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Abstract

It has long been a clinically and experimentally well recognized fact that the hearing organs of man and animal would be impaired by the excessive sound stimuli. It has also been pointed out that the hearing organ of each man is not always impaired in the same degree by the same noise, and their impairments show the individual variation in a considerable range. It is indeed not too difficult to imagine, that, under the same acoustic condition, such individual variation of the acoustic impairment owes to the inherent disposition of each man. But at the same time, this individual variation may more or less owe to the patency of the ear tube; the normal tube having a physiological function to control the unnecessary acoustic stimuli, and on the contrary, the stenosed tube being devoid of this function, induces more impairment of the hearing organ. This latter suggestion, which occured to the author, led him to attempt the following experiment.

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Introduction

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This latter suggestion, which occured to the author, led him to attempt the following experiment.

Experimental Procedure

Guinea pigs were subjected to this experiment. Each animal was operated to have an artificial tubar stenosis on the right ear, leaving the other side ear untouched as a control one. The operative procedure was as follows: The animal having been ether narcosed and fixed in the dorsally recumbent position, its bulla in front of proc. jug. ossis occipitis (touchable by the finger) just inside the angle of the right lower jaw exposed, the periost incised

and was retracted to the front until the triangular processus under which the tube ran sagittally appeared, then the tube was exposed with care not to bleed and cauterized by diathermy from outside.

About a week after the operation, the tympanic membrane would be find grayish-white or opaque, and sometimes retracted. At this point the operated animals were given the sound stimuli in a box, from the ceiling of it to be given equal volume of acoustic stimuli on both ears.

Immediately after these preparations as described above, the animals were submitted to the vital fixation, and in a whole process of making the section, from the fixation to the embedding in celloidin, the specimen were treated without separation of both side ears, the left ear being always left as a control.

The serial sections of 20 μ were thus obtained, on which the corresponding parts of both inner ears mount, being cut pararell to the plane which contains both axis of cochleae.

As it is difficult in the animal experiment, to compare and judge precisely the impairment of hearing organ of animal clinically, there is no better way than to do this by means of histologic examination.

It is clinically and experimentally obvious fact, however, that men and animals suffer acoustic lesions in a certain place of their cochleae by the sound stimuli.

The degree of the acoustic impairments of the animal were therefore, measured by the histologic examination.

As the source of sound stimuli, three different kinds of that are used ; a continuous noise, continuous pure tone and explosion. So the author attempt to describe the experiment in 3 Parts according to the kind of stimuli.

Experimental Results

Part I. Study by the Continuous Noise

As a sound stimulus, a siren of 110 phon is used, which has the physical characteristics of fundamental frequency of 400 c.p.s. and the maximum amplitude frequency of 1200 c.p.s., according to the sound wave analysis. (See the spectrum in Fig. 1.)

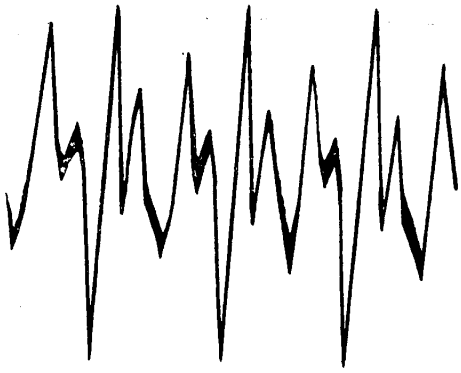
30 animals were operated to have artificial tubar stenosis on the right ear, of which 16 were successful on the otoscopic exa-

mination. 4 among these 16 having been left as control animals, the rest 12 were given the noise on both ears. Among the latter 12, six animals which showed the complete tubar occlusion on the right side ear upon the microscopic examination, presented successful sections.

The histologic lesions of the inner ears of these 6 animals were summarized as follows: the inner ears of all showed the appearance of impairment of the hearing organ by the noise as described in the previous references, and the lesions were severely impaired on the 2nd to the 3rd turns, especially on the lower half of the 2nd turn, and the cells of the organ of Corti of that turn showed remarkable degeneration and atrophy.

