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Acoustical Measurement of Auditory Tubal Opening

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Several methods for the examination of the Eustachian (auditory) tube have been reported, however, most of them have not been generally accepted in everyday clinical use. This Application Note discusses a simple and reliable method – sonotubometry – for accurate measurement of the tubal opening by using sound transmission through the Eustachian tube to the external auditory canal. It also analyses the acoustic events occurring during swallowing while a steady tone is delivered into the nose.

Introduction

The Eustachian or auditory tube forms a mucous-lined connection between the middle ear and the nasopharynx. The primary function of the Eustachian tube is the equalization of the air pressure between the middle-ear cavity and the atmosphere. The middle ear is normally aerated when the Eustachian tube is opened by muscular action during swallowing. The most common malfunction of the auditory tube is the inability of the tube to open, and less commonly, the failure of the tube to close.

There is general agreement that adequate Eustachian tubal function is necessary for successful middle-ear surgery. If the tube fails to open, air is slowly absorbed from the middle ear and the consequences will be permanent retraction of the tympanic membrane and hearing loss. Thus a reliable assessment of the Eustachian tubal function is of great importance for planning surgical procedures, since a correctly functioning Eustachian tube is an essential prerequisite for post-operative aerated middle ear.

Modern aviation, with its rapid changes in altitude, and rapid plunging by divers, often involve large variations in surrounding pressure. These changes may not be equalized in the middle ear because of a poor Eustachian tubal function in some people, and may cause hearing loss, vertigo and pain. It has been suggested that, before starting training for flying or diving, people should be tested with regard to the function of the auditory tube, in order to avoid choosing unsuitable employment or hobbies.

Various methods for the examination of the Eustachian tube function have been reported with the goal of testing the tubal function in an objective way. One of the methods used for this purpose is based on the transmission of sound through the momentarily opened Eustachian tube, caused by swallowing. In this method the test sound is introduced into the nostril and recorded at the side of the ear. A general discussion of the problems in the earlier studies of the sound-conduction method can be found in reference [2] and therefore will not be dealt with here. The following article will be concerned with a new method of this type – sonotubometry. For a more detailed discussion of sonotubometry the reader is referred e.g. to references [2,6].

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Measuring Equipment

The block diagram of the equipment designed for this sound conduction test is illustrated in Fig.1. The equipment consists of an insert earphone (Hearing Aid Earphone, Oticon A/S, Type AF M8) used as a sound source, a calibrated Condenser Microphone Type 4134 connected to a Preamplifier Type 2619 and embedded in a circumaural earmuff (Exel OY, Silenta-Super), a Heterodyne Analyzer Type 2010 functioning as a signal source, an amplifier and as a filter, and a Graphic Level Recorder Type 2307.

