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DYNAMIC APPROACH TO SOUND PITCH*

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Theoretical considerations have provided an analytical expression describing simultaneous changes of the intensity and pitch of the signal emitted by a moving source. Experimental investigations of the perceptibility of the sound-pitch changes accompanied simultaneously by appropriate intensity changes have confirmed mutual coupling of these two quantities in the process of the formation of a general sonic impression. A qualitatively new effect of automasking has been observed and shown to consist in an interaction of the two varying psychoacoustic parameters in the process of sound perception.

1. Introduction

The existence of the Doppler effect leads, from the psychoacoustic point of view, to the formation of complex sonic impression on an observer listening to the signal produced by a moving source. A simultaneous change of the momentary values of two physical parameters of the signal, i.e., its intensity and frequency leads to the formation of a sonic impression of variable intensity and pitch. In the case of a complex signal, a change of timbre occurs additionally.

The function for intensity changes and the corresponding frequency changes for two different velocities of a source of the sinusoidal tone of a frequency $f_0 = 1000$ Hz are presented in Fig. 1.

The source moves steadily along a straight line with respect to an immobile observer. The trajectory of the motion passes at a distance $d = 1$ m from the observer. The value $t = 0$ on the time axis is arbitrarily chosen and denotes the moment when the source passes the observer.

It follows from Fig. 1 that a continuous change of intensity (the right-hand side scale in dB) is accompanied by an almost stepwise change of frequency

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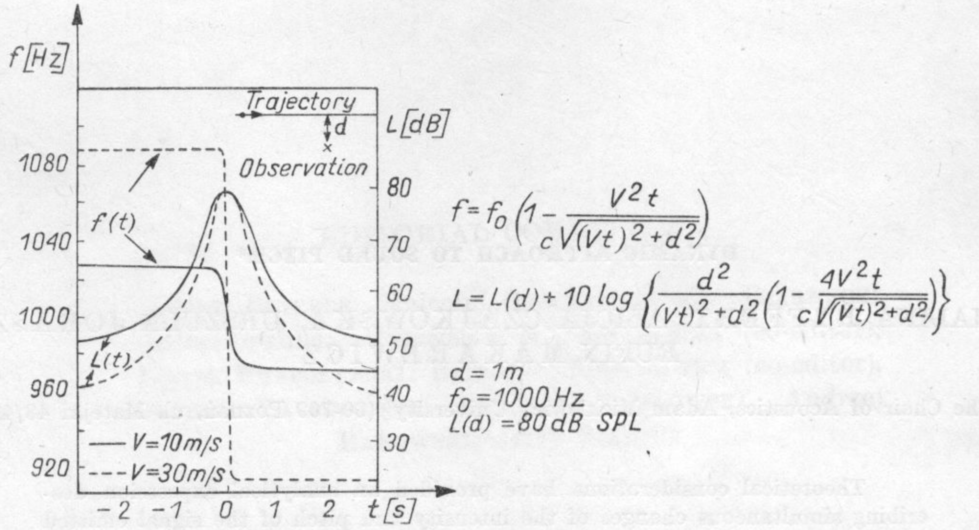

Fig. 1. The changes of intensity (the curves in the form of pulse) and the corresponding changes of frequency (the curves with a distinct fall) in the case of two different motion velocities of a sound source passing the observer

(the left-hand side in Hz). Both, the magnitude of the sudden frequency drop and the moment when it happens depend on the velocity of the source motion.

In our investigations we attempted to estimate the ability to perceive the pitch fall accompanied by continuous loudness changes due to intensity changes.

2. Measurement methods

The system designed for carrying out experimental investigations generated a signal of the form presented in Fig. 2. The duration of the frequency fall varied between 5 ms for $f = 2$ Hz to 10 ms for $f = 24$ Hz which was dictated by experimental facilities. It may be thus assumed that this duration was almost constant. No click was produced at the fall. The intensity pulse was formed photoelectrically. The signal had a form of the tone pulse with a predetermined envelope and a step-like change of carrier frequency. The signal intensity was controlled by a light beam masked by an appropriate diaphragm. The investigations were carried out for three different durations of intensity pulse, i.e., for $t_1 = 0.5$ s, $t_2 = 0.9$ s, and $t_3 = 1.3$ s. The pulse appeared against the background of a signal of a constant intensity lower by 20 dB than the maximum intensity of the signal pulse.

