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GENERALIZED DISCRIMINATION THRESHOLDS AND EVALUATION OF SIMULTANEOUS VARIATIONS IN THE INTENSITY AND FREQUENCY OF A TONE

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The investigations presented in this paper were based on the concept of an interrelation between simultaneously evaluated variations in loudness and pitch of the same tonal signal with varying intensity and frequency. As an example, some elements of this interrelation – related to the perceptibility and to the evaluation of the magnitude of variations in loudness and pitch – were examined for a chosen tone. The results obtained were represented in the form of new, so-called generalized, discrimination thresholds and of the curve of the variations in loudness and pitch sensed to be equal. The results permit the statement that it is possible to sum up the subthreshold effects caused by the simultaneous variations in the signal intensity and frequency and thus to obtain the superthreshold effect in the form of a sensation of loudness variations. For greater variations in the physical parameters, a sort of mutual "masking" of the simultaneous variations in loudness and pitch of the same tone was found, and in the case when both variations were audible simultaneously it was found that it was possible to compare these in terms of magnitude.

1. Introduction

An analysis of the curves of equal loudness and the curves of equal pitch shows some interrelations between the variations in loudness and pitch of a tone. Both subjective characteristics of the tone, loudness and pitch, depend simultaneously on the two physical parameters of the tone, i.e. intensity and frequency. Therefore, in changing the loudness of the tone only by varying the intensity, it is difficult to avoid the simultaneous variation in the pitch of this tone over some ranges. And conversely, when changing the pitch of the tone by modulation of the frequency only, it is possible to achieve simultaneously a change in its pitch.

The investigations presented in this paper were based on the concept of the existence of some interrelation between the variations in loudness and pitch. This interrelation occurs in simultaneous evaluation of these two variations with respect to tonal signals in which simultaneous variations in intensity and frequency occur. It was acknowledged that this interrelation may be significant for deeper knowledge of the mechanism of forming the sensations of loudness and pitch of a tone and an attempt was made to analyze preliminarily some of its elements related to the sensation itself and to the evaluation of the magnitude of simultaneous variations in loudness and pitch.

The investigations consisted in experimental determination of discrimination thresholds different from the previously used, which were called generalized discrimination thresholds, and of curves resulting from an evaluation of variations in intensity and frequency, which were called the curves of variations in loudness and pitch sensed to be equal. It was decided that the investigations were to be performed, for example, for a given tone of 1100 Hz and 70 dB over the range of variation from 0 to 900 Hz and 0 to 20 dB, respectively.

It was decided that "the generalized discrimination thresholds" would refer to a threshold determined for signals in which variations of the two physical parameters, i.e. intensity and frequency, occur simultaneously. Those discrimination thresholds which were known previously and determined for signals involving variations in only one parameter: alternatively, frequency or intensity (the so called frequency discrimination thresholds or intensity discrimination thresholds), were called, in opposition to the new ones, the classical thresholds. Irrespective of considering this division of thresholds from the point of view of the number and quality of variable physical parameters of a signal under examination, it was decided, both in the case of the generalized and classical discrimination thresholds, to specify besides the threshold type the name of the psychoacoustic parameter whose variation undergoes estimation by listeners in terms of perceptibility. For example, "the intensity discrimination threshold for pitch variations" refers to the case when the listener evaluates the perceptibility of variations in pitch in a signal which shows intensity variations. In turn, e.g. "the generalized discrimination threshold for pitch variations" applies to the case when the listener estimates the perceptibility of pitch variations in a signal with simultaneous intensity and frequency variations.

An attempt was made to obtain the curves of variations in loudness and pitch sensed to be equal under the assumption that listeners can perform a kind of evaluation consisting in simultaneous comparison of totally different variations in loudness and pitch in terms of their magnitude.

2. Experimental investigation

In order to achieve in one experiment the data both for the generalized discrimination thresholds and for the curves of variations in loudness and pitch sensed to be equal, a special method of investigation permitting multiple simultaneous evaluation was developed.

