undertaken, is that of the perception of jump frequency changes occurring in a decaying signal, quite frequent in practice. In view of this, research was undertaken with the essential purpose of determining the thresholds of perception by listeners of single and double frequency changes (jumps) occurring in a decaying signal with an exponential envelope, depending on: the duration of these changes, their mutual time interval and the position of these changes with repect to the onset of the signal. The results obtained indicated a strict relation between the course of the thresholds of the perception of jump frequency changes, depending on the time parameters of these changes.

1. Introduction

The previous investigations of the perception of frequency changes have mainly concentrated on the problems of: the perception of frequency modulation, the perception of changes in the frequency increase rate and the determination of the effect of these changes on the evaluation of sound pitch. The papers devoted in the literature to this range of research [2, 4, 8–10, 18, 19] are concerned mainly with signals with time invariable amplitude. However, in the literature there are no publications on the thresholds of perception of rapid frequency changes occurring in signals of decaying nature, which are encountered e.g. in investigating the phenomena of sound decay in a room [5, 11, 13] and in considering some problems in the range of speech, music acoustics etc. Within this range, one should regard as the most essential the investigation of the fundamentals of psychoacoustic evaluation of frequency changes for signals of this type, which is a quite complex problem. This complexity results from the fact that so far no methodology has been developed for the psychoacoustic research on these signals, nor has any better knowledge been obtained of the mechanism itself of the so-called dynamic perception, which will be understood here to mean the perception of signals with physical parameters varying in time. Within this range of problems, one can distinguish a number of interesting questions. One of them is the determination of the thresholds of the perception of jump frequency changes occurring in a signal with an exponential envelope, which is the essential aim of the research undertaken.

2. Perception of frequency changes occurring over the duration of a signal

In the literature, it is possible to distinguish the following two groups of investigations of the perception of frequency changes occurring over the duration of a signal:

a. Research on the perception of frequency changes caused by modulation or changes with the nature of linear frequency increases.

b. Research on the evaluation of the pitch of a signal with frequency varying in time.

Ad.a. ZWICKER'S paper [19] was the work of fundamental significance for the investigations of the thresholds of the perception of frequency changes. In this paper, it was stated that the thresholds of the perception of frequency changes (deviations) caused by the effect of modulation depend on the frequency and amplitude of the carrier tone, and on the frequency of the modulating tone. An increase in the intensity level of a signal to 30 dB causes a drop in the threshold value, moreover, a further increase in this level does not affect a change in the threshold deviation. An increase in the carrier frequency causes a linear increase in the threshold deviation for carrier frequencies higher than 500 Hz. The most essential relation estabilished in paper [19] cited is the depencence of the threshold deviation on the frequency modulation. In this dependence, the following characteristic intervals can be distinguished with respect to the value of f_{mod}:

$f_{\mathrm{mod}} < 15$ Hz, where the hearing organ "follows" the successive frequency changes;

$f_{\mathrm{mod}} = 15$–100 Hz, where there is the so-called sound roughness, described in detail in paper [6];

$f_{\mathrm{mod}} > 100$ Hz, where the high modulation frequency causes the components to separate, as a result of which the modulated signal is detected as a composite sound.

The thresholds of the perception of frequency changes occurring in signals modulated by various modulating processes were the object of investigations described in paper [4]. The results of these investigations, in addition to a full confirmation of those contained in paper [19], demonstrated the existence of a strict dependence of the threshold of the perception of the frequency deviation on the kind of modulating process. In paper [4] it was found e.g. that the lowest threshold of the perception of frequency modulation occurs for a signal modulated by a rectangular process, whereas the highest one is obtained for a signal modulated by a triangular process.

In addition to the so-called roughness effect mentioned above, frequency modulation also involves the so-called trill effect [7, 15]. This effect occurs at low values of frequency modulation, 2–8 Hz. The threshold of the perception of this effect defined this value of frequency deviation at which a signal is sensed to change from one with fluctuating pitch into two tones with different pitch succeeding each other in time.

The perception of frequency modulated signals, also accompanied by amplitude changes, was the object of investigations presented in paper [3]. In addition to the determination of the modulation perception thresholds, these investigations found that in some conditions the amplitude-modulated tone can cause the same sensation as one frequency-modulated, and conversely.

A separate group of studies was carried out on the perception of frequency changes occurring continuously over the duration of a signal, in the limits between the initial, f_p, and the final, f_k, frequencies. The previous investigations performed in this range [9, 10] indicated that the threshold of the perception of frequency changes of this type depends strictly on the duration of the signal, at the frequency f_p or f_k, and also on the length of the time period in which this change occurs. An increase e.g. in the duration of the signal at the frequency f_p or f_k, and also in the length of the interval of continuous frequency change, is accompanied by a drop in the thresholds of the perception of frequency changes which results from facilitated detection of the frequency increment Δf.

Using similar signals, the thresholds of the perception of changes in the frequency increment rate [8] were also studied. The results obtained indicate that the course of these thresholds depends on the frequency increment Δf; moreover, at determinate Δf these thresholds depend on the frequency change rate, with respect to which they are determined. Furthermore, the course of the thresholds discussed depends strictly on the initial frequency f_p.

Ad.b. The evaluation of the pitch of signals characterised by frequency varying in time, was the object of investigations presented in [1]. These investigations consisted in comparing a simple tone with a signal whose frequency varied continuously in the limits between f_p and f_k. Moreover, the amplitude of the signal also varied by about 12 dB/octave, which, in the frequency variability interval used, corresponded to a value of 6 dB or, alternatively, 12 dB. As a result of the experiments performed, the duration of the signal at the frequency

f_p or f_k was found to have a deciding effect on the evaluation of the pitch of the whole signal. The duration of the signal at the frequency f_p, to which 90% of responses ascribes the pitch of the signal presented, is of particular significance for the phenomenon studies. Investigations of the effect of the frequency increment rate on the evaluation of the pitch of the signal indicated the different perception mechanisms for increasing and decreasing frequencies of the signal. Also here, the durations of the signal at the frequencies f_p and f_k were factors determining the evaluation of the pitch. However, it is difficult to establish to what extent the evaluation of the pitch of such signals depends e.g. on the duration of the signal at the frequency f_p or f_k, or on the frequency change rate, as in the investigations carried out the sum of the duration of frequency change and of the duration of a signal at constant frequency was constant.