The duration of a single signal, including the time intervals with the appropriate background, preceding and following the intensity pulse was 6 s. The test presented to the observers in a single measurement series consisted

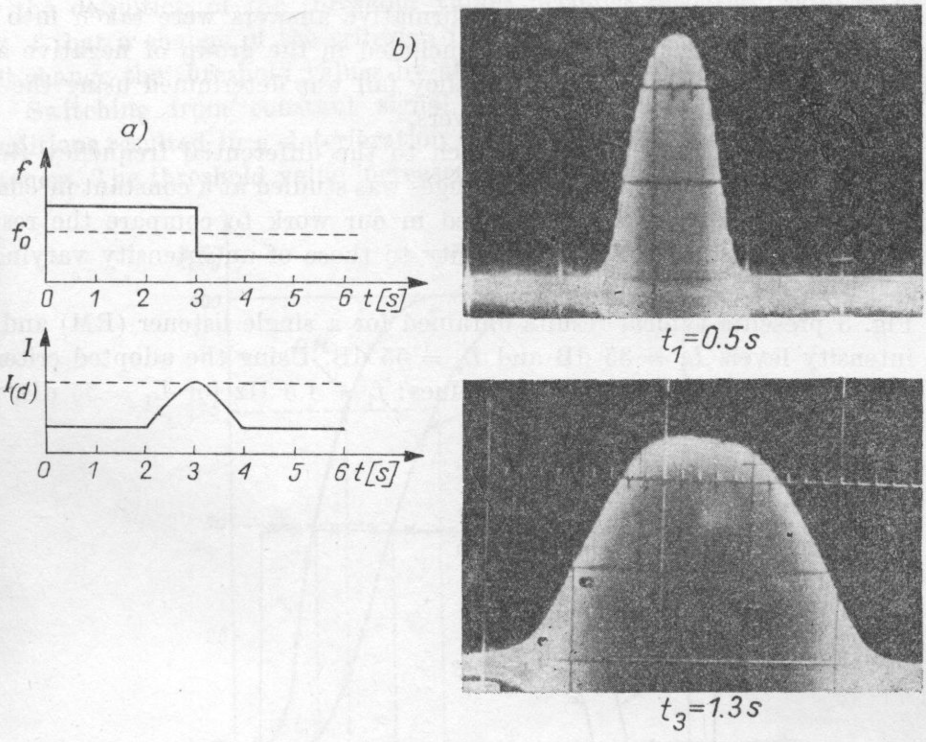

Fig. 2. (a) Schematic presentation of the course of a frequency fall accompanied by an appropriate intensity change. (b) The form of intensity pulses for two various pulse durations

of thirty nine 6-second signals. The interval between the signals, destined for an answer was 3 s. The course of intensity changes in a single measurement series was the same whereas the magnitude of the intensity fall was selected randomly in the range 0-24 Hz in 2 Hz steps. Individual series differed in the duration of intensity pulse and the value of the reference level with respect to the intensity. The dynamics of the process, expressed in dB remained unaltered.

The measurements were performed in a semi- anechoic room. The individual series of signals were tape-recorded and next reproduced from a GD 12/5 (5 W, 4 Ω) loudspeaker located at a height of the observer's head and at a distance of 1 m from him; 5 observers participated in the measurements (3 men and 2 women), 4 of them were musically trained. The observer's task was to evaluate each signal, i.e., to declare whether they had perceived a pitch or not.

3. Analysis of experimental results

The measurement results are presented in the form of diagrams. The values of frequency fall are plotted along the abscissa (the central frequency of each fall was $f_0 = 1000$ Hz) and the percentage of affirmative answers is plotted along the coordinate axis. Only the affirmative answers were taken into account. The hesitant answers [?] were included in the group of negative answers. The threshold value of the frequency fall was determined using the criterion of the 50 % of affirmative answers.

