Spectral Regions Dominant in the Perception of Repetition Pitch

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Summary

Experiments are described to test the concept of dominance with respect to Repetition Pitch. In the experiments a test signal was used consisting of a low-frequency band up to 500 Hz, a centre-frequency band of 700 up to 1400 Hz, and a high-frequency band starting at 2050 Hz. These bands were filled up with noise added to its repetition after a fixed delay. It was found that the low-frequency band was dominant in the perception of Repetition Pitch (corresponding to the reciprocal value of the delay time) for the range up to 100 Hz, the centre-frequency band for the pitch range of 150 to 350 Hz, and the high-frequency band for pitch values above 700 Hz.

The centre-frequency band tends to dominate the pitch sensation as long as its loudness level exceeds a minimum absolute level of about 10 dB SL irrespective of the level of other frequency bands in the signal.

Evidence is provided that the strength of the pitch sensation is an adequate parameter determining the dominance with respect to pitch.

Régions du spectre dominant dans la perception de la hauteur du son de répétition

Sommaire

On décrit les expériences faites pour établir le concept de dominance à l'égard de la hauteur du son de répétition. Dans ces expériences un signal de contrôle était employé, consistant en une bande de basses fréquences allant jusqu'à 500 Hz, une bande de moyennes fréquences de 700 Hz à 1400 Hz et une bande de hautes fréquences commençant à 2050 Hz. Ces bandes étaient remplies d'un bruit superposé à sa répétition après un retard fixé. On a trouvé que la bande de basses fréquences était dominante dans la perception de la hauteur de répétition (correspondant à l'inverse du temps de retard) pour la gamme allant jusqu'à 100 Hz, la bande de fréquence moyenne pour la gamme de hauteurs de 150 à 350 Hz et la bande haute fréquence pour des valeurs de hauteur de son au-dessus de 700 Hz.

La bande de fréquences moyennes tend à dominer la sensation de hauteur du son aussi longtemps que son niveau sonore excède un niveau minimum absolu d'environ 10 dB SL, indépendamment du niveau des autres bandes de fréquences dans le signal.

On montre que la force de la sensation de hauteur du son est un paramètre adéquat déterminant la dominance à l'égard de la hauteur du son.

Dominante Spektralbereiche bei Wahrnehmung der Wiederholungs-Tonhöhe

Zusammenfassung

Es werden hier Experimente beschrieben, die die Konzeption der Dominanz in Hinsicht auf die Wiederholungs-Tonhöhe prüfen sollen. Bei den Experimenten wurde ein Testsignal verwendet, das aus einem Niederfrequenzband bis 500 Hz, einem mittleren Frequenzband von 700 bis 1400 Hz und einem Hochfrequenzband von 2050 Hz an bestand. Diese Bänder wurden mit Rauschen aufgefüllt, das bei der Wiederholung nach einer festen Verzögerungszeit hinzugefügt wurde. Es stellte sich heraus, daß das Niederfrequenzband dominant war bei der Wahrnehmung der Wiederholungs-Tonhöhe (entsprechend dem reziproken Wert der Verzögerungszeit) in dem Bereich bis 100 Hz, das mittlere Frequenzband für den Tonhöhenbereich von 150 bis 350 Hz und das Hochfrequenzband für Tonhöhenwerte über 700 Hz.

Das mittlere Frequenzband neigt dazu, die Tonhöhenwahrnehmung so lange zu beherrschen, wie sein Lautstärkepegel einen minimalen absoluten Pegel von ungefähr 10 dB SL überschreitet, unabhängig von dem Pegel anderer Frequenzbänder beim Signal.

Es wurde offenbar, daß die Stärke der Tonhöhenempfindung ein adäquater Parameter ist, der die Dominanz hinsichtlich der Tonhöhe bestimmt.

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1. Introduction

When a sound is added to its repetition after a delay τ, a pitch is evoked corresponding to the reciprocal value $1/\tau$. BILSEN [1] called this pitch effect "Repetition Pitch" (RP). It was found that for a given delay τ the pitch can be shifted more than a full tone upward and downward changing the polarity of the repeated sound. Namely, after adding the repetition with negative sign (in fact this means that all the frequency components of the repeated sound have been shifted in phase by 180°) a bivalent pitch is perceived, viz. $RP_{180} = 1.14/\tau$ and $= 0.88/\tau$.

