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PITCH STRENGTH OF PURE TONES

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INTRODUCTION

Pitch can be assessed in terms of two different hearing sensations: on the one hand pitch height or magnitude, and on the other hand pitch strength or saliency. This means that two sounds can produce the same pitch (height), although they may differ considerably in pitch strength. Traditionally, pitch strength of sounds was inferred from measurements such as the precision of pitch matches (e.g. Rakowski, 1977), the modulation depth of comb-filtered noise (e.g. Yost and Hill 1978), and the identification rate of melodies (e.g. Houtsma 1983). However, using a method of magnitude estimation, pitch strength can be assessed directly. A survey (Fastl and Stoll 1979) of the pitch strength of rather different types of sounds showed that the most prominent pitch strength is produced by pure tones. In comparison to pure tones, complex tones produce about half the pitch strength, and filtered noise bands show a pitch strength which is by a factor of five to ten smaller. These small values of pitch strength are also found for amplitude-modulated broad band noise (Fastl 1981). However, rippled noise with sharp spectral peaks can elicit the same pitch strength as complex tones (Fastl 1988). The pitch strength of low-pass noise increases with the steepness of the correlated masking pattern (Fastl 1980). Although pitch strength of partially masked pure tones has been described (Hesse 1985), the pitch strength of unmasked pure tones is largely unknown. Therefore, the pitch strength of pure tones was measured as a function of test tone duration, level, and frequency. The results will be given in this paper and discussed in view of other psychoacoustic features of the hearing system, and practical applications.

EXPERIMENTS

Eight normal hearing subjects took part in the experiments. Their age was between 24 and 32 years (median 26 years). All sounds were presented diotically by electrodynamic earphones (Beyer DT 48) with a free-field equalizer (Zwicker and Feldtkeller 1967, p. 40). Tones were presented in pairs with the first tone in each pair fixed, serving as an anchor sound. The pitch strength of the anchor sound was assigned a number, e.g. 100, and relative to this number, the pitch strength of the respective second sound had to be evaluated. Within a pair, tones were separated by pauses of 500 ms duration; pauses between pairs were 1000 ms long. After the presentation of three pairs, the subject had to enter the corresponding number (e.g. 20 for a decrease in pitch strength by a factor of five) via a terminal into a PC. After the subject hit the "return" key, the next three sound pairs were presented. Further details about the procedure are described elsewhere (Fastl and Stoll 1979).

In a session, each comparison sound was presented four times in random order. From the resulting 32 data points of the eight subjects, medians and interquartiles were calculated, which are given in the figures.In each figure, the medians and interquartiles are normalized relative to the maximal median.

RESULTS AND DISCUSSION

Fig. 1 shows the dependence of the pitch strength of pure tones on duration. All test-tone bursts were cut out of a steady-state 1-kHz tone with 80 dB SPL, using a Gaussian-shaped gating signal with 3 ms rise/fall time. Two anchor sounds were used: One anchor with a duration of 1000 ms was asigned the number 100. The corresponding data are given in Fig. 1 as circles. The second anchor sound was a 1-kHz tone of 200 ms duration, assigned also the number 100. Since, however, the maximal median showed up at 1000 ms with a value of 130, all medians and interquartiles were multiplied by 0.77 (squares), in order to get 100 % relative pitch strength for the maximum. Both anchor sounds are indicated in Fig. 1 by filled symbols.