In the conventional, static approach to the differential frequency threshold, the perceptibility of frequency changes was studied at a constant intensity. Such investigations were also performed in our work to compare the results obtained in the case of constant intensity to those of an intensity varying in time.

Fig. 3 presents typical results obtained for a single listener (RM) and for two intensity levels $L_1 = 35$ dB and $L_2 = 55$ dB. Using the adopted criterion we obtained the following threshold values: $f_1 = 4.5$ Hz for $L_1 = 35$ dB, and $f_2 = 6.5$ Hz for $L_2 = 55$ dB.

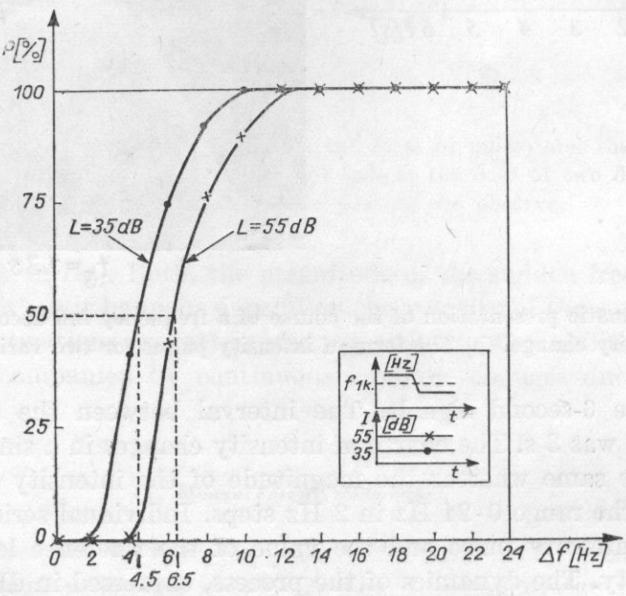

Fig. 3. The results of the preception measurements for a frequency fall of a constant-intensity signal for two various intensity values for a single observer (RM)

Thus, at a higher level of intensity, the threshold value of the perceivable frequency fall increased, i.e., this fall was more difficult to perceive.

The investigations have revealed significant individual differences between the results obtained for various observers. Fig. 4 presents typical results of the same investigations for two listeners (RM and HP) with the lowest and the highest threshold values (both persons were musically trained).

The differences occurred in the threshold value itself as well as in the scatter of answers revealing a certain weakness of perception. In view of a fairly large frequency range (exceeding 10 Hz in individual cases) the choice of the criterion for the definition of the threshold values becomes essential. It is seen from Fig. 4 that a change of the criterion from 50 % of affirmative answers to 75 % will change the threshold values by about 1.5 Hz (RM) and 2.5 Hz (HP).

Switching from constant signal intensity conditions to pulse-intensity conditions resulted in a deterioration of the frequency fall perceptibility for all listeners. The threshold value increased, the weak perception range broadened,

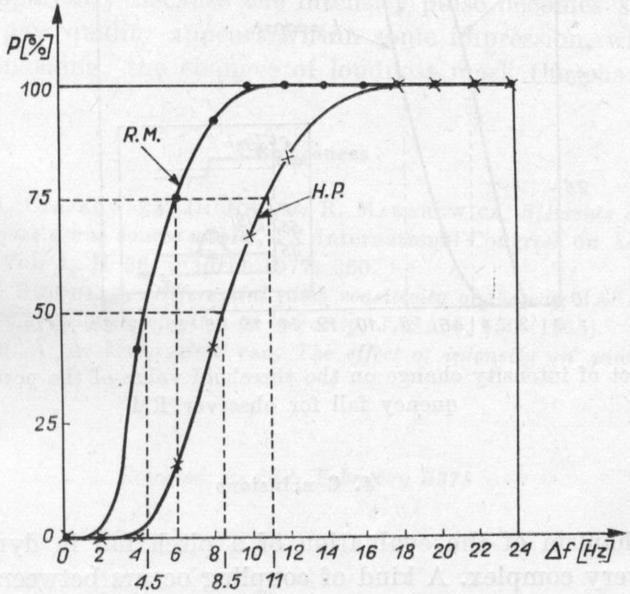

Fig. 4. Threshold values of frequency-fall perception at a constant intensity level for two observers: RM and HP

and some irregularities of psychometric curves began to appear. The increase of threshold values was different for different listeners and ranged between 1 Hz and 8 Hz. Fig. 5 presents a comparison of the results obtained for a single listener at a constant intensity level $L = 35$ dB and the results obtained in the case of an intensity pulse of a duration of 1.3 s. The increase of the threshold value amounted to 3.5 Hz for this observer (RM). The increase has even greater at higher intensity levels.