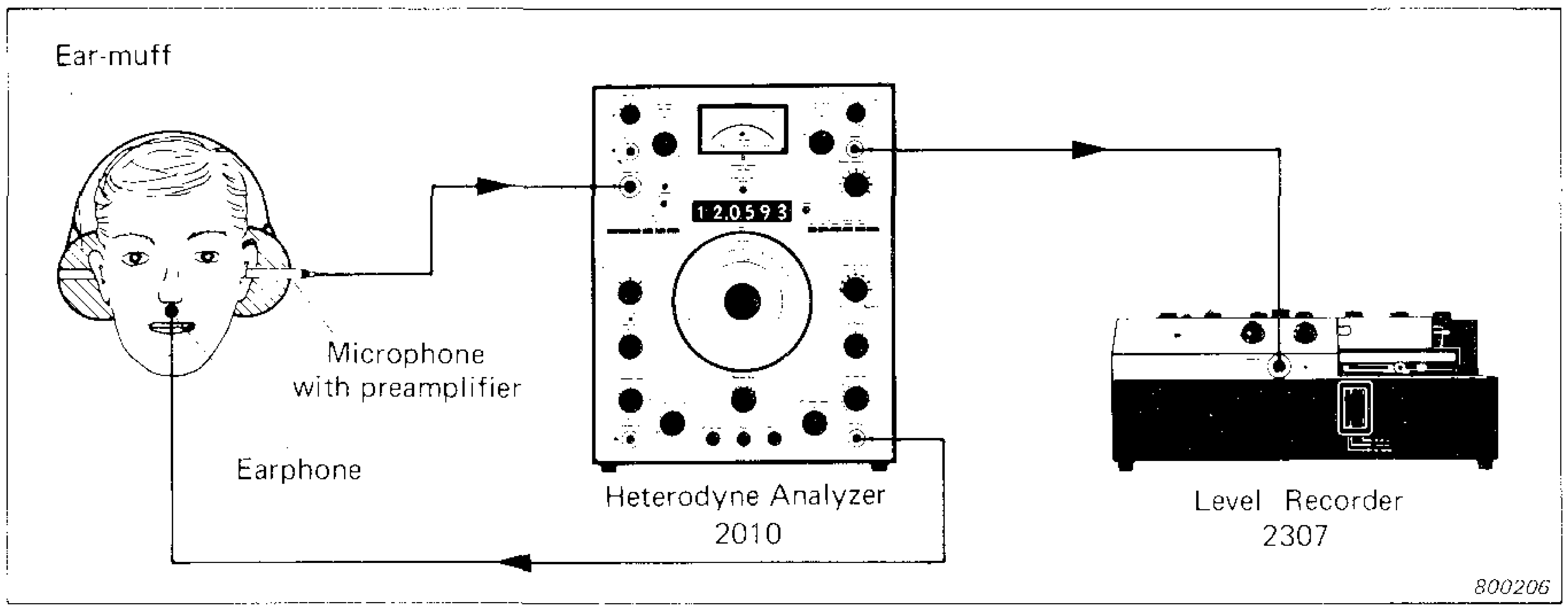

Fig.1. Instrumentation set-up for the test

The insert earphone was connected to an interchangeable nasal olive tip, held snugly by the patient in one of his nostrils. The microphone was coupled into the external auditory meatus with a probe of suitable size (Fig.2). A soft standard ear tip at the end of the microphone probe was slightly compressible enabling it to conform to the contours of the external auditory canal and ensuring a comfortable seal. A thick plastic window was mounted in the wall of the ear-muff and a small light was mounted inside the ear-muff enabling the tip of the microphone probe to be carefully inserted into the external auditory meatus. In the other ear-muff there was a hole for giving instructions to the patient when necessary during the examination. The amplified output of the microphone was fed through a 3,16 Hz band-pass filter in the frequency analyzer in order to suppress background noise, and the sound pressure level from the filter section was recorded by the level recorder. Following trials with various combinations of writing and paper speeds, a writing speed value of 1250 mm/s and a paper speed value of 10 mm/s were chosen, which gave a sufficiently clear record of the essential features of the response.