An acoustic generator of the signal of the type *ABAB...* shown schematically in Fig. 1 was designed and constructed. This signal is a sequence of two-

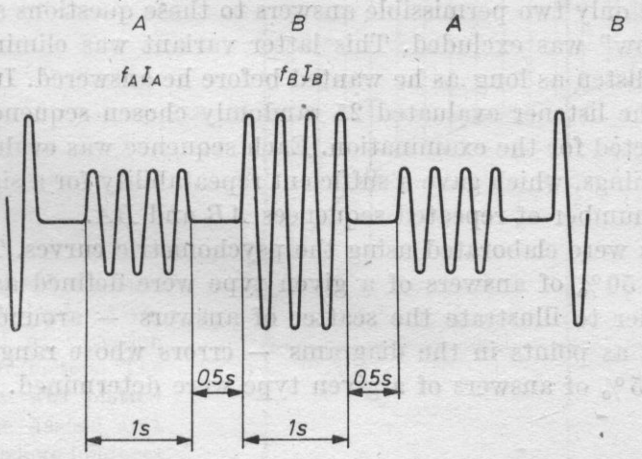

Fig. 1. The signal form used in the investigations

second tonal impulses *A* and *B* of almost rectangular envelope, generated alternatively and after half-second intervals, with the rise and decay times of the order of several milliseconds. In view of the duration of the impulses (and the intervals) these impulses can be simply regarded as tones. One also can neglect the effect on the evaluation of loudness and pitch of these tones, of the randomly changing phase of their start and interruption and the slight, hardly perceptible cracks occurring then. Two constants predetermined for it. and the differences occuring simultaneously between the tones *A* and *B*: in frequency (30 possibilities over the range 0 to 900 Hz) and in intensity (30 possibilities over the range 0 to 20 dB), correspond to a given sequence of tones. These differences were so chosen that in the case when both took values different from zero the tones of higher frequency also had higher intensity.

The signal was supplied to one of listener's ear by earphones in the audiometric booth.

The investigation involved three listerns with normal hearing and different musical ability, chosen from a larger number of listeners in the course of a preliminary examination which at the same time was a training session. In terms of their results these listeners were representative of the whole group examined. At the same time their answers were mostly dilligent, which was confirmed by the infrequent faults in the case of the sequences of the type *AAAA...*

In the case of each sequence *ABAB...* the task of each listener was to answer simultaneously the following three questions:

1. whether the tones *A* and *B* in a given sequence differ in loudness;

2. whether the tones A and B in a given sequence differ in pitch;

and when both of these differences were perceived:

3. which of the variations — in loudness or in pitch — was perceived as dominating.

There were only two permissible answers to these questions and the variant "I do not know" was excluded. This latter variant was eliminated since the listener could listen as long as he wanted before he answered. In a single listening session the listener evaluated 25 randomly chosen sequences of over 300 sequences selected for the examination. Each sequence was evaluated ten times in all the listenings, which gave a sufficient repeatability for a signal containing an unlimited number of repeated sequences AB and BA.

The results were elaborated using the psychometric curves. The values corresponding to 50% of answers of a given type were defined as the threshold values. In order to illustrate the scatter of answers — around the threshold values plotted as points in the diagrams — errors whose range corresponded to 25% and 75% of answers of a given type were determined.

3. Investigation results

The results obtained for three chosen listeners showed that despite individual quantitative differences the general trends of the answers were the same and that the same psychoacoustic effects occurred for all the three listeners. Therefore, the results were elaborated for each listener individually, and it was decided that the results of only one of them will be presented here, as an example typical of all the other listeners participating in the investigations. The results were represented as the curves of the generalized discrimination threshold for variations in loudness, the generalized discrimination threshold for variations in pitch, and the curve of variations in loudness and pitch sensed to be equal. In view of the singularity of psychoacoustic effects occurring for variations in the physical parameters of the order of the classical discrimination thresholds and for greater ones, a division into two ranges, called respectively range I and range II, was introduced.

Fig. 2 shows the generalized discrimination threshold for variations in loudness in range I of variability of the physical parameters. The value of the corresponding classical discrimination thresholds are marked on the co-ordinate axes by the dashed lines. It can be seen that the generalized discrimination threshold for variations in loudness occurs above the classical intensity discrimination threshold for variation in loudness and shows a monotonical increase with increasing the tone frequency simultaneous with the variations in intensity. The same trend also occurs in range II of variations in the physical parameters, i.e. for greater variations than the classical discrimination thresholds. This signifies that the occurrence of frequency variations in a signal may decrease the perceptibility of the variations in loudness resulting only from variations in the intensity of a tone and that in direct proportion to the increase in frequency variations.