Papers [2, 14, 16, 17] are also concerned with similar research problems. Papers [16, 17] considered the problem of the perception of signals whose frequency varied continuously between f_p and f_k and those which were composed of two tonal impulses with the frequencies f_p and f_k, separated by a time interval from each other. On the basis of these investigations, it was found that the two kinds of signals can cause sensations comparable with that caused by a simple tone (with a frequency falling in an interval including the highest and lowest frequencies of a signal varying in time), provided that the frequency change does not exceed some boundary value $|\Delta f|$ over which the two sensations become fuzzy. Just as in paper [1], also here, the effects observed were found to depend on the duration of the signals at the frequencies f_p and f_k, in particular on the duration of the signal at the frequency f_p.

The papers mentioned above within the range of investigations of the perception of frequency changes occurring over the duration of signals, are concerned above all with the determination of the thresholds of the perception of these changes at amplitude constant in time. In the literature, except for paper [12], there are not any other publications devoted to the determination of the thresholds of the perception of frequency changes occurring in signals with a decaying envelope. Bearing this in mind, investigations were undertaken to determine the thresholds of the perception of jump frequency changes occurring in a signal with an exponential envelope. These investigations have essentially a strictly cognitive character. Nevertheless, it should be pointed out that their results can also be of practical significance in establishing e.g. the criterion of the perception of irregular frequency changes occurring for the decay of a signal in a room, whose existence was found in papers [5, 11, 13].

3. Purpose and range of the investigations, equipment and method of the measurement

3.1. *Purpose and range of the investigations*

The essential purpose of the investigations undertaken was to determine the thresholds of the perception by listeners of single and double frequency changes occurring in a signal with an exponential envelope, depending on the duration of these changes, their mutual time interval and the position of these changes with respect to the onset of the signal. The frequency change was assumed to denote jump frequency transition from a value f_0 to some value $f_0 \pm \Delta f$, which remains constant within a time interval ΔT_2 or ΔT_4 (see Fig. 2b), and returns to the value f_0 outside these intervals.

In the investigations carried out, the following signal parameters were assumed to be constant: the intensity level $L_0 = 82$ dB, the fundamental frequency $f_0 = 1000$ Hz, the signal duration $T = 1000$ ms (understood as the total duration of the electric signal) and the duration of the pause between two successive signals $\Delta T = 1500$ ms.

The whole of the investigations was divided into two parts. In the first, attempts were made to determine the thresholds of the listeners' perception of only a single jump frequency change. In this part of the investigations, the variable parameters were the duration of the frequency jump ΔT_2 and the time interval ΔT_1 between this jump and the onset of the signal (see Fig. 2). In the second part of the investigations, attempts were made to determine the threshold of the perception of a single jump frequency change, in the presence of another jump frequency change, in a signal with the predescribed parameters ΔT_1, ΔT_2, Δf_1 (see Fig. 2). In these investigations, the following scheme of changes, frequency jumps, was assumed:

– the first change – predescribed (with a value over or below the threshold);

– the second change, whose threshold of perception was determined.

The time parameters defining the second change were:
ΔT_3 – the time interval between the frequency changes – and ΔT_4 – the duration of the second frequency change.

3.2. *Equipment and method of the measurement*

Fig. 1 shows a schematic diagram of the equipment set-up used to investigate the thresholds of the perception of jump frequency changes occurring in a signal with an exponential envelope. The basic unit of this set-up was the generator of a tone with an exponential envelope *2*, which was voltage controlled, due to which it was possible to obtain any changes in the output frequency of this generator in the direct proportion to the voltage fed to the control input. By means by a pulse, the generator *2* triggered the work of the generator of control processes *4*, which in turn generated the desired voltage process. This process was fed to the control input of the generator *2*, caused a signal with determinate – in terms of value and duration – changes, frequency jumps, to occur at its output (see Fig. 2b). The other elements of the measurement system consisted of a set of digital meters serving for continuous control of the time parameters of the signal and for continuous control of frequency, all of its time fragments. The set-up was complemented by signalling boards for mutual communication between the listeners and the experimentator. Fig. 2 shows schematically the sinusoidal signal with an exponential envelope (with a growth time of 50 ms) and jump variable frequency, obtained at the

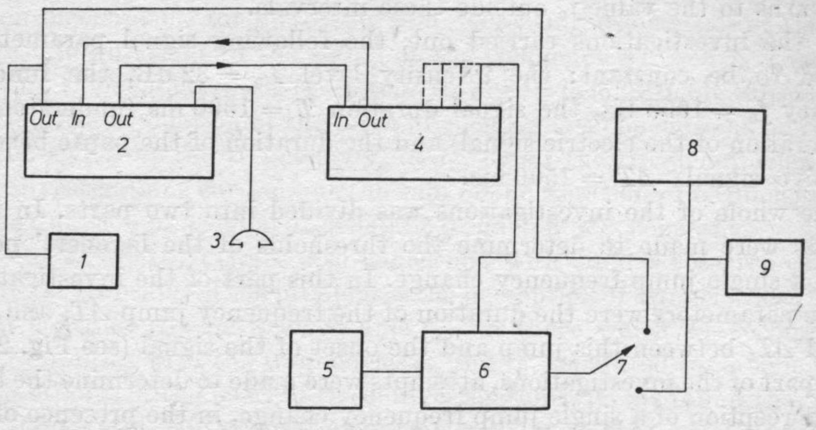

Fig. 1. Schematic diagram of the measurement system, *1* – digital frequency meter, *2* – generator of sinusoidal tone voltage-controlled, *3* – headphones, *4* – generator of control processes, *5* – impulse counter, *6* – time gate, *7* – switch, *8* – generator of the standard tone, *9* – frequency meter

output of the measurement system. In this signal, the following parameters could be modified independently:

– the value and direction of the frequency changes (jumps) Δf with respect to the frequency f_0 filling the signal;

– the duration of the particular frequency changes ΔT_2 and ΔT_4;

– the time interval between these changes ΔT_3;

– the time interval between the frequency change and the signal onset, ΔT_1.