A description and an explanation of this pitch behaviour have been given in a previous paper by BILSEN and RITSMA [2]. There it was concluded that the perception of Repetition Pitch and identical pitch effects, known in the literature as "Reflection Tone", "Time Difference Tone", "Sweep Pitch", and "Time Separation Pitch" is based on the same principles as the perception of pitch of periodic complex sounds known in literature as "Residue Pitch" and "Periodicity Pitch".

Further an explanation for this pitch behaviour was given, based on three hypotheses, in the way as was done for periodic sounds — AM-sinusoids, periodic pulse trains —.

For signals with a narrow bandwidth the perceived pitch appears to correspond to the reciprocal value of the time interval between two prominent positive peaks in the temporal fine structure of the displacement waveform, evoked by the signal, on a particular place of the basilar membrane. Signals with a broad bandwidth, however, give displacement waveforms shaped by the specific properties of the membrane at different places along the membrane — spectral analysis —. Dependent on the signals used these membrane waveforms will differ strongly at different places. Fig. 1 gives an outline of various membrane responses to broad band periodic pulses of alternating polarity (cf. FLANAGAN [3]).

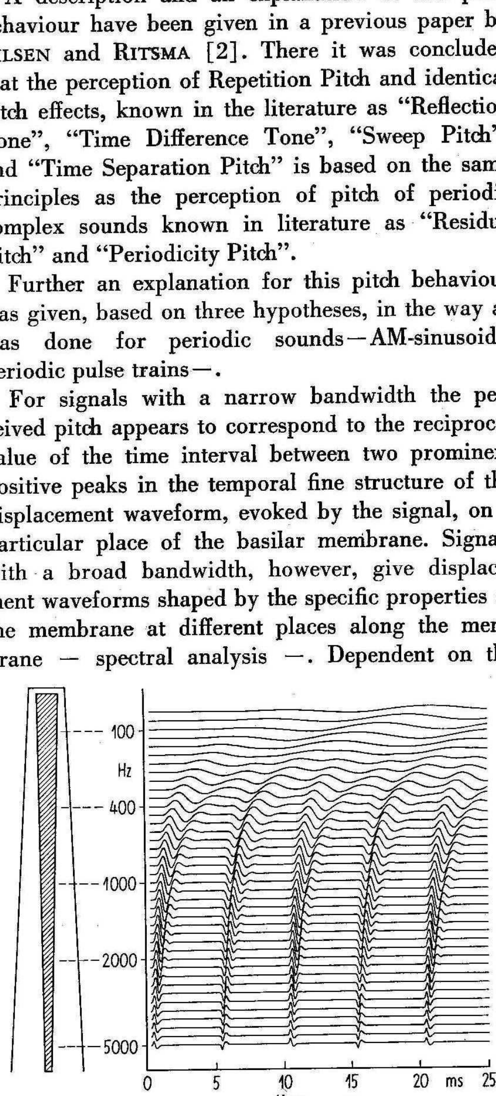

Fig. 1. Basilar membrane responses at various points to broad-band periodic pulses of alternating polarity (after FLANAGAN, [3]).

For signals with a broad bandwidth the physical correlate of pitch cannot be found directly.

To overcome this difficulty the concept of dominance was introduced: if pitch information is available along a large part of the basilar membrane the ear uses only the information from a narrow band. This band is positioned at 3 to 5 times the frequency value of the pitch. By means of this concept of dominance the pitch value can be calculated and is in accordance with the experimental result.

The concept of dominance has been tested experimentally for periodic complex sounds (RITSMA [4]).

Indeed, it was found that for pitch values in the range of 100 to 400 Hz and for sensation levels of the entire signal up to at least 50 dB, the frequency band consisting of the third, fourth, and the fifth harmonic tends to dominate the pitch perception as long as its amplitude exceeds a minimum absolute level of about 10 dB above threshold.

In the following sections experiments are described to test the concept of dominance with respect to Repetition Pitch.

