PARACUSIS WILLISII

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Introduction

The phenomenon that certain hard-of-hearing patients hear conversation better in conditions of noise than silence, was described originally by Willis in 1672. Later on another phenomenon occurring in the same patients was established namely that compared with normal-hearing subjects, they were better able to perceive any constant signal in conditions of noise.

The explanation of these two phenomena has occupied many investigators. For instance Willis supposed that the tension of the eardrum and therefore the conduction of sound improves in the presence of a background noise; Politzer (1901) thought that the fixed stapes was loosened by vibration of low frequency and Jenkins (1928) ascribed the improvement to a raised excitability of the cochlea in background noise. In the opinion of many investigators three factors coincide to produce paracusis:

1. The background noise is low pitched.
2. The patient suffers from a low-tone deafness.
3. In conversation against background noise, the voice of the speaker unconsciously is raised (Lombard (1911)).

In order to study these factors, normal-otosclerotic-and other hard-of-hearing subjects were studied in several circumstances. Moreover, the character of a paracusis-producing noise was analysed.

Occurrence

Some patients report spontaneously that they can hear better in noise; more often, however, this symptom is confirmed or denied only when specially asked for. Among 100 patients, chosen at random, suffering from otosclerosis, paracusis was admitted by 77. Ewertsen (1949) found paracusis in 59 %, Cawthorne (1955) in 84 % and Clerc (1959) in 75 %.

In our patients presenting paracusis, the mean air-conduction hearingloss is 54dB, whereas in those denying paracusis this loss was only 44dB. In patients suffering from losses above 60dB paracusis is often present, but if bone conduction is impaired, paracusis is less frequent. Normal bone conduction furthers paracusis but is not an absolute requirement.

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* Our much regretted collaborator Dudok de Wit died at the age of 38 years in 1960. He left, among others, experimental data, which enabled me to finish this paper (Van Dishoeck).

According to Rebattu and Martin (1949) the presene of paracusis requires two condictions, namely a valid inner ear and a defective conductive system. Lanos (1952) and Fournier (1959) state that the type of hearing loss is of lesser importance than the degree, and that moreover, in perceptive deafness, paracusis can be found too. In our experience, occasionally in other types of conductive deafness, paracusis is present and we, too, observed occasionally paracusis in perceptive deafness.

The spectrum of the background noise

In train-noise paracusis is very marked. Already in 1927 Escat made a train-journey with a patient to study paracusis, and thus we chose this particular noise for analysis. Measurements made in a train between Leiden and