As a result of calibration of the equipment set-up described above, it was found that the error of the frequency measurement at any time fragment of the output signal did not exceed 0.2 Hz, whereas the error involved in the measurement of the time interval distinguished in the signal fell within 0.2 ms.

The following method was applied in the investigations. The listener was asked to evaluate a pair of decaying signals in exponential envelopes. The first in the pair was the standard with a constant frequency of 1000 Hz, whose occurrence was signalled to the listener by a light signal; the other was a test signal containing a jump frequency change. (In turn, in determining the threshold of the perception of a double frequency change, the standard was a signal containing an appropriately chosen frequency change (see section 4.2).)

The listener's task was to state whether he noticed a difference in sound between the standard and the test signal.

The threshold values of the perception of frequency changes were determined from two measurement series:

– descending series (↓) – beginning from large values of frequency changes (jumps), always noticed by the listeners, decreasing it by 1 Hz from signal to signal, until the answer "I can hear the test signal without deformation" was obtained;

– ascending series (↑) – beginning from low values of frequency changes (jumps) and increasing it by 1 Hz from signal to signal, until the answer "I can hear the test signal with some deformation" was obtained.

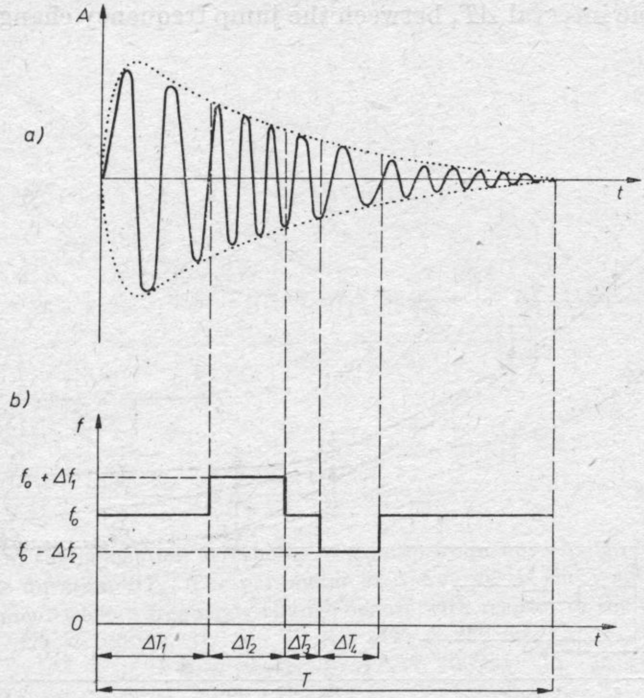

Fig. 2. Time history of the signal obtained at the output of the measurement system (*a*) and the corresponding frequency changes (jumps) (*b*)

The threshold value of frequency changes was determined for one pair of signals ΔT_1 and ΔT_2 on the basis of 10 descending and 10 ascending series. In view of the different mean values for the two series, first a variance analysis (Snedecor F-test) to verify whether the results obtained came from one population) and a test of agreement between the mean values, at the significance level $\alpha = 0.01$, were carried out. These tests gave affirmative results, permitting joint consideration of the results from the two series.

Two listeners, *AF* and *AS*, with audiologically correct hearing, took part in the investigations. A single measurement series did not exceed 15 minutes, and, moreover, over 3 hours no more than 4 series of this type were performed.

4. Measurement results and their analysis

4.1. The threshold of perception of a single jump frequency change

As was already mentioned above, in the first part of the investigations, attempts were made to determined the thresholds of the perception of a single jump frequency change which always occurred towards frequencies lower than the frequency filling the signal. These thresholds were determined, depending on:

— the duration ΔT_2 of the lowered frequency,

— the time interval ΔT_1 between the jump frequency change and the onset of the signal.

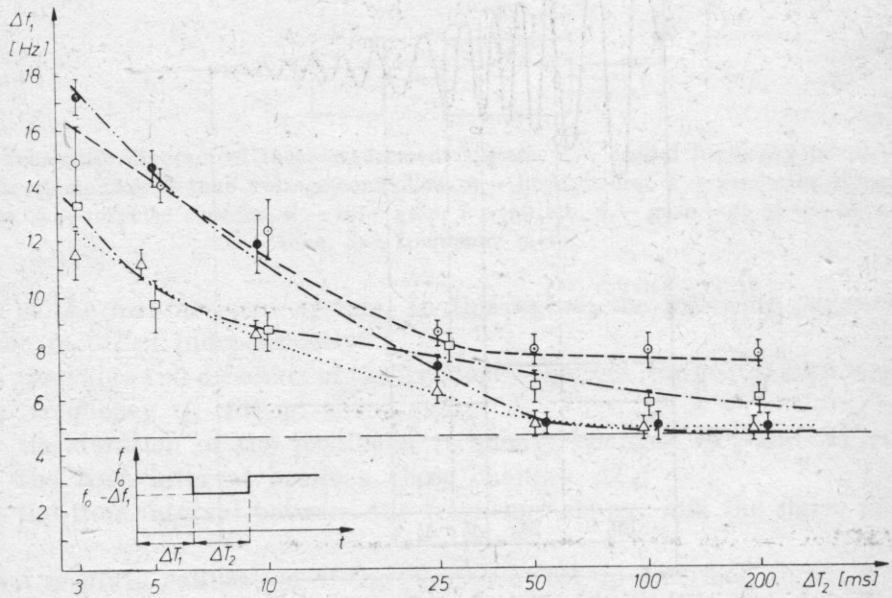

Fig. 3. Courses of the perception thresholds of a jump frequency change for the listener *AF*, depending on its duration ΔT_2, The parameter of the curves is the value of the time ΔT_1, defining the moment when a frequency change occurs with respect to the onset of the signal. ⊙ — — — — $\Delta T_1 = 100$ ms, □ — · — · — $\Delta T_1 = 250$ ms, △ . . . . . $\Delta T_1 = 450$ ms, ● — · · — · · — $\Delta T_1 = 700$ ms