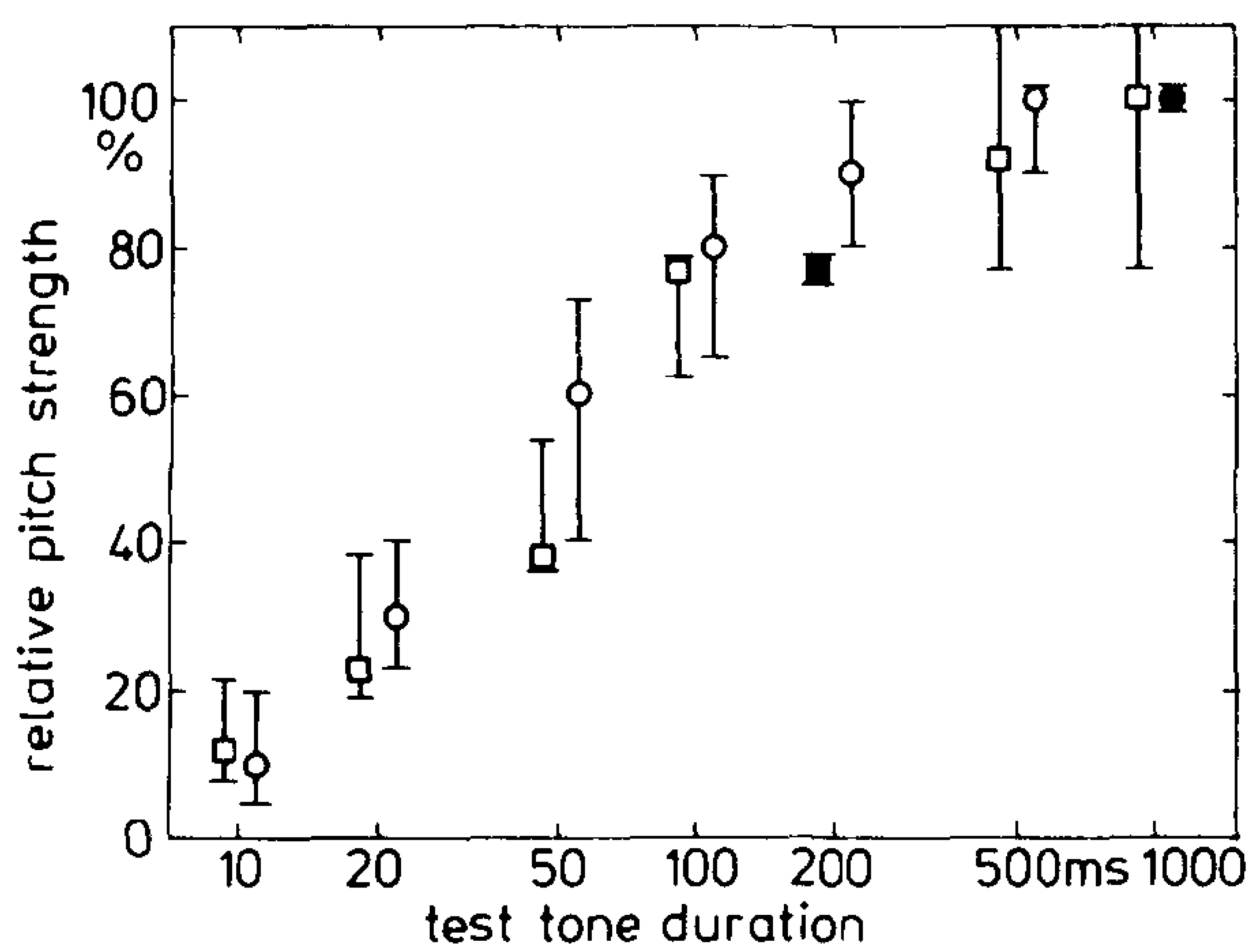

Fig.1: Pitch strength of pure tones as a function of test-tone duration. Test-tone frequency 1 kHz, test-tone level 80 dB.

The results displayed in Fig. 1 suggest an almost linear increase of pitch strength with the logarithm of test-tone duration up to a duration of about 300 ms. At that duration, pitch strength reaches its maximum and stays constant for even longer durations. This increase of pitch strength up to a "critical duration" (Zwicker 1974) can be compared with temporal integration in loudness: Up to a duration of about 100 ms, loudness increases with duration, but stays constant for longer durations. Fig. 2 shows the dependence of pitch strength on test-tone level for 1-kHz tones with 500 ms duration. Two anchor sounds were used: one with 30 dB SPL (circles) and the other with 70 dB SPL (squares). The anchors were assigned the numbers 50 and 100, respectively, and all data were normalized relative to the maximum pitch strength. Again, the anchor sounds are illustrated by filled symbols.