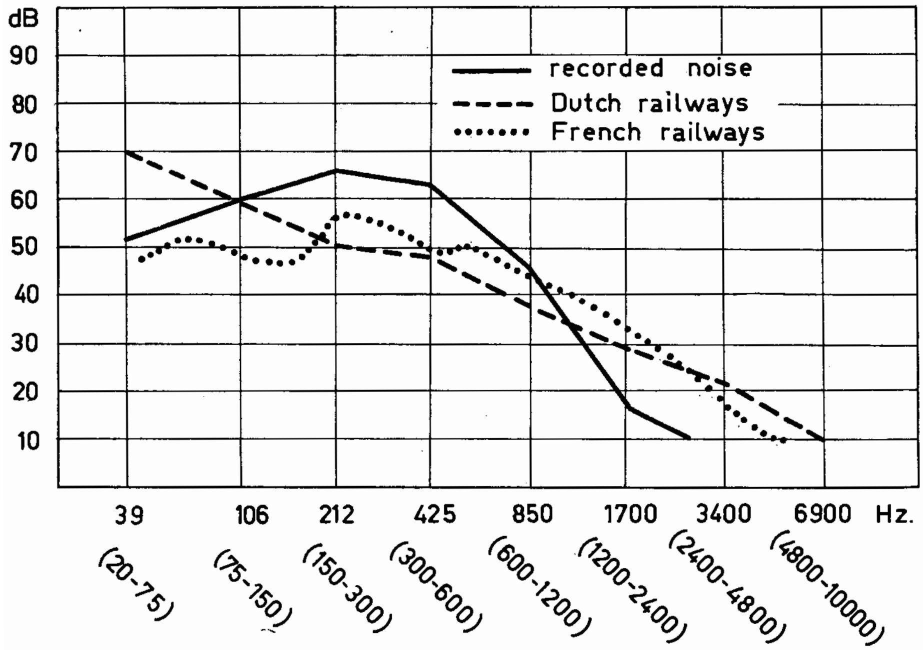

Fig. 1. Spectrum levels of train-noises.
. . . . Spectrumlevels in a compartment of the French Railways. All over intensity 79dB.
——— Spectrumlevels in a compartment of the Dutch Railways. All over intensity 90dB.
——— Spectrumlevel of the recorded noise used in our experiments. All over intensity 91dB.

Haarlem were compared with an analysis made by the French Railway on the section of Blois.

The intensity levels measured by the Société des Chemins de Fer Français were 80dB in the compartment; we calculated 90dB in the compartment. This difference might be partly due to the technique of measuring as in our measurements with 1/3 octave bands a large part of the low-tones below 125 cps was included, resulting in a greater all-over intensity. The bandrecorded noise used for our experiments possessed an all-over intensity of 91dB. (fig. 1).

From these spectrum levels the very marked low-tone character of train-noise clearly appears.

The spectrum of the hearing-loss *

The hearing-loss in otosclerosis was measured by continuous audiometry. This method gives more exact values, especially in sloping curves and circumscript losses as the Carhart Notch. In 150 audiograms these losses were read of at the usual frequencies and computed in collective audiograms (fig. 2-4). The audiograms were devided in three age-groups: 10-30; 31-50; 51-70 years.

In this way it appeared that in air-conduction a marked low-tone deafness with a rising curve towards 2000 cps exists indeed, but that on the contrary there is a considerable high-tone loss in bone conduction. Consequently the "gap" between air-and bone conduction diminishes from 125-2000 cps and is constant beyond 2000 cps. In the older age-groups, a considerable increase in high-tone loss was noted, probably due to presbyacusis (fig. 2). After correction for presbyacusis, according to the standards of Jatho and Heck,

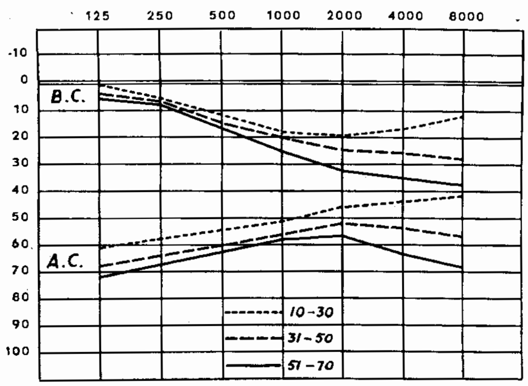

Fig. 2.

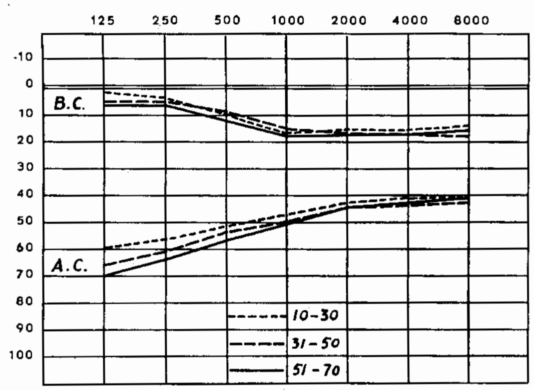

Fig. 3.

Fig. 2. Collective audiograms in otosclerosis of three age-groups: 10-30, 31-50 and 51-70 years. Not corrected for presbyacusis and Carhart Notch.
Note: the older age-groups show an increasing loss for high tones for air and bone-conduction.