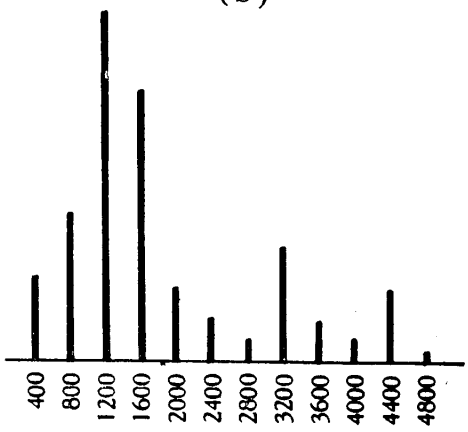
Fig. 1.

(a)



Waves of the siren used in this experiment photographed by a magnetic oscillograph.

(b)

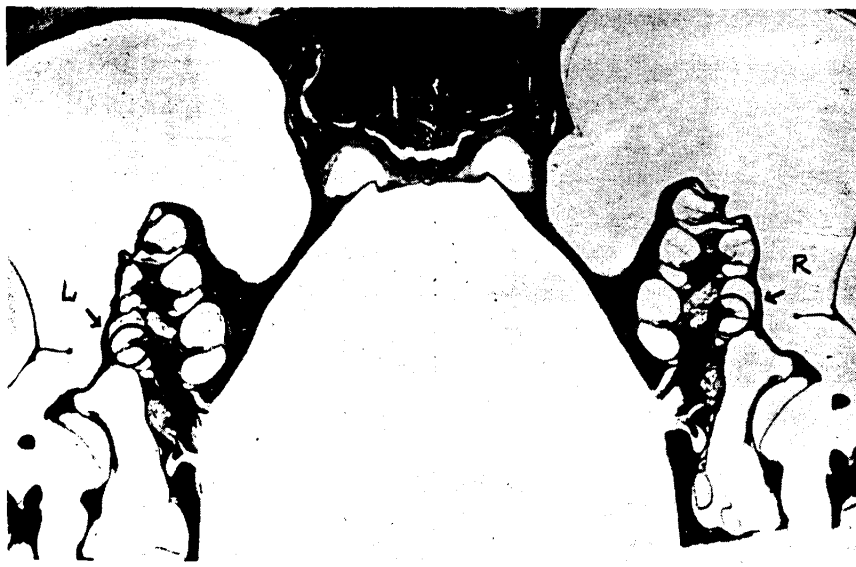


Wave analysis of (a).

Comparison of the lesions between the right and left cochlea in each case, showed little difference in 2 of the 6 animals, but the rest 4 showed remarkable lesions of the cochlea on the tube stenosed side as compared with the left side, and particularly in 1 case of these 4, the difference of the lesions between both cochlea was as striking as illustrated in Fig. 2, showing remarkable contrast of the degeneration of the organ of Corti in the lower half of the 2nd turn of the cochlea. The organ of Corti was as a whole slightly atrophic in the left ear, while in the right tube stenosed ear, it is severely degenerated to the group of cells in a single layer. As a result, the tunnel of the organ of Corti was easily confirmable in the left ear, while in

Fig. 2.

(a)



(b)

(a) Both sides of cochlea on the same section. Inside of ○, the organ of Corti in the lower half of the 2nd turn of both cochleae.
L. normal tube side, *R.* stenosed tube side.

(b) Enlargement of ○, in (a).
R. side much impaired.

the right tube stenosed ear, it is severely degenerated to the group of cells in a single layer. As a result, the tunnel of the organ of Corti was easily confirmable in the left ear, while it is difficult in the right ear. Other cells of the organ of Corti, the external hair cells, *Deiter*'s cells, *Hensen*'s cells and others are all somehow discriminative of each on the left cochlea, but entirely otherwise on the right cochlea. The other 3 cases of the 4 also clearly showed more impairment on the right cochlea, in the same manner, though the difference of the lesions was not so distinct as described above.

The control group of 4 animals which were operated to be stenosed the right ear tube only, but given no noise and survived just as long as the noise-given-animals did, presented sections showing the tubar stenosis on the right ear but no lesion on both cochleae. This was the proof that the foregoing lesions in the cochleae were all exclusively caused by the noise and not at all by the tubar stenosis operation.