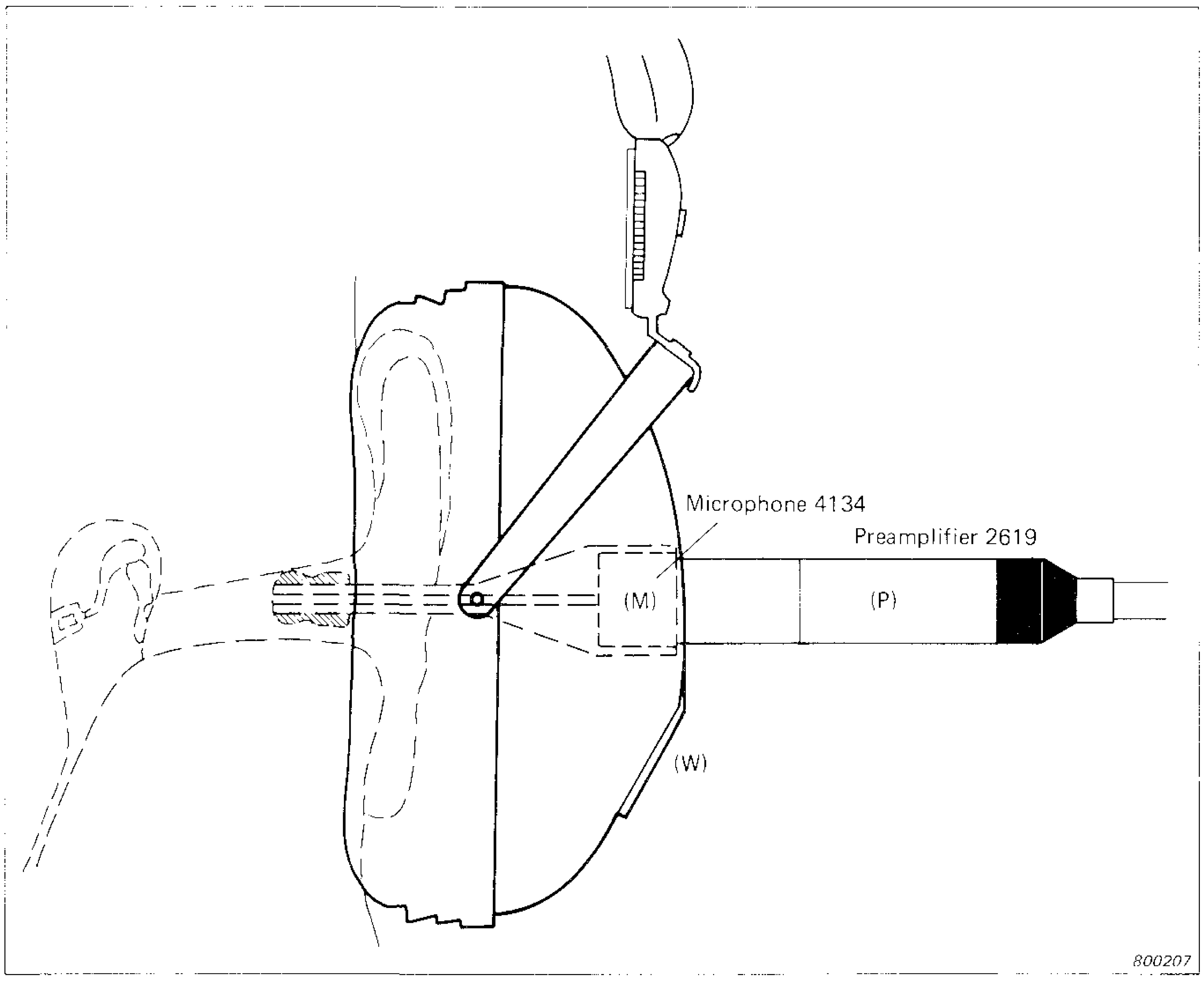

Fig.2. A sketch of the ear-muff with a microphone M, a preamplifier P and a plastic window W

Fig.3 shows typical records of tubal openings obtained on an otologically normal subject with and without test tone delivered into one nostril. A low level signal, due to vibration of the soft tissues and bones of the head, is recorded as background level and becomes the base-line on the recording paper.