Fig. 3. Collective audiograms in otosclerosis of three age-groups: 10-30, 31-50 and 51-70 years. Corrected for presbyacusis according to the standards of Jatho and Heck.
Note: surprising similarity in the three age-groups viz only little progress of the otosclerotic process.

above 2000 cps, in air conduction, a small rise resulted and a considerably more normal bone conduction curve (fig. 3).

The resulting bone conduction loss is caused by two factors.

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* Read in 1959 at the meeting of the Dutch E.N.T.-Society.

1. The Carhart Notch which is a "middle ear bone-conduction loss" and not the expressions of cochlear damage (Huizing jr. 1963).
2. A. real perceptive deafness caused by cochlear damage due to the otosclerotic process.

After correction for presbyacusis and the Carhart Notch, the bone conduction curves of most patients were nearly normal (fig. 4). In the collective bone conduction audiogram a relatively small loss remained, caused by a small number of patients presenting a mixed deafness (± 5 %). In the different age-groups the gap did not increase (fig. 5). Most probably when an otosclerotic patient needs help, a final stage of fixation is already reached, and

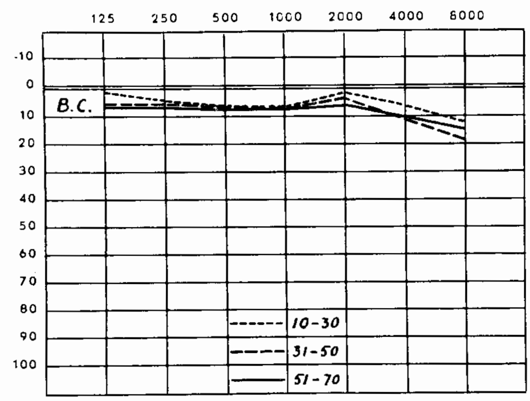

Fig. 4. Collective bone-conduction audiograms in otosclerosis of three age-groups: 10-30, 31-50 and 51-70 years. Corrected for presbyacusis and the Carhart Notch.
Note: nearly normal bone-conduction. The loss in this collective audiogram is mainly caused by some patients suffering from a mixed deafness (5 percent).

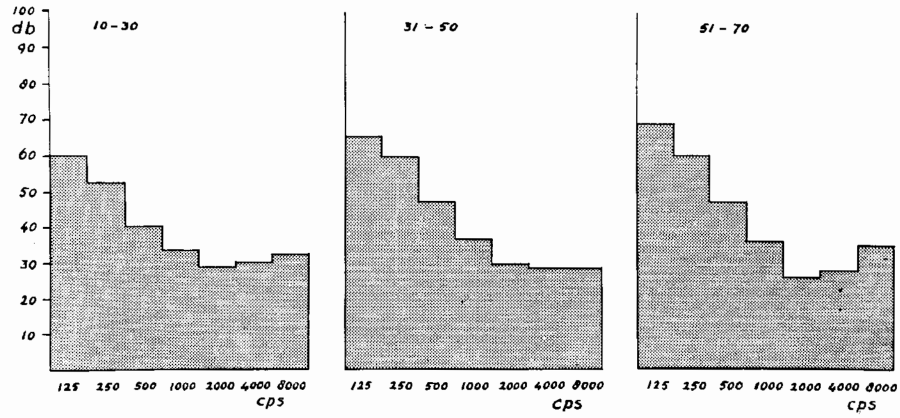

Fig. 5. The "gap" between air-and bone-conduction in the collective audiograms of three age-groups: 10-30, 31-50 and 51-70 years.
Note: surprising similarity of the three gaps.

increase of the focus in later years does not alter the conductive hearing-loss of 50-60dB. This concept explains the uniformity of the hearing-loss in otosclerosis.