The results obtained in this part of the investigations are shown in Figs 3, 4, 5 and 6, where, apart from the mean values, the standard deviations are also indicated. Figs 3 and 4 show the dependencies of the threshold of the perception of jump frequency change on its duration ΔT_2, respectively, for the listeners *AF* and *AS*. The parameter of these thresholds is the time interval ΔT_1 between the onset of the signal and the moment when the frequency jump occurs. Analysis of the data given in these figures shows that the thresholds of the perception of frequency changes are qualitatively similar for all the values of the parameter ΔT_1 and for the two listeners. Thus, it can be stated, in general, that as the duration of the jump frequency change decreases, the threshold of the perception of this change is increasingly high; moreover, for very short durations ΔT_2 of the order of 3 ms, it falls between 12–17 Hz. This

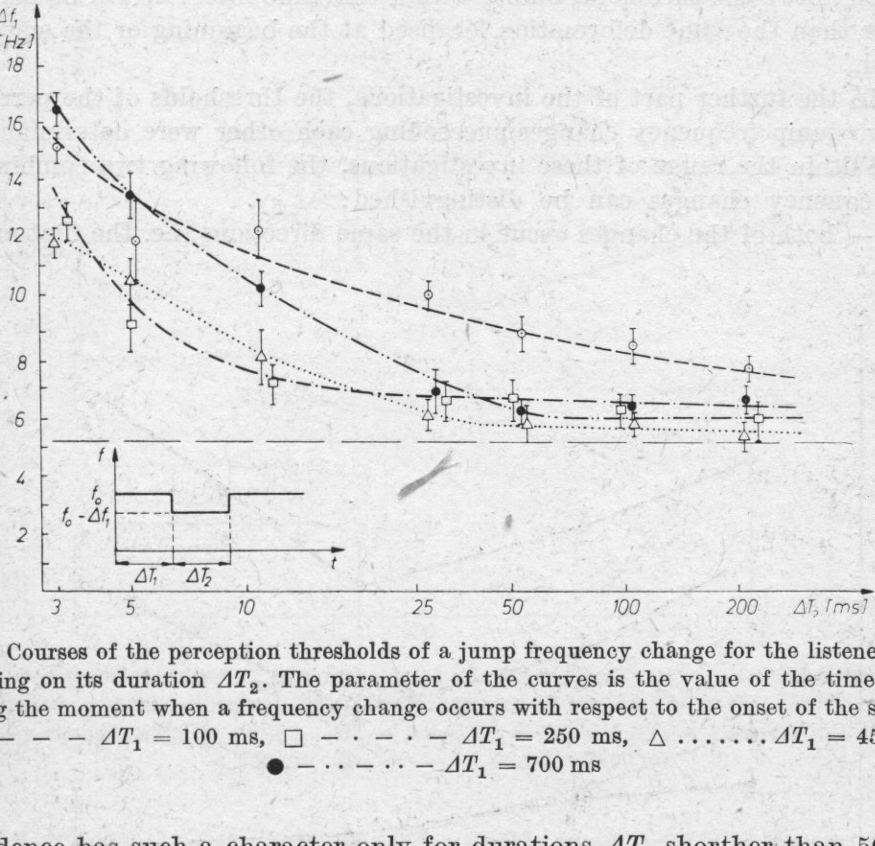

Fig. 4. Courses of the perception thresholds of a jump frequency change for the listener *AS*, depending on its duration ΔT_2. The parameter of the curves is the value of the time ΔT_1, defining the moment when a frequency change occurs with respect to the onset of the signal· ⊙ — — — — $\Delta T_1 = 100$ ms, □ — · — · — $\Delta T_1 = 250$ ms, △ ...... $\Delta T_1 = 450$ ms, ● — · · — · · — $\Delta T_1 = 700$ ms

dependence has such a character only for durations ΔT_2 shorther than 50 ms, whereas above this value an increase in the duration ΔT_2 does not any more cause a change in the threshold value. This value remains constant, falling between 5–7 Hz. The existence of this finite and nonzero limit of the dependence discussed admits the presence in the decaying signal, of jump frequency changes with values below 5 Hz, which the listener never notices, irrespective of the duration of these changes. It seems interesting to verify the validity of this statement in relation to the perception of real sounds of speech or music.

Figs 5 and 6 show the thresholds of the perception of jump frequency changes, depending on the time interval ΔT_1. The parameter of these data is the duration of the frequency changes, ΔT_2. Just as in the previous case, the course of the thresholds in the case of the changes ΔT_1 is qualitatively similar for all the values of the parameter ΔT_2 and for the two listeners. It is interesting to note the fact that these thresholds have a characteristic minimum contained in the interval $\Delta T_1 \in (200\text{–}500\ \text{ms})$, and, moreover, this minimum is more distinct for shorter durations of the frequency change, ΔT_2. This fact suggests that for a signal decaying exponentially over this time interval, the hearing organ exhibits the best ability of perceiving frequency changes, i.e. any frequency deformation above the threshold, falling within this time interval, will be perceived better than the same deformation localised at the beginning or the end of the signal.

In the further part of the investigations, the thresholds of the perception of two jump frequency changes succeeding each other were determined.