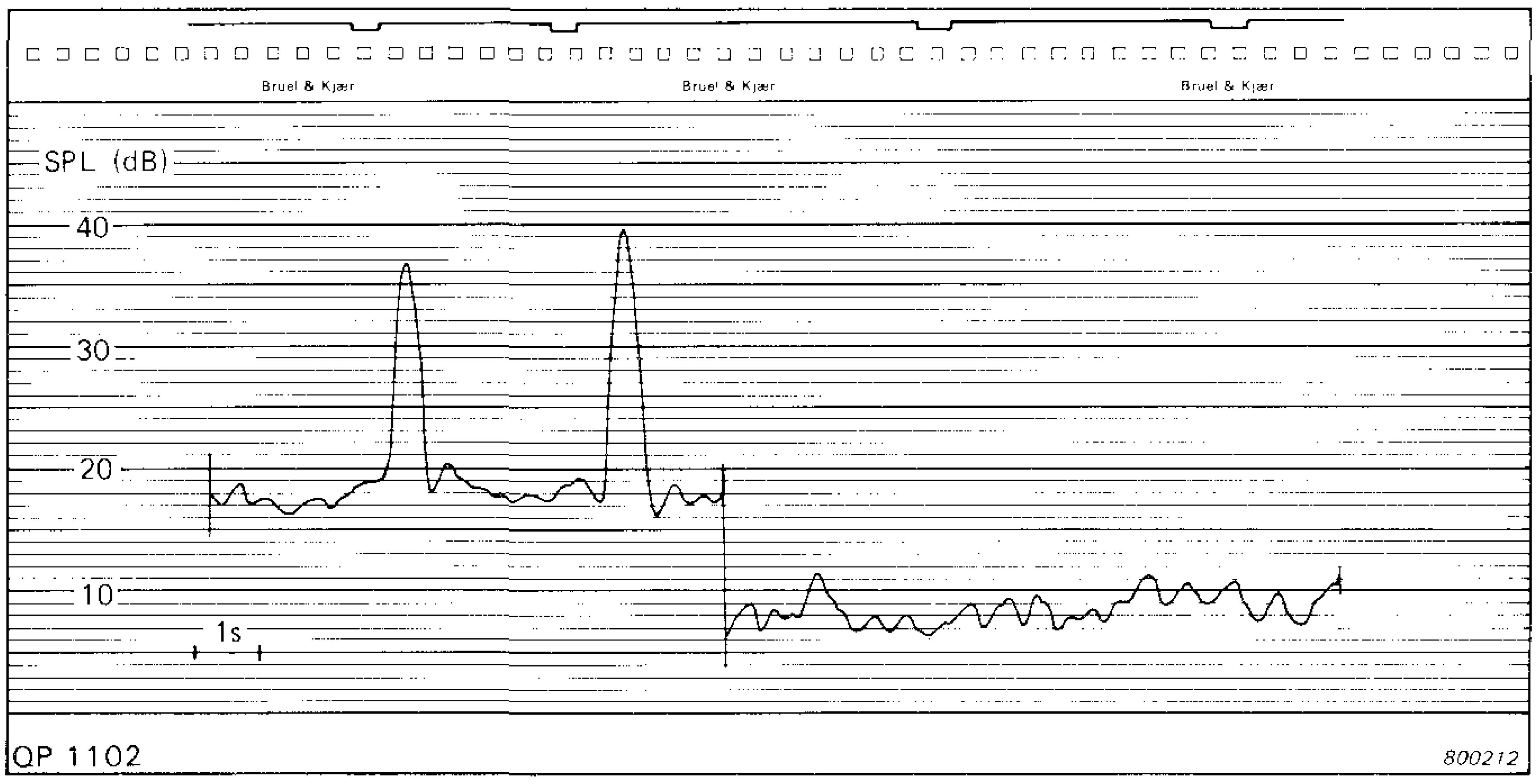

Fig.3. Typical records of tubal openings with a 7 kHz tone (left) and without tone (right) introduced into the nose and recorded at the external auditory meatus. At the top of the chart the markings of the swallowing moments

Preliminary experiments

In order to evaluate the mechanics of sound transmission through the Eustachian tube during swallowing and to interpret the acoustic phenomena related to tubal function as measured from the ear canal, the following experiments were carried out.

Sensitivity of earphone to pressure change

During ordinary swallowing the open state of the nose does not allow any pressure changes to develop in the nasopharynx, but under conditions of nasal obstruction pressure changes in the nasal cavity may be generated. It is thus possible that these pressure changes (+ 32 mm Hg to −34 mm Hg) in the nasal cavity may influence the earphone diaphragm. The effect of these rapid changes of static air pressure on the sensitivity of the earphone was determined as follows.

The earphone was made air-tight by means of a suitable adapter to the coupler of the Pistonphone Type 4220, and a pressure change in the coupler was produced manually by means of a syringe, and registered with a manometer. Here the earphone was used as a microphone, because the relative change in its sensitivity is the same as when it is used as a sound source, and the Pistonphone was used as a constant level sound source (124 dB SPL at 250 Hz frequency). The output voltage of the earphone was mesured as a function of the static pressure generated in the coupler, and fed to the Level Recorder.

The change in the output voltage of the earphone was found to be less than 1 dB for an abrupt change of static pressure from + 40 cm H_2O to −30 cm H_2O. Thus possible pressure changes in the nasal cavity do not influence the sensitivity of the earphone during swalloging and can be disregarded.

Transfer function between nostril and ear canal in the frequency range 100 – 2000 Hz

A sinusoidal test sound was delivered to one nostril through the nasal olive and the frequency response curve was recorded in the range 100 – 2000 Hz from both ear canals and also from the other nostril on 15 subjects without them swallowing.

Fig.4 shows some frequency response curves (A) when recorded from the ear canal and (B) from the other nostril. As can be seen they are similar in form but the levels of the base-line are different depending upon whether the test sound was picked up from the other nostril or from the external auditory meatus. There are resonance and antiresonance peaks in all of the recorded curves and they vary significantly even for the same subject in successive measurements.