2. Experimental set-up

In the experiments a test signal (Fig. 2) was used consisting of the sum of (1) a low-frequency band and a high-frequency band of a noise signal

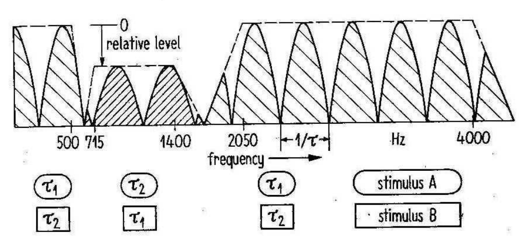

Fig. 2. Frequency presentation of the test signal.

added to its repetition after a delay τ_1 (or τ_2) and (2) a centre-frequency band of the noise signal added to its repetition after a delay τ_2 (or τ_1).

The upper cut-off frequency of the low-frequency band was 500 Hz; the lower cut-off frequency of the high-frequency band was 2050 Hz. The cut-off frequencies of the centre-frequency band were 715 and 1400 Hz. Between the low-frequency band and centre-frequency band as well as between the centre-frequency band and high-frequency band a gap of at least 30 dB existed. The level of the centre-frequency band could be varied independent of the level of the low-frequency band and the high-frequency band.

A block diagram of the experiment is given in Fig. 3. The noise signal consists of a random sequence of pulses with equal amplitude, but with variable, randomized, width. If the average distance between the pulses is short enough, this type of noise cannot be discerned subjectively from white

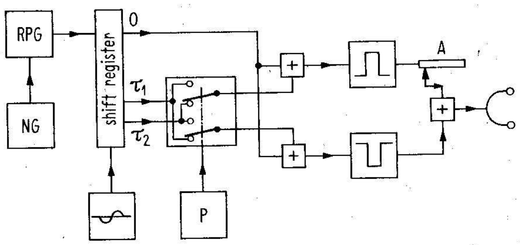

Fig. 3. Block diagram of the experiment.

gaussian noise (SCHOUTEN and DIJK [5]). The signal is obtained by conversion from white gaussian noise — noise generator NG (Peekel 230 R) — by a special electronic device — a random pulse generator RPG —. It is quite simple to delay this kind of signal by a shift register, because it has a digital character. The shift register is branched off at two places corresponding to delay times τ_1 and τ_2, while the values of τ_2 were always 6 per cent higher than those of τ_1. The values of τ_1 and τ_2 could be adjusted precisely by the setting of the clock frequency controlling the shift register.

Each of the two delayed signals could be added to the undelayed signal and fed either to the centre-frequency band or to the low-frequency band and high-frequency band by means of two parallel switches, directed by a random program (P).

Listening to the low-frequency band and high-frequency band only, a pitch was heard which corresponded to τ_1 (or τ_2). Listening to the centre band only, a pitch was perceived which corresponded to τ_2 (or τ_1). Listening to both parts of the signal, added together as drawn at the end of the block diagram, a pitch was perceived, which, depending on the value of τ_1, corresponded to either τ_2 or τ_1. In trying to determine systematically which pitch was dominant, a dynamic approach was used similar to that used for periodic signals (PLOMP [6], RITSMA [4]).

Subjects were presented with two stimuli (see Fig. 2): stimulus A with a duration of 200 ms and stimulus B with a duration of again 200 ms. For stimulus B the delays τ_1 and τ_2 had been interchanged. Between the stimuli a silence of 300 ms was introduced. If the low-frequency band and high-frequency band were dominant, and when A preceded B, the subject would hear a downward pitch-jump (bear in mind that τ_1 is taken to be smaller than τ_2); in the case of dominance of the centre band the subject would hear an upward pitch-jump. For every parameter condition the subject, listening by headphones (Beyer DT96A) in a soundproof booth, had to respond to 20 pairs of stimuli the sequence of which was randomized by means of P (see Fig. 3). After each presentation of a pair of stimuli, the subject was obliged to respond whether the pitch shift was "up" or "down".

Four trained subjects participated in the experiments.