Within the range of these investigations, the following two combinations of frequency changes can be distinguished:

— both of the changes occur in the same directions (i.e. the first and the

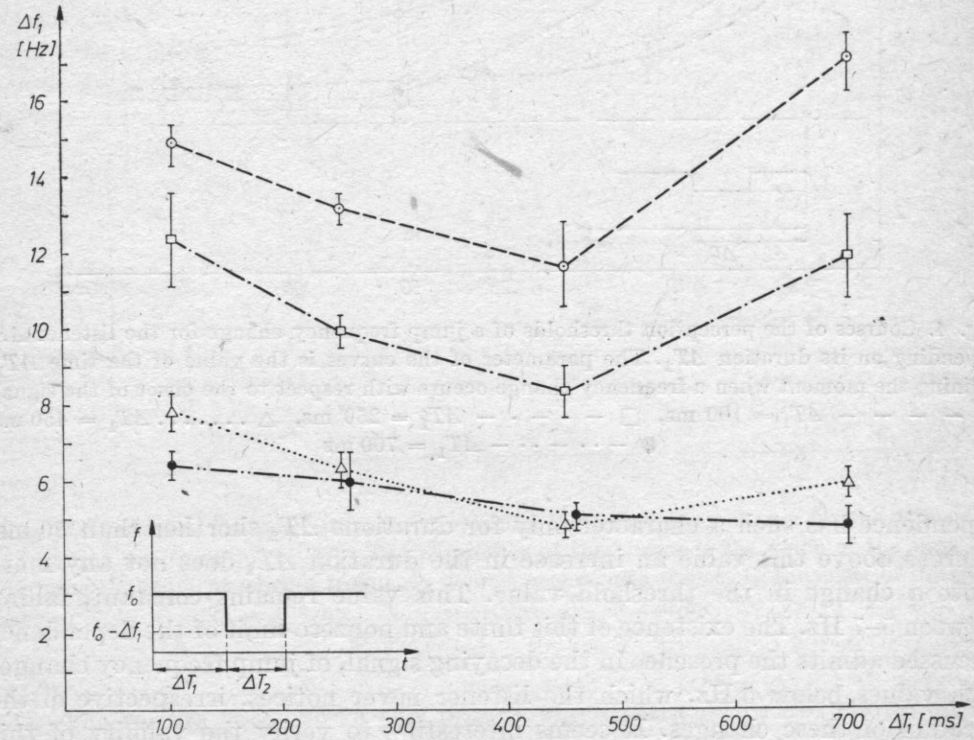

Fig. 5. Courses of the perception thresholds of a jump frequency change for the listener AF, depending on the time interval ΔT_1. The parameter of the curves is the duration of the frequency change, ΔT_2. ⊙ — — — $\Delta T_2 = 3$ ms, □ — · — · — $\Delta T_2 = 10$ ms, △ . . . . $\Delta T_2 = 200$ ms, ● — · · — · · — $\Delta T_2 = 500$ ms

second changes are temporary increases or decreases in frequency with respect to the frequency filling the signal);

— the changes occur in the opposite directions (i.e. the first change occurs towards higher frequencies, the second towards lower ones, with respect to the frequency filling the signal).

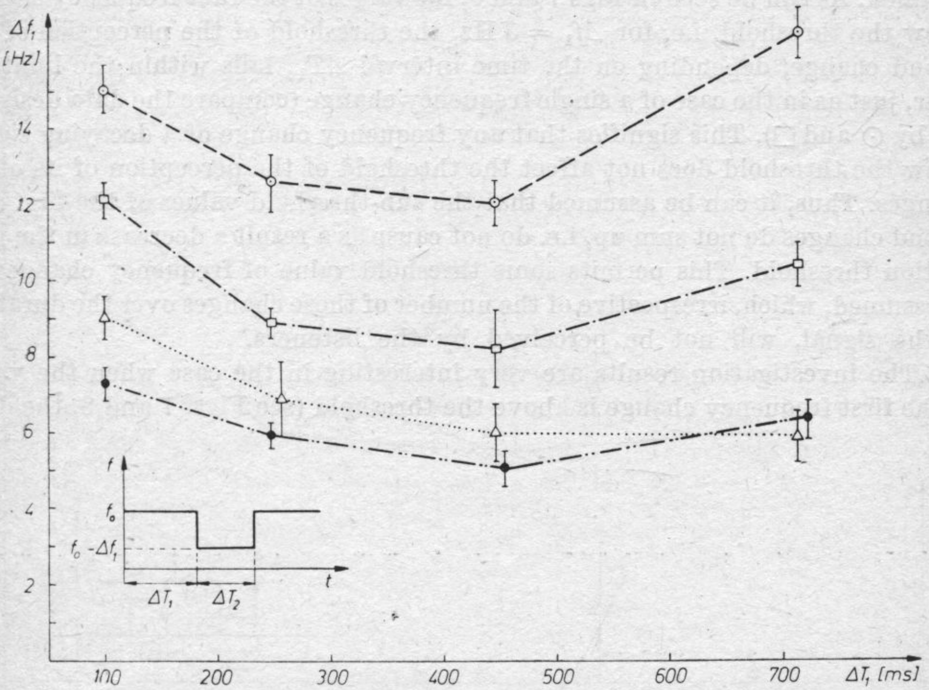

Fig. 6. Courses of the perception thresholds of a jump frequency change for the listener AS depending on the time interval ΔT_1. The parameter of the curves is the duration of the frequency change, ΔT_2. ⊙ — — — $\Delta T_2 = 3$ ms, □ — · — · — $\Delta T_2 = 10$ ms, △ . . . . $\Delta T_2 = 200$ ms, ● — · · — · · — $\Delta T_2 = 500$ ms

4.2. *Threshold of the perception of a double jump frequency change*

4.2.1. *Jump frequency changes occurring in the same directions*

The purpose of the investigations performed was to discover the mutual interactions of two jump frequency changes succeeding each other. In these investigations, with the predescribed time intervals $\Delta T_1 = 250$ ms, $\Delta T_2 = \Delta T_4 = 25$ ms and the predescribed value Δf_1 of the first change, the threshold of the perception of the second frequency change was determined, depending on the value ΔT_3 defining the time interval between these changes. In the first case, the value of the first frequency change Δf_1 was 5 Hz (below the threshold) and 10 Hz in the second case (above the threshold).