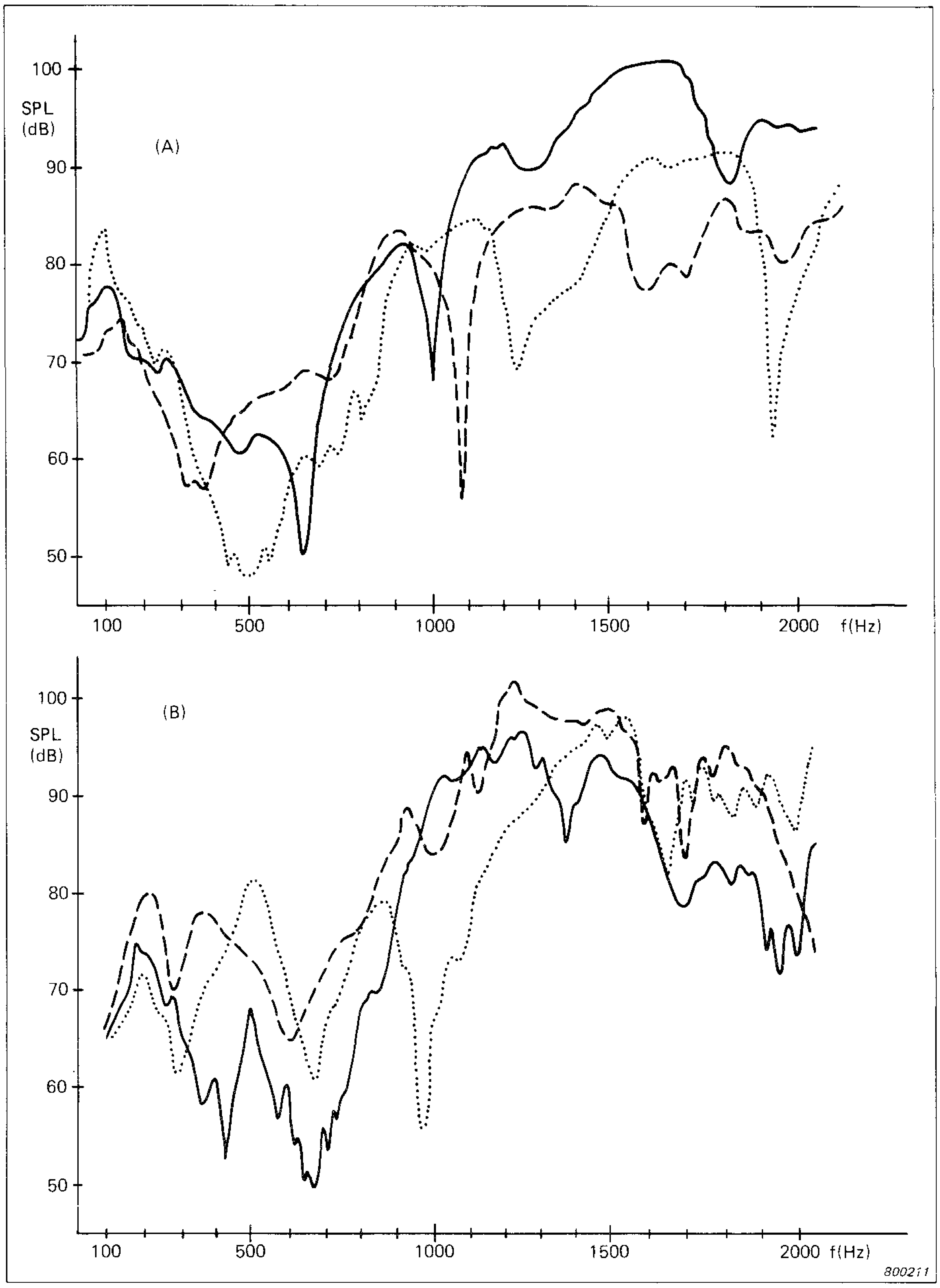

Fig.4. **Individual response curves in the range 100 – 2000 Hz as mesured (A) from the external auditory canal, and (B) from the other nostril. The curves drawn with a continuous line represent the same subject**

Fig.5 shows how the test tone of 500 Hz (B) is attenuated, while the one of 400 Hz (A) describes the tubal opening in successive swallowings very clearly. The tubal opening response without the test tone (C) exhibits a component of 400 Hz from the swallowing sound which was able to pass through the filter. On the frequency response curve of the same person a corresponding antiresonance peak can be seen at 500 Hz.

Spectrum of swallowing sound

The frequency analysis of the swallowing sound itself was measured from the external auditory meatus in 14 normal adults. The test procedure was as follows: each subject, while sitting in a relaxed position quietly, and with the mouth closed was asked to swallow either a sip of water or saliva several times. The sound of swallowing was picked up by the microphone inserted in the circumaural ear-muff, and a third-octave spectrum was obtained from both ears of each subject using a Real-Time 1/3 Octave Analyzer. The integration time of the analyzer was chosen such that the complete event was averaged and captured on the display.

The spectra of all the swallowing sounds showed to be similar on the display screen. 35 of these spectra were chosen at random, the mean value of which is shown in Fig.6 where the broadband character of swallowing sound can be seen. The variations in the spectra from different swallowings of the same subject were most significant in the frequency range of 100 – 2000 Hz, and above 7 kHz the sound pressure did not exceed the level of 30 dB.

The frequency response curves meaured from the external ear canal and nostril were similar in form to the spectra of swallowing sound in the range of 100 – 2000 Hz. Thus, the swallowing sound is also influenced by the resonance and antiresonance effects of nasal and oral cavities, hypopharynx and pharynx. On the basis of these data the frequencies most suitable for the Eustachian tube opening measurements would be the high frequencies, above 6 kHz, where the intensity of swallowing sound is weakest.