In conclusion it appears that in otosclerosis a very marked low-tone deafness is present, and that the difference of the air-bone conduction gap diminishes for higher frequencies and is remarkably uniform in the age-groups.

Consequently a low pitched noise (train and engine noises) will be perceived by an otosclerotic patient at a very reduced sensation-level and will not mask his hearing.

Voice-lift in noise

The conversation level of 20 normal-hearing subjects and 20 patients suffering from otosclerosis was measured in conditions of silence and low-tone noise of 150-600 cps (decreasing 3dB for each octave). They were invited to read a story at a distance of 1 M from a sound level meter, while the noise was presented to their ears with increasing intensity by means of headphones. It appeared that when the noise level exceeded 70dB the tested person unconsciously started to raise his voice. At a noise level of 90dB a voice-lift of 10-15dB was measured. At higher noise-levels the tested persons involuntary raising of voice became voluntary, conscious "shouting". Individual differences were observed. The average vocal intensity of normal tested persons submitted to a noise of 80dB by means of headphones and measured at a distance of 1 M, proved to be 70dB, whereas this value for 20 otosclerotic patients in the same condition was only 60dB.

Fletcher (1953) examined the intensity level for conversational speech in a large number of patients. He found as an average 65dB. Lanos (1952) found the average noise level of the Parisian subway to be 85dB and an average speech-level in this noise of 75dB. Pohlman and Kranz (1927) observed that the conversation level of two otosclerotic patients, seated back to back, did not increase in the presence of loud noise nor dit the patients understand each other better than in conditions of silence.

Consequently, in noise, a normal-hearing subject will raise his voice, provided that the noise exceeds 70dB. The involuntary voice-lift will be ± 15dB, namely from 65-80dB, in noise of 90dB. This will be to the advantage of the otosclerotic patients. In higher noise-levels, the voice may be raised more or less consciously even further. This phenomenon might be called "conversational paracusis".

Discrimination of recorded speech in noise

Conversation in noise-levels above 70dB induces in speakers a voice-lift of 15 dB and consequently the deafness of otosclerotic patients is diminished by this amount.

In order to study the adventage these patients experience by being not masked, recorded speech in noise, was presented to normal and deaf subjects. The low-tone noise had a spectrum of between 125-600 cps decreasing 3 dB for each octave, and the high-tone noise a spectrum of 1200-4800 cps. The noises were measured above their sensation-threshold.

Departing from the threshold for recorded conversational speech, which proved to be ± 30 dB in our arrangement, background noise increasing with 10 dB steps was added, and at each step the threshold for speech was measured. This procedure was done in normal experimental persons, patients suffering from otosclerosis and patients suffering from perceptive deafness.

It appeared (fig. 6) that in conditions of our low-pitched masking noise, normal hearing subjects needed an increased speech level starting from 45 dB noise (a). This noise level does not hinder the otosclerotic patients (70 dB hearing-loss), who need an increased speech level not earlier than in a noise of 100 dB (b). In this noise of 100 dB the normal hearing subjects are considerably masked, needing a speech level of 80 dB (c). Consequently below this speech level starting from 90 dB the not masked otosclerotic patients will, in the same noise, perceive speech at a lower intensity than the masked normal subject.

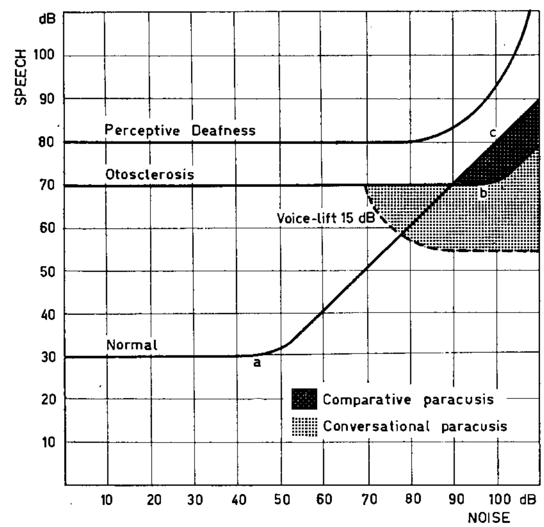

Fig. 6. Relation between the threshold for conversational speech and a low pitched masking noise (150-600 cps).