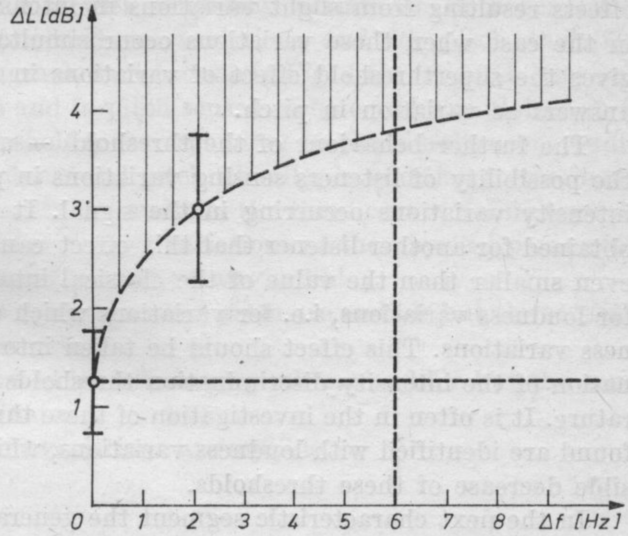

Fig. 2. The generalized discrimination threshold for loudness variations in range I of variation of the physical parameters. The scatter of answers was plotted every ± 25%. The dashed area denotes the region where loudness variations are audible

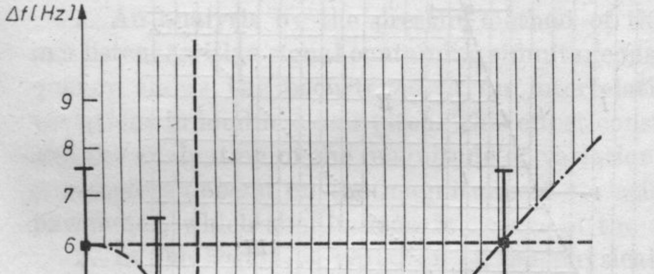

Fig. 3. The generalized discrimination threshold for pitch variations in range I of variations of the physical parameters. The scatter of answers was plotted every ± 25%. The dashed area denotes the region where loudness variations are audible

Fig. 3 shows the characteristic of the simultaneously determined generalized discrimination threshold for variations in pitch in range I. Several segments can be distinguished in this characteristic.

The first one shows a monotonical decrease in this threshold from the value of the classical frequency discrimination threshold for variations in pitch to the value $\Delta f = 0$ reached for a variation in intensity equal approximately to the value of the classical intensity discrimination threshold for variations in loudness. This decrease suggests the possibility of "summing up" the subthreshold effects resulting from slight variations in intensity and frequency of a signal in the case when these variations occur simultaneously. This "summing up" gives the superthreshold effect of variations in the signal, estimated in most answers as variation in pitch.

The further behaviour of the threshold — under the abscissa — suggests the possibility of listeners sensing variations in pitch as a result of only slight intensity variations occurring in the signal. It can be seen from the results obtained for another listener that this effect can occur for intensity variations even smaller than the value of the classical intensity discrimination threshold for loudness variations, i.e. for variations which do not cause perceptible loudness variations. This effect should be taken into consideration in the determination of the intensity discrimination thresholds as they are called in the literature. It is often in the investigation of these thresholds that all the variations found are identified with loudness variations, which evidently involves the possible decrease of these thresholds.