Tubal opening response in the frequency range 1 – 20 kHz

Measurements of the tubal function were made on 42 otologically normal persons. After delivering the

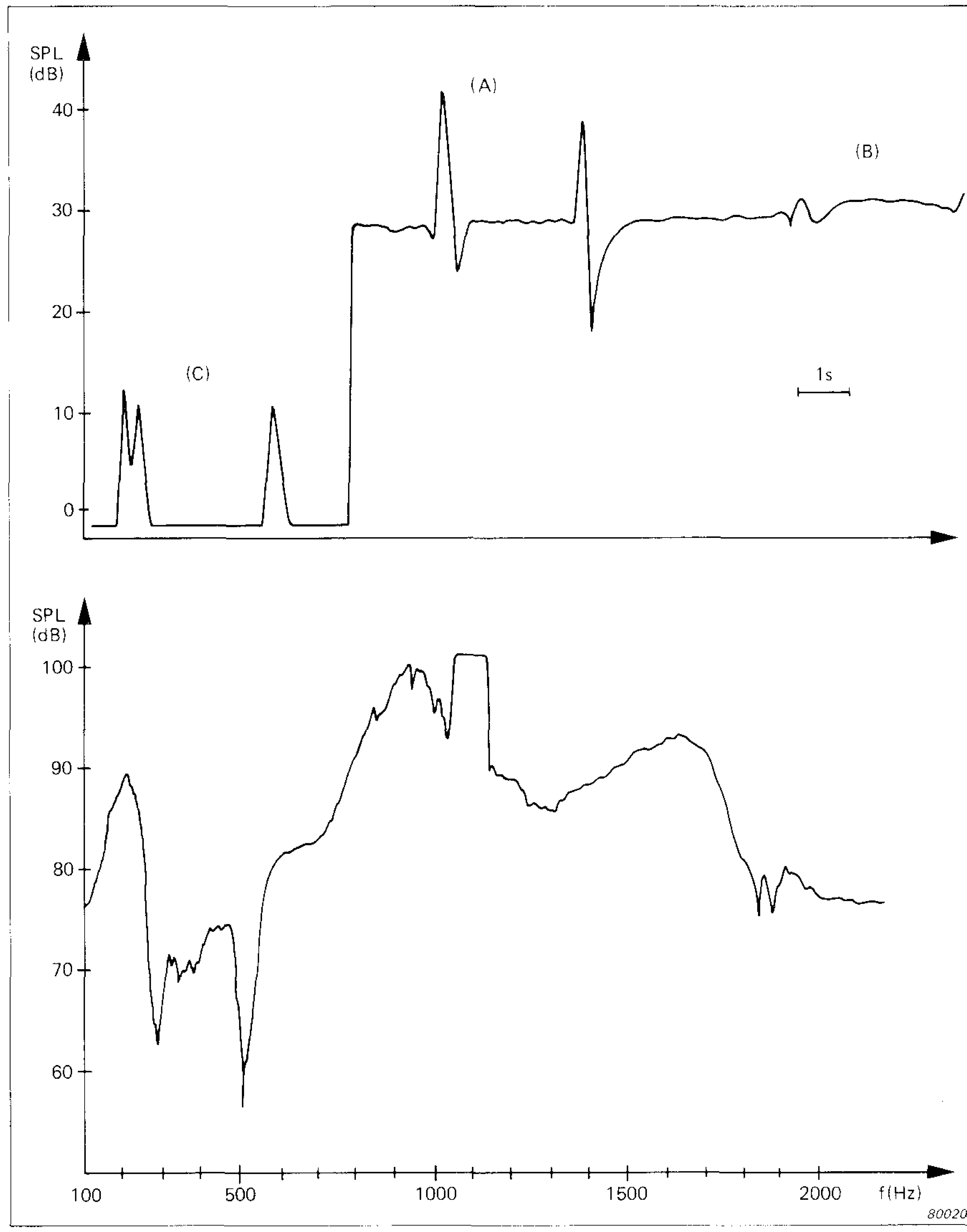

Fig.5. Tubal opening response with a test tone of 400 Hz (A) and 500 Hz (B) and without the test tone (C). Below, frequency response curve from 100 – 2000 Hz measured at the ear canal of the same person