The two changes – frequency jumps – introduced were always made towards frequencies lower than that filling the signal. The results of these investigations are shown in Fig 7 and 8. In those two figures, the symbol ⊙ denotes in addition the values of the threshold of the perception of a single frequency change with the duration $\Delta T_2 = 25$ ms, facilitating comparison of the results obtained. As can be seen in Figs 7 and 8, for values of the first frequency change below the threshold, i.e. for $\Delta f_1 = 5$ Hz, the threshold of the perception of the second change, depending on the time interval ΔT_1, falls within the limits of error, just as in the case of a single frequency change (compare the data designated by ⊙ and □). This signifies that any frequency change of a decaying signal below the threshold does not affect the threshold of the perception of its other changes. Thus, it can be assumed that the sub-threshold values of the first and second changes do not sum up, i.e. do not cause as a result a decrease in the perception threshold. This permits some threshold value of frequency changes to be assumed, which, irrespective of the number of these changes over the duration of the signal, will not be perceived by the listeners.

The investigation results are very interesting in the case when the value of the first frequency change is above the threshold (see Figs. 7 and 8, the data

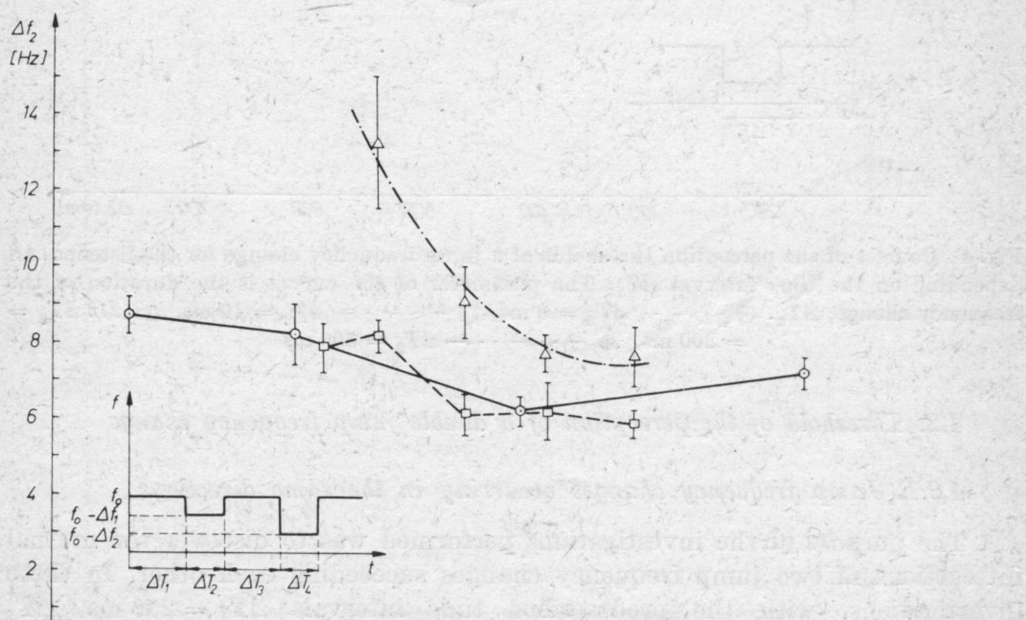

Fig. 7. Courses of the perception thresholds of two jump frequency changes occurring in the same directions, for the listener AF, depending onthe value of the time ΔT_3. ⊙ – – – threshold of perception of single change, □ – – – $\Delta f_1 = 5$ Hz, △ – · – · – $\Delta f_1 = 10$ Hz, $\Delta T_2 = \Delta T_4 = 25$ ms, $\Delta T_1 = 250$ ms

marked by Δ). It is then that the existence of the value of the first frequency change above the threshold causes a considerable increase in the threshold of the perception of the succeeding change. The increase in this threshold is the greater, the shorter is the time interval ΔT_3 between these changes. These experimental data can be interpreted in the light of the phenomenon of the second change being "masked" by the first one. It follows from the above