Summary:

After having been operated to have an artificial tubar stenosis on one side ear each, the guinea pigs used were on their both side ears given simultaneously a continuous noise of equal volume caused by the siren, and the lesions of the both side ears each were comparatively examined.

1) Upon histologic examination, all of the 6 animals which had been definitely identified as having tubar stenosis on one side ear, showed the lesions of the organ of Corti in the cochleae on both side ears as described in the references so far.

2) 2 of these 6 animals showed no difference of the lesions of the organs of Corti between both cochleae, while the rest 4 showed increased lesions on the tube stenosis side.

3) This suggests that the tubar stenosis acts to accelerate the acoustic lesion of hearing organ.

4) As a supplementary to the physiological function of the ear tube, it is supposed that the ear tube has a function to by-pass an excessive continuous noise as much as possible, to protect the hearing organ.

Part II. Study by the Continuous Pure Tones of High and Low

It was uncovered in Part I that tubar stenosis accelerate the

lesion of the hearing organ caused by a continuous noise. However, it has never been cleared up which of the pure tones composing the continuous noise cooperates with tubar stenosis ; whether high tone cooperates with tubar stenosis or low tone does to give more impairment on the hearing organ. The following experiment was carried out to investigate this point analytically.

As a source of high pure tone a whistle of excellent sound wave was used. It has frequency of 3400 c.p.s. and the loudness of 95 phon. This high tone was whistled for 30 days, 8 hours daily.

For a source of low pure tone, the use of a whistle being technically difficult, an electric oscillator was blown from a loudspeaker through a sound filter and an amplifier. The frequency of it was 256 c.p.s. and the loudness 105 phon. This low pure tone was blown for 60 days, 8 hours daily.

In the high tone experiment, in all 4 animals the lesion of the organ of Corti was perceived in the 2nd turn of cochlea, especially in the lower half of it, and no lesion in other turns. Therefore, the difference of the lesions between both ears was recognized in the 2nd turn and not in other turns. 3 of these 4 cases increased the lesion of the right ear and showed clearly the difference between right and left ear, but the rest 1 case did not show the difference. The difference between both ears, however, was so slight that in the left ear, the cells of the organ of Corti fuse slightly each other, whereas in the right ear, the fusing of the cells somewhat increased and the nuclei of the cells lost its arrangement and stained poorly.

In the low tone experiment, in all 4 animals the lesions of the organ of Corti covered from the upper half of the 1st turn to the 4th turn, but was found mainly in the 2nd and 3rd turn, and slightly in other turns. The difference of the lesions between both ears was confirmed only in the 2nd turn, and the right ear was more impaired. The lesions of the most impaired organs of Corti in the 2nd and 3rd turns of all 4 animals were slight in comparison with those of the 2nd turn caused by the high tone as described before. This accords with the views that the hearing organ is less impaired by the lower tone on account of strong resistance of the organ of Corti in the lower tone part of the cochlea. The lesions of the organ of Corti in the 2nd turn caused by the lower tone are explainable by the auditory pattern of *Fletcher*

Summary:

1) In the experiment where the animals were given the continuous high tone of 3400 c.p.s., the lesions of the organ of Corti were confined to the 2nd turn of the cochleae, especially in the lower half of it, and the lesions were severer on the tube stenosed side.

2) In the experiment of continuous pure low tone of 256 c.p.s., the lesions of the organ of Corti spread from the upper half of the 1st turn to the 4th turn of the cochlea, although the lesions were slighter than that caused by the high tone, and the difference of the lesions between both ears was confirmed only in the lower half of the 2nd turn, the organ of Corti having been more impaired on the tubar stenosis side.

3) These differences of the lesions between both ears by the high or low pure tone were apparently accounted for by the tubar stenosis.

Part III. Study by the Explosion

The professional deafness is not always caused by a continuous noise, but also by one or several or continuous explosions in factories or battle-fields. And it is known in the latter cases severe lesion of hearing organ is often introduced. It seems to be necessary, therefore, to study the effect of tubar stenosis upon the lesion of inner ear which would be caused by explosions. Hence the study was performed by shooting a kind of signal pistol used in races under the same experimental condition as described in Part I and Part II.