This phenomenon, which might be called "comparative paracusis", is only manifest when an otosclerotic patient and a normal hearing subject are listening to the same speech in the same noise as to the radio in a moving car. Thus when moving the patient will adjust the radio to a lower level, but as soon as the car and the engine are stalled, he will adjust the radio again to a higher level. The normal subject will do the opposite.

In our high-pitched noise (fig. 7) in all groups masking starts at a lower level. In normal subjects masking starts already at 20 dB noise (a) and in a group of otosclerotic patients at 60 dB (b), the speech-noise ratio being for both 1 : 1. In this 60 dB noise normal subjects need not more thans 45 dB speech intensity (c). The area of " comparative" paracusis could not be de-

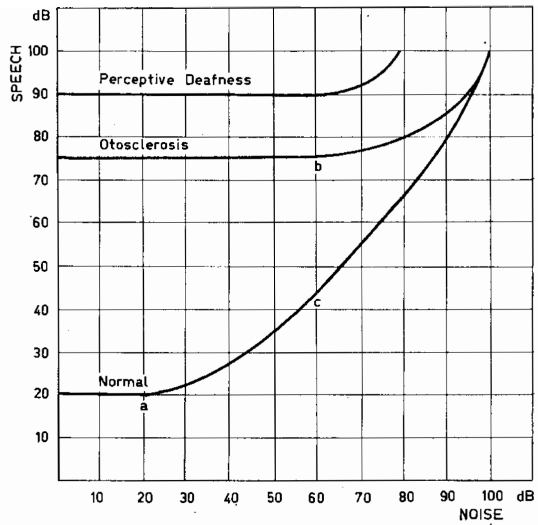

Fig. 7. Relation between the threshold for conversational speech and a high pitched masking noise (1200-4800 cps).

monstrated. In conversation, voice-lift must happen too, but most probably its favourable effect is neutralised by the infavourable effect of the highgrade masking.

Jenkins (1928) suspected and later Bombelli and Manfredi (1955) measured in background noise a lowering of the threshold for pure tones in the speech area and thus for speech (Willismetry). However, in our experiments we could not demonstrate any sloping curve (fig. 6) such as should result from this increase of sensitivity and thus this kind of paracusis can not be confirmated by us. Gunderson (1958) too denies in paracusis patients a true influence of background noise on cochlear sensitivity. According to him paracusis can never be the result of an objective improvement in the signal-noise ratio.

The limits of paracusis

In the greater part of patients suffering from otosclerosis, paracusis is present, but nevertheless by a considerable number of patients the excistence of this phenomenon in denied. Formulating the conditions causing paracusis, we feel the obligation to establish also the conditions in which paracusis is absent. Here, up to now, experimental evidence is lacking and we must base our conclusions on theoretical considerations.

Certain limits for the occurance of paracusis can be established.

1e. If the noise level is under 70 dB or above 110 dB.

2e. If the patient is not deaf enough, he will not need the voive-lift in noise. This will happen when his hearing loss is less than 30 dB — the normal speech level bein 60 dB and the threshold for speech discrimination 30 dB.

3e. If in otosclerosis the hearing for low tones is unusually good preserved the patient will be masked by low pitched noise and consequently will not profit from the voice-lift of his companion.

4e. If the character of the noice is not matched to the hearing loss, f.i. low tone deafness and a high pitched noise or inversely.

5e. If the patient is too deaf, he will not be masked but the increased speech intensity of his companion will not be enough. This will happen when the hearing loss exceeds 60-70 dB; speech of ± 80 dB (60-70 dB normal intensity + 15-20 dB voice-lift) permits a hearing loss of ± 60 dB.