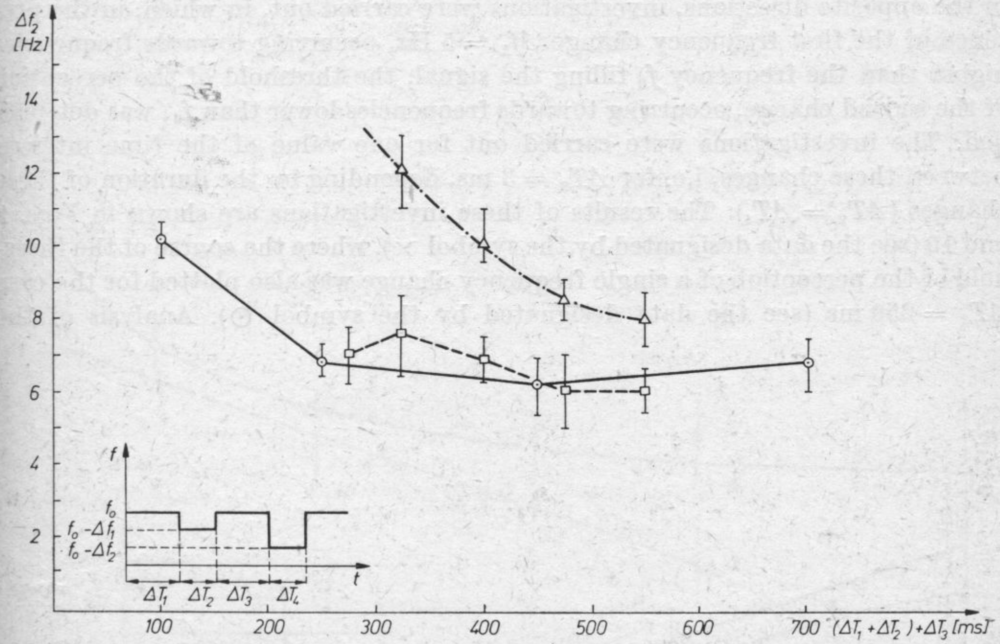

Fig. 8. Courses of the perception thresholds of two jump frequency changes occurring in the same directions, forthe listener AS, depending on the value of the time ΔT_3. ⊙ ——— threshold of perception of single change, □ — — — $\Delta f_1 = 5$ Hz, △ — · — · — $\Delta f_1 = 10$ Hz, $\Delta T_2 = \Delta T_4 = 25$ ms, $\Delta T_1 = 250$ ms

considerations that of two just perceptible frequency changes lying close to each other on the time scale, only the first will be perceived by the listener. This phenomenon permits the classiffication of some signal frequency changes above the threshold as imperceptible, on the condition, however, that these changes follow each other with only a slight (about 50 ms) shift in time.

Another aspect of the phenomenon discussed here is the problem of the listeners' perception of two frequency changes succeeding each other, both with values above the threshold. Thus, it follows from the listeners' report that it is very difficult to perceive the second frequency change when these changes lie close to each other on the time scale. Nonetheless, in general, it was possible to find that for durations ΔT_3 longer than 50 ms, the two jump frequency changes with values above the threshold are perceived separately by the listeners.

4.2.2. *Jump frequency changes occuring in the opposite directions*

In order to grasp the cooperation of two jump frequency changes occurring in the opposite directions, investigations were carried out, in which, in the presence of the first frequency change $\Delta f_1 = 5$ Hz, occurring towards frequencies higher than the frequency f_0 filling the signal, the threshold of the perception of the second change, occurring towards frequencies lower than f_0, was determined. The investigations were carried out for one value of the time interval between these changes, i.e. for $\Delta T_3 = 3$ ms, depending on the duration of these changes ($\Delta T_2 = \Delta T_4$). The results of these investigations are shown in Figs. 9 and 10 (see the data designated by the symbol $\times$), where the course of the threshold of the perception of a single frequency change was also plotted for the case $\Delta T_1 = 250$ ms (see the data designated by the symbol $\odot$). Analysis of the

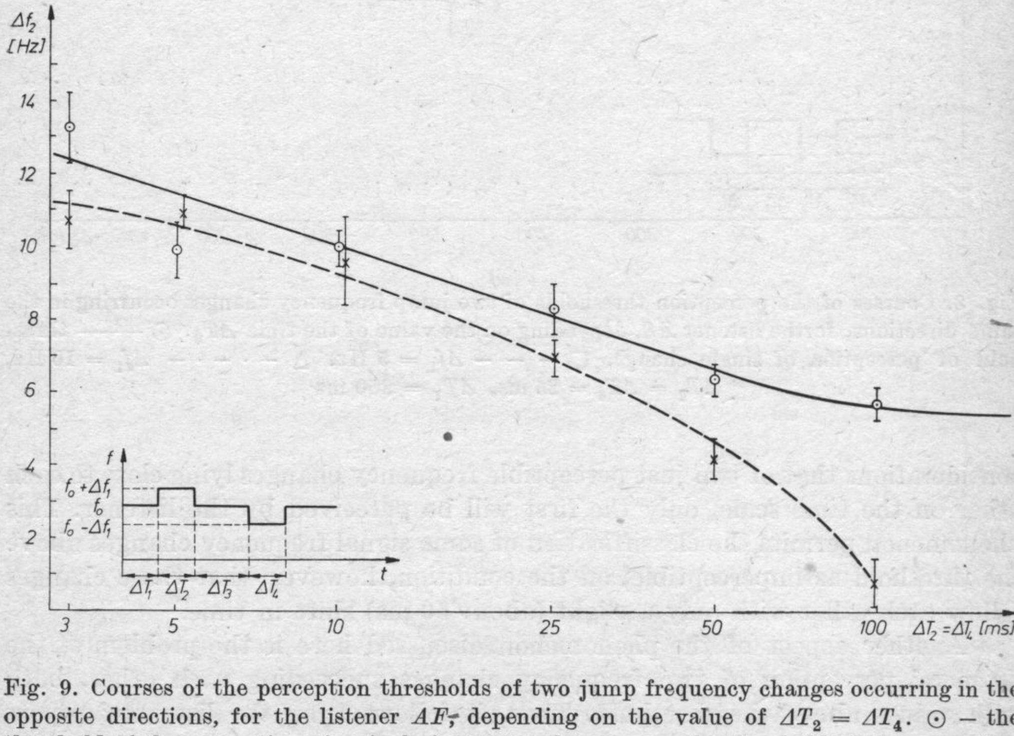

Fig. 9. Courses of the perception thresholds of two jump frequency changes occurring in the opposite directions, for the listener *AF*, depending on the value of $\Delta T_2 = \Delta T_4$. $\odot$ – the threshold of the perception of a single frequency change, x – the threshold of the perception of the second frequency change for the perscribed first change. $\Delta T_1 = 250$ ms, $\Delta T_3 = 3$ ms

course of the thresholds shown in these figures indicates that they are qualitatively similar, for both listeners, and, moreover, in these courses, two characteristic time intervals can be distinguished:

— the interval $\Delta T_2 = \Delta T_4 \in (3\text{–}30 \text{ ms})$, where the threshold of the perception of the second change is independent of the occurrence of the first change;

— the interval $\Delta T_2 = \Delta T_4 > 30$ ms, where the effect of the first frequency change is seen in the continuous decrease in the threshold of the perception of the second change.