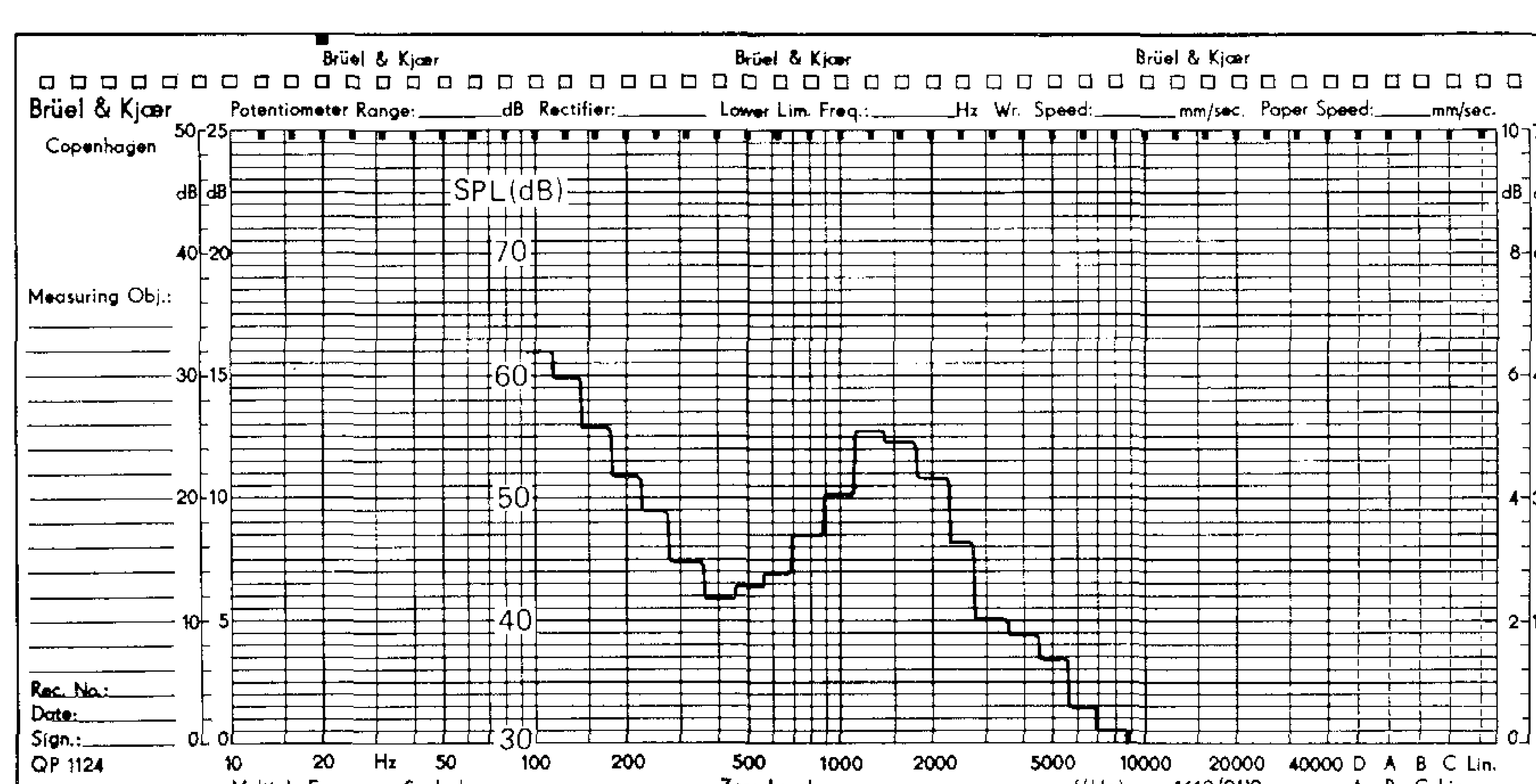

Fig.6. An average third-octave spectrum of swallowing sound recorded at the external auditory meatus

test tone to the nose the subjects were asked to swallow first a sip of water, and then saliva. This was done in one kHz increments in the range of 1 – 20 kHz. For analysis of the results an opening response was considered affirmative if the increase in the sound pressure level was ⩾ 5 dB at the moment of swallowing. It is probable that with this criterion some smaller openings are overlooked, but pen excursions are easily distinguished from the background activity recorded from the external auditory canal. It can be seen (Fig.7) that the response of the tubal opening was most evident at 6, 7 and 8 kHz.