In the next characteristic segment the generalized discrimination threshold

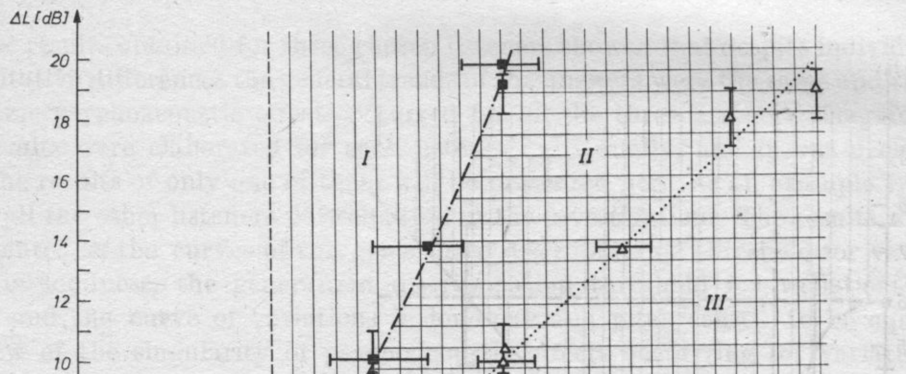

Fig. 4. A comparison of the generalized discrimination threshold for loudness variations —o—, the generalized discrimination threshold for pitch variations, —■—, and the curve of the variations in loudness and pitch sensed to be equal ...△... for range II of variation of the physical parameters. The scatter of answers was plotted every ± 25%

for pitch variations shows a monotonical increase also in range II of variation of the physical parameters. This signifies that the perception of pitch variations can worsen as a result of introduction into a signal of adequately great intensity variations simultaneous with frequency variations. Both generalized discrimination thresholds: for loudness variations and for pitch variations, can be represented in one diagram, as it is done in Fig. 4 for range II. The curve of the variations in loudness and in pitch sensed to be equal was plotted in the area between the above thresholds, corresponding to the simultaneous audibility of both variations in loudness and pitch. Finally, in addition to the inaudibility region, where no variations are audible, the three curves define the following regions in the investigated area of variations of the physical parameters:

range I where only loudness variations are audible;

range II where variations in loudness and pitch are audible but the sensation of loudness variations dominates;

range III where variations in loudness and pitch are audible but the sensation of pitch variations dominates;

range IV where only pitch variations are audible.

4. Conclusions

1. An analysis by the present method of the complex sensation produced in a listener with a signal containing simultaneous variations in intensity and frequency shows the occurrence of an interrelation between the simultaneous variations in loudness and pitch. This effect consists in that both the perception and the evaluation of the magnitude of variation of one of these psychoacoustic parameters depend on the magnitude of variation in the other psychoacoustic parameter, which simultaneously occurs in the same signal.

2. In the region of variation of the physical parameters near the classical discrimination thresholds, this interrelation can be seen in the form (see Fig. 3) of "summing up" of subthreshold variations in intensity and frequency, giving as a result a superthreshold variation evaluated by the listeners as pitch variation.

3. The lowering of the generalized discrimination threshold for pitch variations to the value $\Delta f = 0$ (see Fig. 3) is an effect which should be considered in the determination of the intensity discrimination thresholds as they are called in the literature.

It follows from the investigations performed that slight variations in the tone intensity can produce in a listener a sensation of pitch variation, and therefore, identification of the sensation resulting from intensity variation with only pitch variation can lead to a decrease of the thresholds mentioned above.

In this connection, the necessity mentioned in the introduction of ordering and newly specifying the terms in the field of discrimination thresholds is confirmed. It is essential that there should be no doubt as to which variable physical parameters of the signal the given thresholds relate, and with the evaluation of which psychoacoustic parameters they are connected.

4. The increase in the generalized discrimination thresholds both for pitch and loudness variations with respect to the classical discrimination thresholds (Fig. 4) signifies that as if mutual "masking" effect of simultaneous variations in loudness and pitch of the same signal occurs for variations of physical parameters greater than the classical discrimination thresholds.

5. The simultaneous variations in loudness and pitch of the same signal, despite their different nature, can be compared in terms of magnitude. The regularity and monotonical increase of the curve of variations in pitch and loudness sensed to be equal signifies that listeners are quite consistent in the evaluation, based on some standard pattern for the equality of both variations.

6. The effects found cannot be explained by using the curves of equal loudness and the curves of equal pitch, which suggests the particularity of the mechanisms of evaluating simultaneously the variations in loudness and pitch by the hearing organ. There are also no data in the literature which could be comparable enough with those obtained in the present investigations, since investigations of approximately similar problems are mostly fragmentary and diversified (cf. References), and the present approach is different from concepts proposed therein.

Interpretation of the results obtained in terms of the theory of hearing needs further accurate investigations to give a full quantitative image of the psychoacoustic effects and a deeper knowledge of the physiology of hearing.

7. The simultaneous variations in intensity and frequency are characteristic of the natural sounds of speech and music. It seems therefore possible to use, in the future, the results of investigations in this field, first of all in the acoustics of music and audiology, and also in the room acoustics.

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