3. Test results

For six values of the delay τ_1, corresponding to the reciprocal values of 100, 120, 150, 250, 400, and 700 Hz, the degree of dominance in pitch perception of the centre band was determined as being a function of the relative level of the centre band — adjusted by the attenuator A, Fig. 3 —. The results for the four subjects are shown in Fig. 4. The ordinate represents the percentage of judgments corresponding to the pitch shift in the centre band, the abscissa represents the relative level of the centre band.

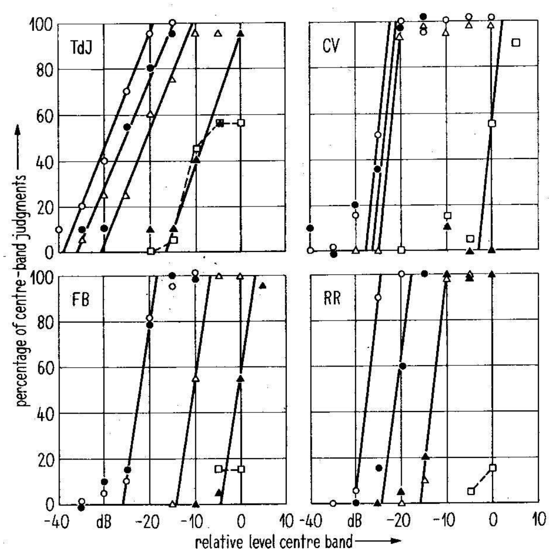

Fig. 4. Percentage of judgements corresponding to the pitch shift of the centre-frequency band as a function of the relative level of the centre band, for four subjects and various values of $1/\tau$, viz. ▲ 120 Hz, ● 150 Hz, ○ 250 Hz, △ 400 Hz, □ 700 Hz. SL = 40 dB.

The overall sensation level in the case of equal amplitude in the low-frequency, centre-frequency, and high-frequency band was 40 dB.

For a delay τ_1 corresponding to 150, 250, and 400 Hz the centre band had to be given a negative relative level before its pitch dominance was affected. For three subjects the reversal in judgments occurred rather sharply within a single step of 5 dB. One subject (TdJ) reversed his judgments within a range of 15 dB. For a delay corresponding to 700 Hz the centre band was no longer dominant. In the case of equal amplitude two subjects responded at random (50%) and two subjects responded to the low-frequency and high-frequency band. For a delay τ_1 corresponding to 100 Hz all subjects responded to the pitch shift in the low-frequency and high-frequency band; for a τ_1-value corresponding to 120 Hz one subject (CV) still preferred the low-frequency and high-frequency band.

In Fig. 5 the relative level of the centre band for 50% centre-band judgments, called the critical relative level of the centre-band, has been plotted as a function of the reciprocal value of τ_1, i. e. the pitch value.

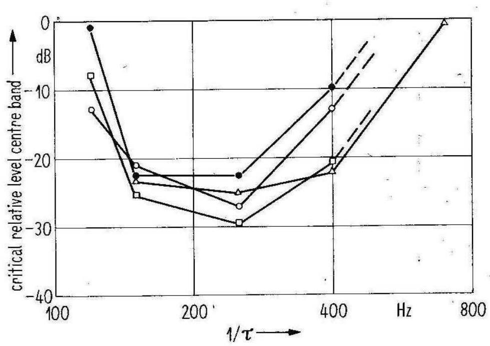

Fig. 5. The critical relative level of the centre-frequency band as a function of $1/\tau$, for four subjects: ● subj. FB, □ subj. TdJ, ○ subj. RR, △ subj. CV. SL = 40 dB.

From this graph it is seen that the critical relative level of the centre band is minimal for pitch values of about 250 Hz. As the critical relative level may be taken as a measure of effectiveness in pitch dominance, we may conclude:

(1) A dominant frequency region exists for Repetition Pitch.
(2) The frequency band of 700 up to 1400 Hz is most dominant for Repetition Pitch in the range of 150 to 350 Hz.

4. Dependence on sensation level

For periodic signals it has been found (Ritsma [4]) that for pitch values in the range of 100 to 400 Hz and for sensation levels of the entire signal up to at least 50 dB above threshold, the spectral region consisting of the third, fourth and fifth harmonic tends to dominate the pitch sensation, as long as its amplitude exceeds a minimum absolute level of about 10 dB. It is of interest to ascertain whether dominance of the centre band in the perception of Repetition Pitch also depends on the absolute level.