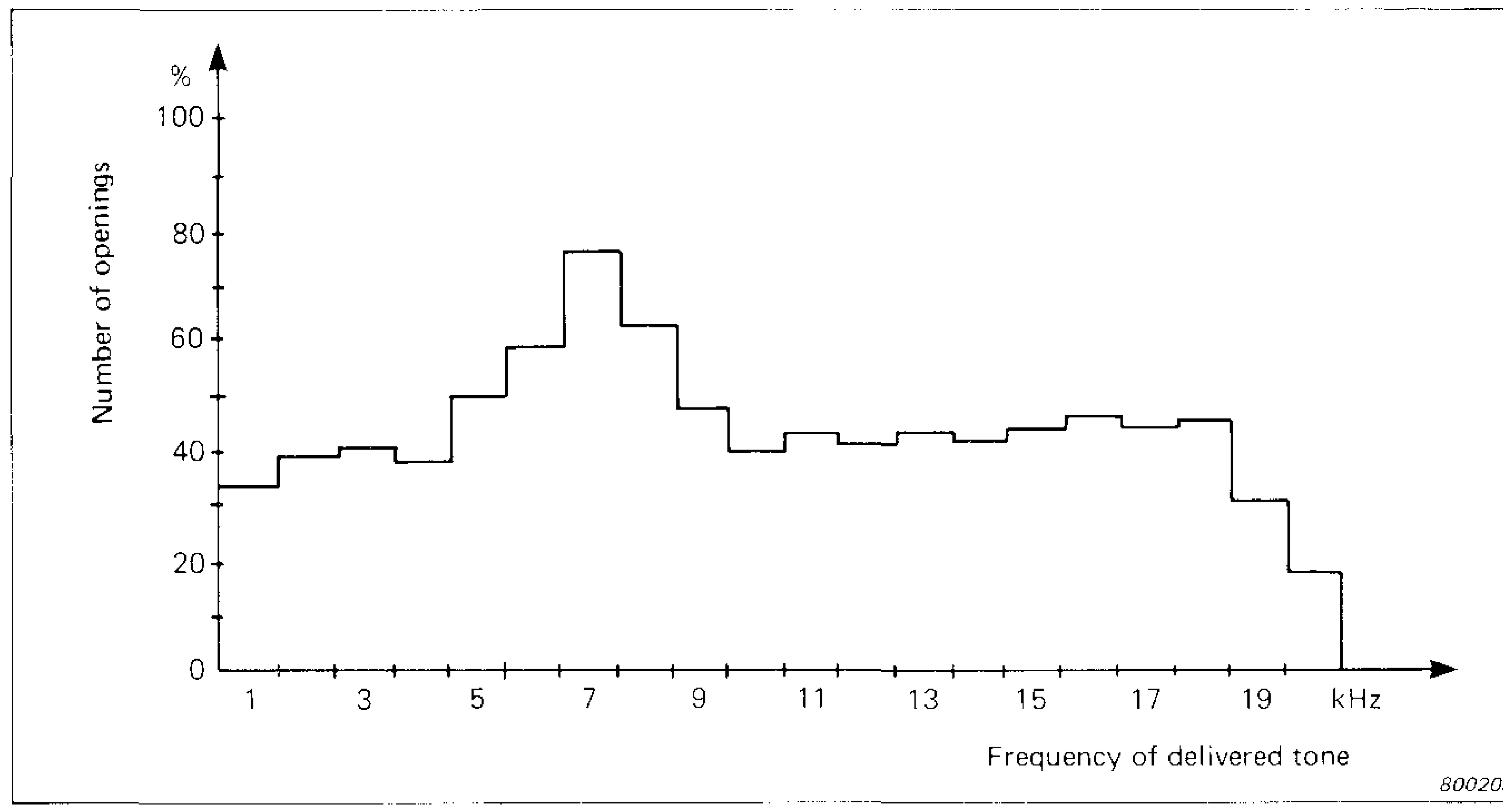

Fig.7. Tubal opening responses in 42 otologically normal subjects in the frequency range 1 – 20 kHz

Conclusions

The results of the experiments revealed that the useful frequency range for measurements by the sound conduction method is above 6 kHz. One may reasonably expect that various kinds of resonance effects of head cavities also influence the higher frequencies (> 6 kHz), but the wider dynamic range here makes it possible to record the acoustic phenomenon. Since the use of only one frequency did not always provide reliable information on account of the resonance effects, use of three frequencies (6, 7 and 8 kHz) is generally advisable. Ambient noise does not interfere with the test and even small changes in the acoustic energy can be recorded. The change in the sound pressure level, indicating tubal opening, was registered in 95% of normal subjects during swallowing. Repeated tests showed good reproducibility and the experiments performed in the presence of the upper respiratory tract infection testify to the sensitivity of this method. A thorough discussion of these experiments can be found in reference [2].

Sonotubometry is a physiological test and as such gives a reliable picture of the opening of the Eustachian tube during swallowing.

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