The results plotted in Fig. 2 suggest a linear increase of the pitch strength of pure tones with increasing test-tone level. Starting with a value of 40 % at 20 dB SPL, relative pitch strength increases by about 10 %

for each 10 dB increase in test-tone level. Whereas the pitch strength of a 1-kHz tone increases by a factor of 2.5 for an increase in level from 20 dB to 80 dB, the corresponding increase in loudness amounts to as much as a factor of 10. Therefore, the results plotted in Fig. 1 can not be understood in terms of the loudness reduction as a function of duration, but in addition an influence of spectral splatter has to be assumed.

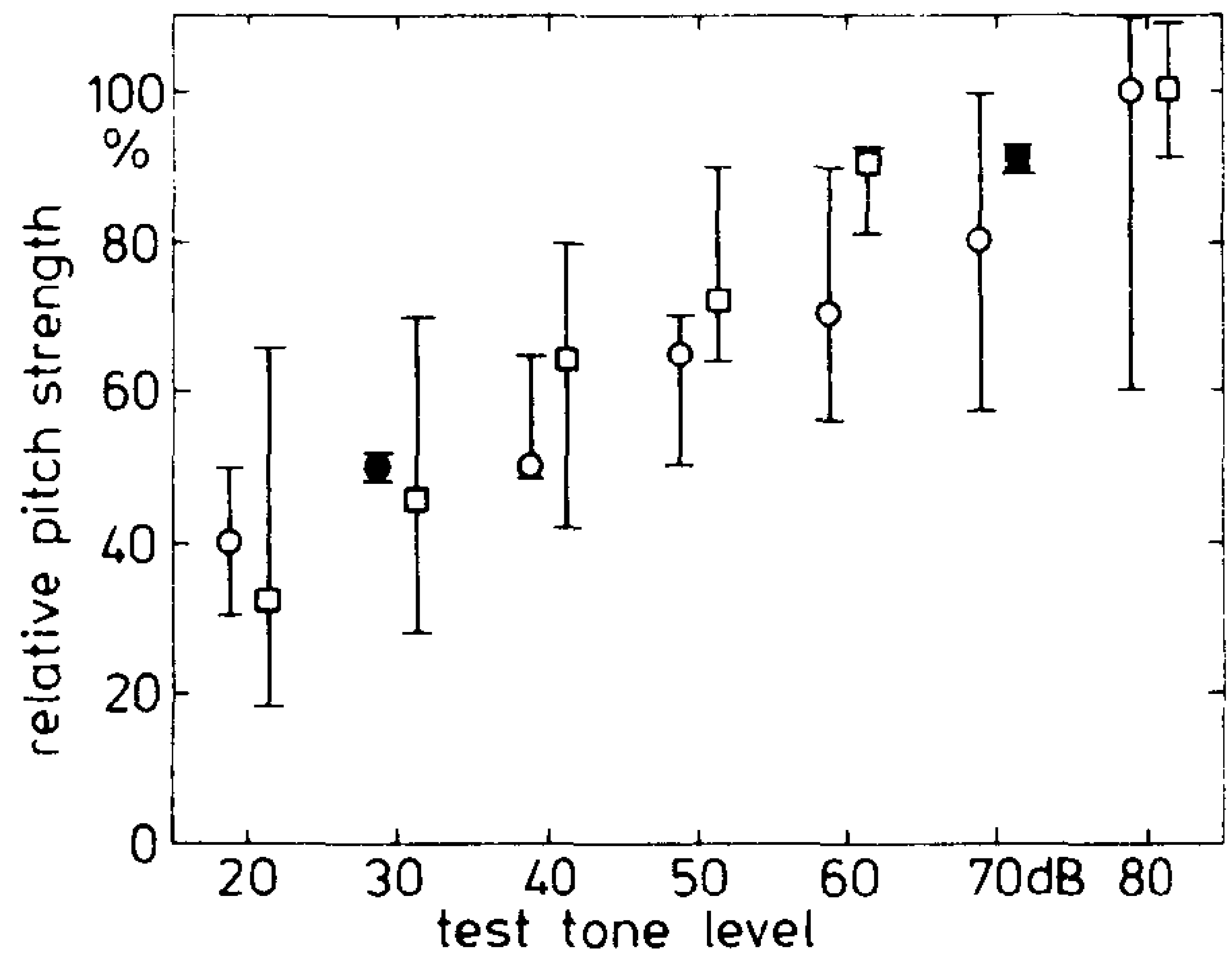

Fig.2: Pitch strength of pure tones as a function of test-tone level. Test-tone frequency 1 kHz, test-tone duration 500 ms.