Not always did the results obtained in the conditions of intensity pulse yield such a regular curve and such a distinct deterioration of the threshold value. Particularly large discrepancies occurred in the case of an observer who was not musically trained.

It has been also found that the percentage of uncertain answers and the threshold value increase when the duration of intensity pulse decreases.

Frequently the intensity pulse itself gave the impression of a pitch fall even if the fall was absent (for instance, the observer with no musical training gave 40 % affirmative answers at $\Delta f = 0$ Hz).

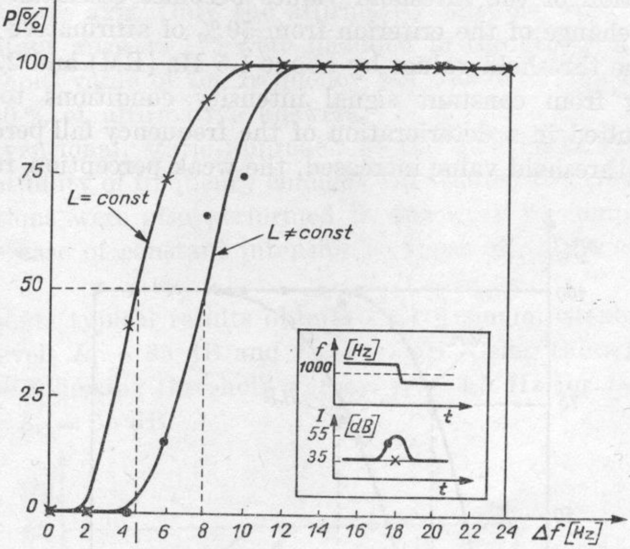

Fig. 5. The effect of intensity change on the threshold value of the perceptibility of a frequency fall for observer RM

4. Conclusions

The mechanism of the evaluation of a pitch fall in dynamic conditions seems to be very complex. A kind of coupling occurs between the impressions of loudness and pitch changes. The sonic impression is apparently dominated by the effect of loudness changes whereas the performed investigations required the observers to concentrate on the perception of a pitch fall. Thus it happened that loudness changes were perceived by the observers as pitch changes. Hence this type of investigation is very difficult to conduct with listeners with no musical training.

The problem of mutual relation between two psychoacoustical parameters: loudness and pitch was undertaken by Stevens [3] as early as in 1935. However, those investigations as well as subsequent attempts (cf. e.g. [4]) were limited to only static conditions. The observers compared loudness or the pitch of a tone of fixed parameters (intensity and frequency). The compensation method was used which balanced the difference in loudness by a change of the signal frequency. The results confirmed the mutual affect of the two psychoacoustic parameters on the formation of sonic impression. The investigations carried out in this work in dynamic conditions and thus concerned with the effect of loudness changes on the evaluation of pitch changes with the esential physical parameters of the signal continuously changing in time have confirmed the existence of a mutual coupling between the impression of loudness and pitch. In all dynamic conditions this coupling is very distinct and complex. It depends on the assumed theoretical model associating the changes of intensity with those of frequency. For instance, in the Doppler effect model, adopted in the present investigations, a decrease of intensity-pulse duration occurs simultaneously with the increase of the value of frequency fall. Thus it could be anticipated that the signal perceptibility should improve. Actually the experiment shows that the uncertainity of the observers as for the perception of a pitch fall increases, apparently because the intensity pulse becomes simultaneously steeper. Thus a new quality appears within sonic impression, which we could refer to as automasking: the changes of loudness mask the changes of pitch.

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