The explosion stimulus used in the experiment had a spectrum which contained all frequencies and the amplitude curve of it showed maximum between ca 2500 c.p.s. and 3000 c.p.s. Its loudness was measured by then index-noisemeter to be above 130 phon. The shooting was done at 10 cm above the head of each operated guinea pigs suffering artificial tubar stenosis on its one side ear, 5 times for the 1st group and 50 times for the 2nd group per hour successively for 1 hour.

After a lapse of 24 hours, vital fixation was performed on the animals and the serial sections were made of them for the microscopic observations.

As a result of the observation of the 1st and 2nd groups, it was uncovered that the hearing organ was impaired by the explosion of the signal pistol, mainly at the organ of Corti in the upper half of the 1st turn and secondly at that in the lower half of the 2nd turn, and little impaired in other turns.

The lesion of the organ of Corti was similar to that caused by the continuous tone ; the outer hair cells, *Deiter*'s cells and other cells having been all degenerated and fused each other. The grade of the lesion was slighter than that had been caused by the siren in Part I, but severer than that by the pure tone in Part II.

The difference of the lesions of the organs of Corti between both ears was the most distinct in the upper half of the 1st turn. The difference in the lower half of the 2nd turn was scarcely perceived in the 2nd group. The difference in other turns was not recognized. And the difference was always severer on the tubar stenosis side.

It was expected that the peculiar results might be obtained in this experiment unlike those obtained in Part I and II, because the explosion stimulus, differing from the continuous noise or continuous pure tones, had such physical characteristics as (1) irregular wave, no periodicity, containing almost all the frequencies, (2) more intensity though momentarily to exceed 130 phon of the highest audible range, (3) and severe mechanical action of blast, besides the property of tone. But the result revealed, as described before, no peculiarity except the fact that the upper half of the 1st turn had been especially impaired.

The lesion in the upper half of the 1st turn is considered to be accounted for by the spectrum and the severe sound pressure of the explosion.

Summary :

1) Though explosion stimulus has a physical characteristics remarkably different from continuous noise or continuous pure tone, it gives almost the same lesion to hearing organ as continuous tones.

2) The inner ear with tubar stenosis is much more impaired than that with a normal tube by explosion too.

Comment

It is uncovered by the experiments as described above that the

cochlea with tubar stenosis is more impaired by the excessive sound stimuli in comparison with that of normal tube.

What should account for this increased grade of lesion of the cochlea in the case of tubar stenosis? Some explanations for it will be offered by the author as follows.

1) If it is allowed to postulate that, just as the M. tensor tympani and M. stapedius contract reflective to the excessive sound stimuli and protect the hearing organ from it (*Kato*), both the M. tensor veli palatini which is innervated by the III branch of N. trigeminus as M. tensor tympani and M. levator veli palatini which is innervated by the N. facialis as M. stapedius, as a muscle of tube, contract reflective to the sound and open the tube to bypass the surplus sound stimuli and protect the hearing organ, it becomes evident that the ear with tubar stenosis, being devoid of this protecting function, should be more impaired than that of normal tube by the excessive sound.

2) Excessive sound stimulus is perceived not only by the drum membrane but also by the body surface, especially the head surface, by means of so called bone conduction, consequently it is easily suggestible that the ear with increased perception of bone conduction in the case of tubar stenosis is prone to be more impaired by the acoustic stimuli. *Wittmaack* stressed, according to his experiment, the effect of bone conduction as a factor of acoustic lesion. This must be still more stressed in factory plants where the direct bone conduction due to the vibration of machine is inevitable.

3) When one ear has a tubar stenosis, owing to an insufficient ventilation in the middle ear, the ear tissue reduces its resistance and decreases its ability to recover from the transcient acoustic lesion caused by a single sound stimulus, and likewise, every time the acoustic stimuli superpose on it, the lesion of the ear accumulate until the permanent acoustic impairment is introduced.

4) It is explained, after all, that when a specific people suffers from a severer impairment of hearing organ than the other people by the same noise, the tubar stenosis in that specific people is often accounted for it. This experimental result seems to be quite significant, especially for protective hygienic of factories, in which many employees are apt to contract tubar stenosis caused by the chronic pharyngitis owing to the bad hygienical environment of

factories where dust is abundant and the provision for ventilation and heating are poor, differing from common living houses.

Conclusion

Tubar stenosis is supposed to accelerate the professional deafness.