Fig. 3 shows the dependence of pitch strength on test tone frequency for pure tones with 80 dB SPL and 500 ms duration. Four anchor sounds were used: 500 Hz (circles), 1.5 kHz (squares), 2 kHz (downward pointing triangles) and 3 kHz (upward pointing triangles). All anchor sounds are illustrated by filled symbols; they were assigned the number 100 except the anchor at 3 kHz, which was assigned the number 50.

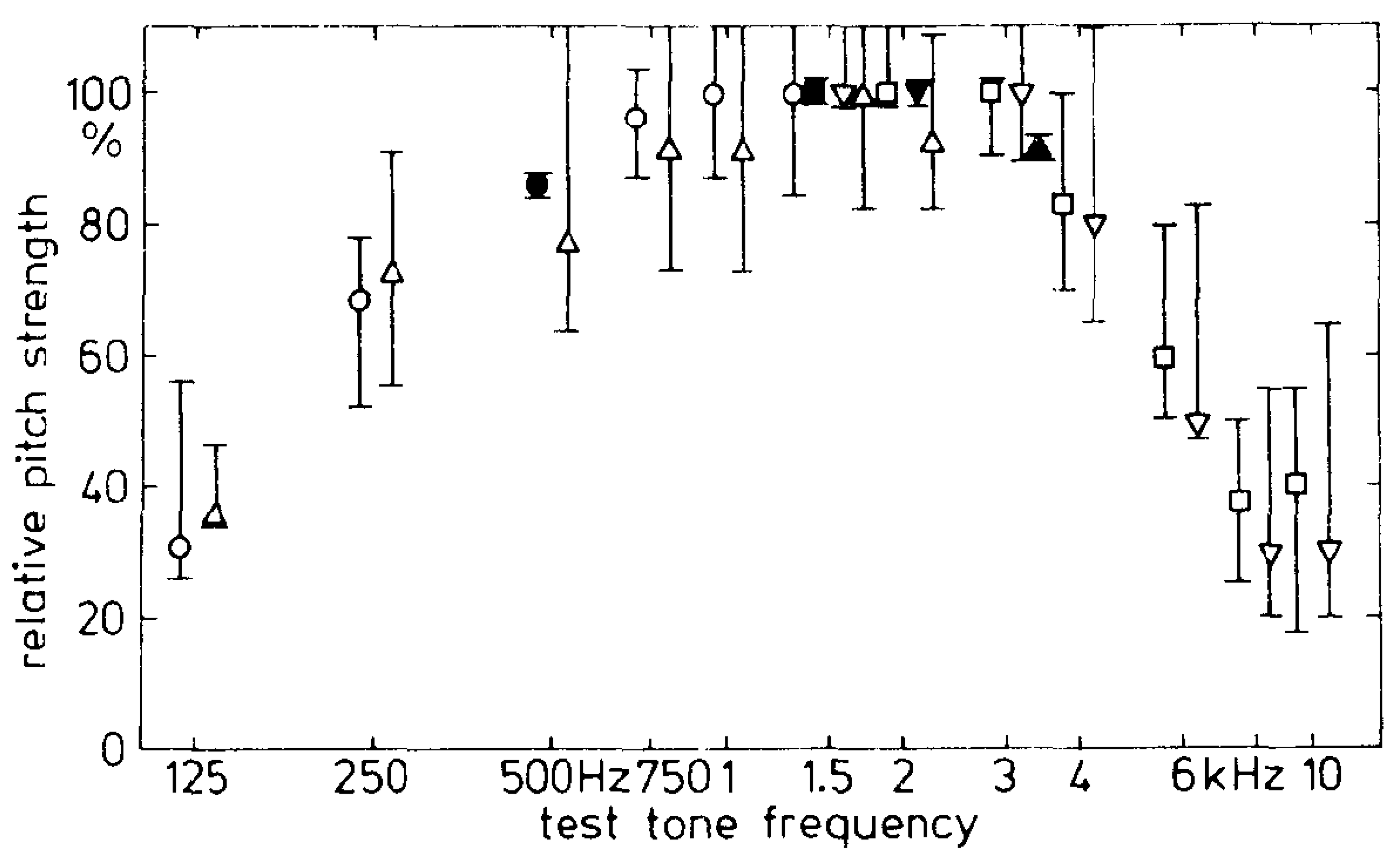

Fig. 3: Pitch strength of pure tones as a function of test-tone frequency. Test-tone level 80 dB, test-tone duration 500 ms.

Regarding the results displayed in Fig. 3, three regions can be distinguished: First, from 125 Hz up to about 750 Hz, pitch strength of pure tones increases almost linearly with the logarithm of test tone frequency. Second, from about 750 Hz up to about 3 kHz, pitch strength stays almost constant at its maximum value. Third, for frequencies between 3 kHz up to 10 kHz, pitch strength of pure tones decreases almost linearly with the logarithm of test-tone frequency. At low (125 Hz) and high (10 kHz) frequencies, pitch strength of pure tones reaches about one third of the maximal pitch strength produced at mid frequencies around 1.5 kHz.

CONCLUSION

Pitch strength as a relatively new attribute of sounds seems to deserve more attention in view of at least two important practical applications: On the one hand, pitch strength represents a new tool for music composers as a modern implementation of the "Klangfarbenmusik" of Impressionist composers (Debussy etc), where the pitch (height) is kept constant, but the tone colour and hence the pitch strength is changed. While Impressionist composers had only limited possibilities to produce with traditional instruments sounds of same pitch height but different pitch strength, modern technology offers today to the composer an almost infinite number of possibilities for variations in pitch strength, while maintaining pitch height.