Therefore similar series of measurements were undertaken for pitch-values of 150, 250, and 300 Hz with five different overall sensation levels. Fig. 6 represents the results for 300 Hz from three subjects. The psycho-physical method used was similar to that described above.

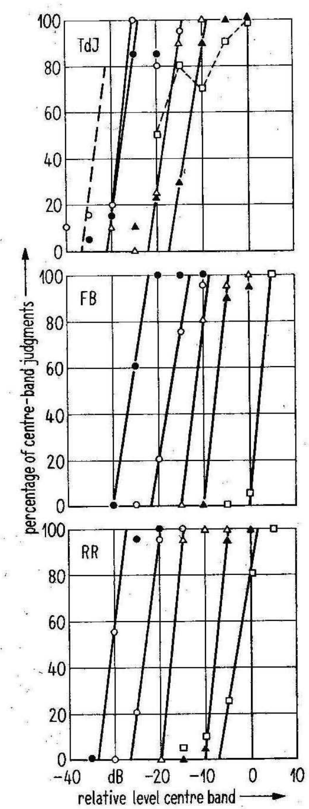

Fig. 6. Percentage of judgments corresponding to the pitch shift of the centre-frequency band as a function of the relative level of the centre band, for three subjects and various values of the overall sensation level: □ 10 dB, ▲ 20 dB, △ 30 dB, ○ 40 dB, ● 50 dB. $1/\tau = 300$ Hz.

Fig. 7 represents the abridged results for three pitch values; the lower graph has been derived from Fig. 6.

The ordinate is the critical relative level of the centre band: 50% judgments corresponding to the pitch shift in the centre band. The abscissa is the

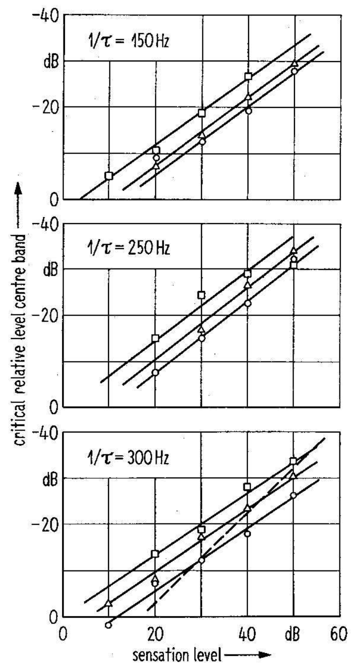

Fig. 7. The critical relative level of the centre-frequency band as a function of the overall sensation level, for three values of $1/\tau$ and three subjects, viz. □ subj. TdJ, △ subj. RR, ○ subj. FB.

overall sensation level of the signal. There seems to be a linear relation between the critical relative level of the centre band and the overall sensation level. The slope of the curves is not unity; the decrease in critical relative level of the centre band is less (0.7) than the increase in overall sensation level. So we may not speak of a minimum absolute level. However, on raising the overall sensation level the centre band will be increasingly masked by both the low-frequency and high-frequency band. Due to the asymmetry of the masking curve the low-frequency band will mask the centre band more than the high-frequency band does. Therefore the measurements were repeated for two subjects (FB and RR) without the low-frequency band in the test signal. The results are represented by the dotted line in the lower graph of Fig. 7, which has a slope corresponding approximately to unity. For the sake of clarity in the graph the individual results have not been plotted. From this experiment we conclude that also in the case of Repetition Pitch dominance in the perception of the pitch of the centre band depends on an absolute sensation level of about 10 dB.

5. Parameters influencing the dominance

Up till now only one parameter affecting the dominance in the centre band, was used: the loudness level of the signal in that band. Listening to such a dominant frequency band in isolation the strength of the pitch sensation diminishes when the loudness level is decreased. The pitch sensation can also be made weaker by attenuating the repetition keeping the undelayed signal constant. So we look for the influence of the attenuation of the repetition on the aspect of dominance.