6e. If by courtesy and knowingly the companion raises his voice still more, the upper limit of paracusis will be shifted to a higher level, up to the point where masking sets in. The more the hearing loss is high, the more the patient will profit from shouting in noise.

An otosclerotic patient having the usual hearing loss of ± 50 dB will profit from the voice-lift of his companion in the presence of a noise of 80-100 dB. Above this limit he still may profit from his not being masked, enabling him to hear the same voice intensity in the presence of a higher noise. In a high pitched noise the masking is for all groups much more intensive preventing as well conversational as comparative paracusis.

SUMMARY

Paracusis Willisii is present in about 70 per cent of otosclerotic patients. This phenomenon occurs also in other kinds of conductive deafness and even in perceptive deafness under appropriate circumstances. In our patients with paracusis the mean loss proved to be higher (54 dB), as compared to patients without paracusis (44 dB).

Three factors must coinside to produce paracusis in the patient: a low pitched background noise with a low-tone deafness (or high-tone noise with high-tone deafness) and a proper voice-lift in conversation due to the background noise.

From our measurements in train-compartments it appeared that the paracusis producing train-noise in markedly low pitched, and that the noise level in the compartment is 80-90 dB.

From studying the hearing loss in otosclerosis it appeared that a very marked low-tone deafness exists. After correction for presbyacusis and for the Carhart Notch the curves proved to be remarkably similar for different age-groups, with the air-bone gap diminishing for higher frequencies. A complicating inner ear deafness, probably of otosclerotic origin, was exceptionally encountered (± 5 %).

Voice-lift in noise starts from a noise level of 70 dB viz. when the noise level exceeds the normal speech level by 10 dB. With 90 dB noise the maximum involuntary voice-lift of 15-20 dB was reached. This is to the advantage of the otosclerotic patient. In higher noise levels the voice may be raised, more or less consciously, even further.

The consequences of the coincidence of these three factors is that two kinds of paracusis in otosclerosis exist:

1. Conversational paracusis f.i. improved conversation in the train, due to two factors, namely voice lift by the speaker and not being masked in the case of the patient.

2. Comparative paracusis f.i. adjusting the car-radio to a lower level when the car is in motion, contrary to the adjustment to a higher level by a normal-hearing passenger. This is due to one factor, namely that the patient is not masked.

A true increase of cochlear sensitivity caused by the noise could not be established. Factors limiting paracusis are:

The noise level must be sufficiently high and not too high.

Social-hearing of speech in silence must be absent viz. the patient must be sufficiently deaf but not too deaf.

The character of the deafness and the noise must be matched to each other.

An otosclerotic patient having the usual hearing loss of 50 dB will profit from the voice-lift of his companion in the presence of a noise of 80-100 dB. Above this limit he still may profit from his not being masked enabling him to hear the same voice intensity in the presence of a higher noise.

Patients suffering from perceptive deafness are easily masked by low-pitched noise because their low-tone hearing is relatively well preserved. However, they prove to be also easily masked by high-pitched noises. Theoretically in such patients paracusis should be present if their high-tone deafness is matched to the noise spectrum. In one patient suffering from occupational deafness, a ship-engineer, paracusis was indeed present in the engine-room.

Moreover if by courtesy and knowingly the companion raises his voice still more, the upper limit of paracusis will be shifted to a higher level, up to the point where masking sets in. The more the hearing loss is high the more the patient will profit in noise from this shouting.

RÉSUMÉ

On observe la paracousie de Willis dans environ 70 % des cas d'otospongiose. Ce phénomène apparait également dans d'autre cas de surdité de conduction et, dans certaines circonstances, même dans des cas de surdité de perception. Chez nos malades présentant une paracousie, nous avons trouvé une perte moyenne d'audition plus importante (54 dBs) que celle de nos malades sans paracousie (44 DBs).