The other example for the application of pitch strength is related to noise evaluation: Noises are rated as highly annoying, if they contain tonal components. In such situations, the "magnitude of the tone content" can be assessed quantitatively on the basis of the hearing sensation pitch strength, and hence the severeness of the annoyance can be predicted.

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REFERENCES

Fastl, H., (1980), Pitch strength and masking patterns of low-pass noise. Psychophysical, Physiological and Behavioural Studies in Hearing. (G. van den Brink, F.A. Bilsen, eds.), Delft, University Press, 334-339.

Fastl, H., (1981), Ausgeprägtheit der Tonhöhe pulsmodulierter Breitbandrauschen. Fortschritte der Akustik,DAGA`81, VDE-Verlag, Berlin, 725-728.

Fastl, H., (1988), Pitch and pitch strength of peaked ripple noise. Basic Issues in Hearing, Academic Press, London, 370-379.

Fastl, H. and Stoll, G., (1979), Scaling of pitch strength. Hearing Research 1, 293-301.

Hesse, A. (1985), Zur Ausgeprägtheit der Tonhöhe gedrosselter Sinustöne. Fortschritte der Akustik, DAGA`85, Verl.: DPG-GmbH, Bad Honnef, 535-538.

Houtsma, A. J. M., (1983), Pitch salience for various complex sounds. Music Perception.

Rakowski, A., (1977), Measurements of pitch. Catgut Acoust. Soc. Newsl. 27.

Yost, W. A. and Hill, R., (1978), Strength of the pitches associated with ripple noise. J. Acoust. Soc. Am. 64, 485-492.

Zwicker, E., (1974), Time constants (characteristic durations) of hearing. J. Audiol. Technique 13, 82-102.

Zwicker, E. und Feldtkeller, R., (1967), Das Ohr als Nachrichtenempfänger, 2. erw. Auflage, Hirzel Verlag, Stuttgart.