In principle, the experimental set-up and the procedure were the same as has been described before. First, in attenuating the loudness level of the centre band, the critical relative level was determined for which a subject could discriminate a 6 per cent pitch variation corresponding with the pitch variation in the centre band (thus, for dominance of the centre band), with a score of correct answers of 72 per cent.

Second, using the same criteria, the critical relative level of the repetition has been determined. Fig. 8 represents the results of both experiments for one subject. Both graphs have their minimum for $1/\tau \sim 250$ Hz, but the curve for the first experiment falls more steeply than that for the second experiment.

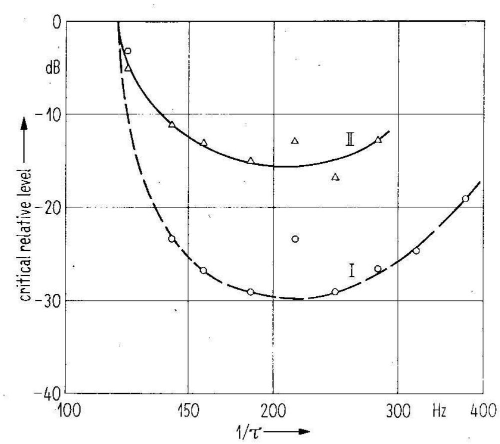

Fig. 8. Critical relative level of both the loudness (I) and the repetition (II) of the signal within the centre band for 72 per cent centre band judgments as a function of $1/\tau$ (one subject).

Next the threshold of perceptibility of pitch in the centre-frequency band has been determined. For this purpose the repetition in the low- and high-frequency band was removed. It was maintained only in the centre-frequency band. In attenuating the loudness level of the centre band the threshold was determined for which a subject could discriminate a 6 per cent pitch variation with a score of correct answers of 72 per cent. This was done for the $1/\tau$ values as indicated in Fig. 8. Likewise, in attenuating the level of the repetition within the centre band, keeping the original noise signal constant, the threshold level of the repetition was determined for the same $1/\tau$ values.

Knowing, thus, the threshold of perceptibility of pitch for both parameter conditions a new plot of the results represented in Fig. 8, has been made. In Fig. 9 the difference between the critical relative

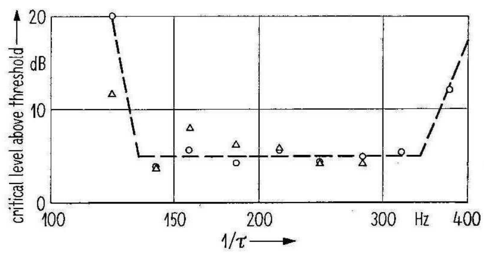

Fig. 9. Critical level above threshold for 72 per cent centre band judgments as a function of $1/\tau$ for one subject. ○ experiment (I). △ experiment (II).

levels and the corresponding threshold values of perceptibility of pitch has been plottet as a function of the value $1/\tau$.

From Fig. 9 it is seen that both parameters normalized to their thresholds, coincide. Moreover, the plot in Fig. 9 seems to be, more or less, a reflection of the centre-frequency band on a reduced frequency scale; the reduction factor is about 4. These results suggest that the strength of the pitch sensation is an adequate parameter determining the dominance with respect to pitch.

6. Conclusions

The hypothesis that the principle of pitch dominance is also valid in the case of Repetition Pitch, has been tried out experimentally. It was found that the frequency band of 700 up to 1400 Hz was dominant in the perception of Repetition Pitch for the range of 150 to 350 Hz. This frequency band tends to dominate the pitch sensation as long as its loudness level exceeds a minimum absolute level of about 10 dB above threshold irrespectively of the level of other frequency bands in the signal. These results are in full accordance with previous findings on dominant centre frequencies which were calculated as (3.9 ± 0.2) times the pitch values (BILSEN and RITSMA [2]). They also are in full accordance with the results from the tests with periodic pulses where the region of the third, fourth, and fifth harmonic proved to be dominant as long as its amplitude exceeds a minimum absolute level of about 10 dB.

Therefore we may conclude that the ear reacts in the same manner for both a periodic signal and for a noise signal added to its repetition after a delay τ.

Finally, the strength of the pitch sensation seems to be an adequate parameter determining the pitch dominance.

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