Trois facteurs doivent coïncider pour déterminer une paracousie: un bruit environnant donnant une sensation de hauteur basse, avec une surdité pour les sons graves (ou un bruit environnant donnant une sensation haute avec une surdité pour les sons aigus), et un accroissement de la voix normale de la conversation, étant donné la présence du bruit environnant.

Les mesures que nous avons effectuées dans des compartiments de chemin de fer, nous ont montré que le bruit du train produisant la paracousie donnait une sensation particulièrement grave et que le niveau du bruit dans les compartiments était d'environ 80-90 dBs.

Si lon considère la perte d'audition dans l'otospongiose, on 's asperçoit qu'il existe une surdité particulièrement marquée pour les sons graves. Tenant compte de la presbyacousie et de l'encoche de Carhart, les courbes apparaissent remarquablement semblables étant donné les différents groupes d'âges,

avec un écart conduction aérienne-conduction osseuse diminuant pour les fréquences plus élevées. Nous n'avons qu'exceptionnellement rencontré (plus ou moins 5 %) une surdité d'oreille interne par complication, probablement d'origine otospongieuse.

L'augmentation de la voix dans le bruit, commence à partir d'un niveau de bruit de 70 dBs, c'est-à-dire lorsque le niveau dépasse de 10 dBs le niveau de la conversation normale; axec 90 dBs de bruit, on atteint le maximum d'accroissement involontaire de la voix qui est de 15 à 20 dBs. C'est ce fait qui est à l'avantage du malade otospongieux. Lorsqu'il existe des niveaux de bruit encore plus élevés, la voix doit être augmentée plus ou moins consciemment.

La conséquence de la coïncidence de ces trois facteurs, fait qu'il existe deux sortes de paracousie:

1°. la paracousie de conversation, par exemple: l'amélioration de la conversation dans un train, dûe à deux facteurs: accroissement de la voix de celui qui parle et absence de masking environnant uniquement pour le malade;
2°. la paracousie de comparaison, par exemple: le réglage de l'auto-radio à une puissance moins forte lorsque la voiture est en marche, contrairement à un réglage à un niveau plus fort par un passager à l'audition normale. Ceci est dû à un seul facteur: l'absence de masking environnant pour le malade. Un véritable accroissement de la sensibilité cochléaire causé par le bruit n'a pu être démontré.

Les facteurs limitant la paracousie sont les suivants:

— le niveau du bruit doit être suffisamment élevé mais pas trop élevé,
— l'audition de la parole normale dans le silence doit être absente, le malade doit être suffisamment sourd, mais pas trop sourd,
— le caractère de la surdité et celui du bruit doivent s'accorder.

Un malade otospongieux ayant une perte d'audition d'environ 50 dBs profitera de l'accroissement de la voix de son compagnon, en présence d'un bruit de 80 à 100 dBs. Au-dessus de cette limite, il pourra encore tirer un certain profit, car n'étant pas masqué par le bruit environnant, il sera capable d'entendre la voix avec la même intensité, en présence d'un bruit plus fort.

Les malades souffrant d'une surdité de perception seront facilement gênés par le masking d'un bruit donnant une sensation de hauteur basse car leur audition pour les sons graves est relativement bien conservée. Il se trouve cependant qu'ils sont également et facilement gênés par le masking des bruits donnant une sensation aigüe. Théoriquement chez de tels malades, on observera la paracousie, si la courbe de leur surdité pour les sons aigus, s'accorde avec la courbe du bruit. Chez un malade porteur d'un traumatisme sonore, mécanicien de bateau, nous avons observé une paracousie dans la chambre des machines. De plus si par courtoisie ou parce qu'il en a connaissance, le compagnon augmente la voix encore plus, la limite supérieure de la paracousie sera portée à un niveau plus haut, jusqu'au moment où le masking deviendra gênant pour le malade. Plus la perte d'audition est grande, plus le malade profitera de cet accroissement dans le bruit.

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