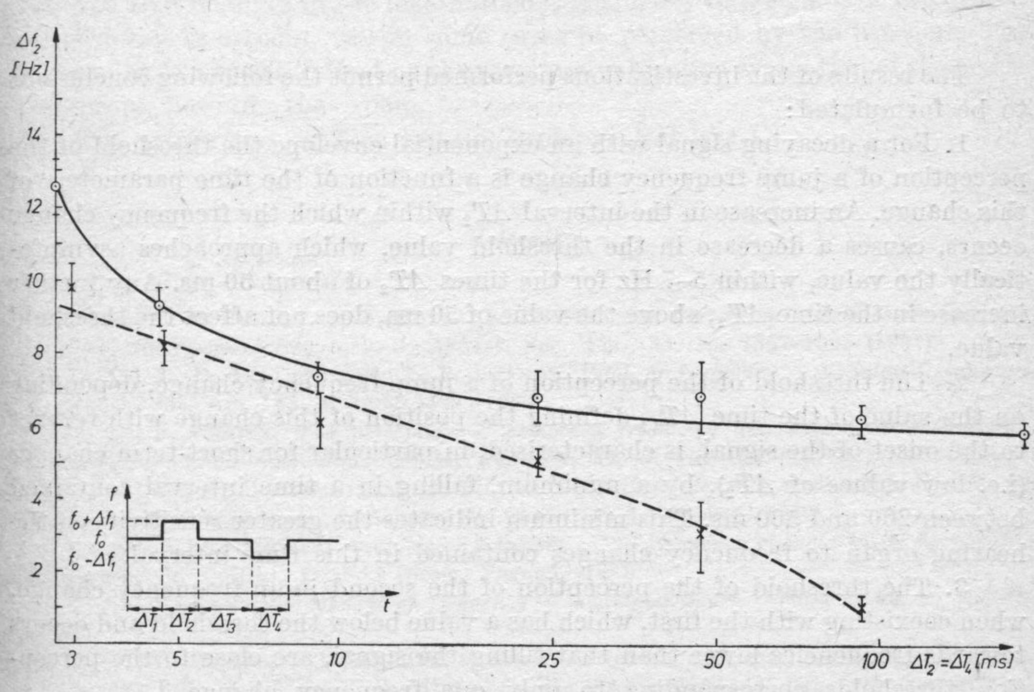

Fig. 10. Courses of the perception thresholds of two jump frequency changes occurring in the opposite directions, for the listener *AS*, depending on the value of $\Delta T_2 = \Delta T_4$. ⊙ — the threshold of the perception of a single frequency change, x — the threshold of the perception of the second frequency change with the prescribed first change. $\Delta T_1 = 250$ ms, $\Delta T_3 = 3$ms

Such a course of the thresholds signifies that for very short durations (up to 30 ms) of frequency changes of the order of $|\Delta f_1| = |\Delta f_2| = 5$ Hz, occurring in the opposite directions, these changes will not be perceived by the listeners.

It is not fully possible to refer the results presented above to those contained in the literature, since there are no publications on the perception of jump frequency changes in signals with amplitude varying in time. As was already mentioned in section 1, the existing papers on the perception of frequency changes are concerned with the thresholds of the perception of frequency modulation [19], the evaluation of the pitch of signals with frequency varying in time [2, 14], the difference pitch thresholds [17], or the evaluation of the pitch of signals with intensity and frequency varying in time [1], and, moreover, the changes in the respective physical parameters are far greater than the threshold values.

5. Final conclusions

The results of the investigations performed permit the following conclusions to be formulated:

1. For a decaying signal with an exponential envelope the threshold of the perception of a jump frequency change is a function of the time parameters of this change. An increase in the interval ΔT_2 within which the frequency change occurs, causes a decrease in the threshold value, which approaches asymptotically the value, within 5–7 Hz for the times ΔT_2 of about 50 ms. Any further increase in the time ΔT_2, above the value of 50 ms, does not affect the threshold value.

2. The threshold of the perception of a jump frequency change, depending on the value of the time ΔT_1, defining the position of this change with respect to the onset of the signal, is characterised, in particular for short-term changes (i.e. low values of ΔT_2), by a minimum, falling in a time interval contained between 200 and 500 ms. This minimum indicates the greater sensitivity of the hearing organ to frequency changes contained in this time interval.

3. The threshold of the perception of the second jump frequency change, when coexisting with the first, which has a value below the threshold and occurs towards frequencies lower than that filling the signal, are close to the perception thresholds corresponding to only one frequency change.

4. The occurrence of two jump frequency changes occurring in the same direction, is accompanied by the phenomenon of "masking", causing an increase in the threshold of the perception of the second change, in the case when the first one has a value above the threshold. It follows from this fact that some signal frequency changes can be recognized as imperceptible, even when they are greater in value than the changes "masking" them, on the condition that the time interval between these changes does not exceed the value $\Delta T_3 = 50$ ms.

5. The threshold of the perception of two jump frequency changes occurring in the opposite directions is, on the assumption that the value of the first of them is below the threshold, determined by the parameters of the two changes. It was found that for short durations of these changes, $\Delta T_2 = \Delta T_4 < 30$ ms, localised close to each other in time ($\Delta T_3 = 3$ ms), the occurrence of the first change does not affect essentially on the threshold of the perception of the

second change. Thus, the role of the sub-threshold frequency change in the definition of the value of the threshold of the second frequency change is slight. In turn, for the times $\Delta T_2 = \Delta T_4 > 30$ ms, the effect of the first frequency change already becomes quite large, causing a considerable decrease in the value of the threshold of the second change.

In conclusion, it is interesting to note that the values of the thresholds of the perception of frequency changes obtained in these investigations, are lower than some changes of the so-called instantaneous frequency, occurring in the process of sound decay in a room [5, 11, 13]. Thus, on this basis, it can be believed that changes in the instantaneous frequency of a signal, in the process of its decay in a room, will in some cases be perceived by the listeners. This fact can have a specific effect on the resultant subjective evaluation of the acoustic properties of the room.

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