Principles and acoustical foundations of the computer-based hearing screening method

H. Skarzynski, A. Czyżewski, B. Kostek
Institute of Physiology and Pathology of Hearing
Warsaw, Poland
e-mail: hearing@telewelfare.com

The hearing impairment is one of the fastest growing diseases in modern societies. Therefore it is very important to organize screening tests allowing to find people suffering from this kind of impairment. The computer-based system was designed to conduct hearing screening, mainly in children and youth. The test uses automatic questionnaire analysis, audiometric tone test procedure and testing speech intelligibility in noise. The starting point of the test, is an automatic interview with the individual to be tested. Based on the interview, the electronic questionnaire is filled out. After the questionnaire has been filled out and the specially conceived three tone audiometric test is completed, it might be selected the mode of the speech-in-noise based test as appropriate for the specific age. When all the testing is completed, the system "I CAN HEAR..." automatically analyzes the results for every person examined. Based on the number of wrong answers those who may have hearing problems are referred to co-operating medical consulting centers. In the paper foundations and principles of the hearing tests are discussed and results of testing of more than 200.000 children with this method are demonstrated.

I. INTRODUCTION

The objective of the audiometric measurements using computer-based system is to conduct a quick and at the same time credible assessment of the hearing sensitivity of individuals. The system solves the problem of making audiometric measurements easily accessible for the public by providing cost-effective solutions based on the software for testing hearing installed in local personal computers or in network servers.

The telemedicine project called “I can hear...” [1][2][3] enables mass screening to identify people who are suffering or may suffer from hearing problems, using a standard multimedia PC terminal, and to direct those identified to appropriate centers for medical care. The system was developed in collaboration between the Warsaw-based Institute of Physiology and Pathology and the Technical University of Gdansk and was supported by the Ministry of Health. It addresses the technical difficulties of organizing mass screening tests of hearing caused by the low number of audiometric equipment and their high cost. The project was targeted at screening school children thus enabling schools to use the system to detect hearing problems that can cause difficulties in learning, and then directing these children to the network of medical consultants. The network provides the "link between the virtual reality of cyberspace and real life", with its existing medical personnel and facilities.

The important features of screening examinations are the costs and sensitivity given in [%]. This rate shows how effective the test is in distinguishing people with hearing impairments from an entire population. The screening methods known so far can be divided into three groups:

- questionnaires only
- physiological and audiometric measurements [4]
- both questionnaires and measurement tests.

The concept of screening examinations presented in this paper belongs to the last mentioned group. The test includes interviews, electronic questionnaires, three tone audiometric tests and speech-in-noise tests. Persons showing signs of difficulty and not passing the set thresholds are then referred to specialized centers which have been connected via the Internet and provided with special database access that allows them to automatically register and track patients. Pictograms instead of text are used for young children in the speech-in-noise tests, and the screening tests are supervised then by adults. Parents are engaged in the process by completing questionnaires, which heightens their awareness of possible problems.

II. TECHNICAL MERITS

Even though the audiometers known and manufactured today are very well suited for hearing measurements, they are specialized devices manufactured in relatively small quantities, which makes them costly and not commonly available. At the same time, due to the growing epidemiology of hearing impairments and the resulting demand for hearing loss prevention, audiometric testing needs to be done in schools, in local health centers and other health care and medical institutions as well as in workplaces exposed to noise risk. As the personal computer is becoming more and more common and given the fact that it has the capacity to read data recorded on optical, magnetic or magneto-optical media, it seems possible to increase the availability of audiometric tests using a computer-based hearing screening system. Moreover, to make audiometric tests more available is to allow the tests to be done via a computer networks, e.g. Internet network. In this case, a computer that stores measurement signals may also serve as audiometry signal network server. Thanks to this solution test signals can be played back by another computer provided with properly calibrated amplifier and headphones and connected to the server via a computer network. Therefore, the system solves the problem of how to develop a new method of making audiometric measurements without having to use specialized diagnostic devices.

Commonly known and used are numerous types of audiometers including those based on digital and microprocessor technology, which are made as specialized measurement devices. The current advancement of methods for digital signal recording makes it possible to store the signals directly in the digital form on computer media. Also, their amplitudes and frequencies are accurate and highly stable. Therefore, there is no need to use a design with an additional converter connected to a source of model voltage, neither is it necessary to perform a computer synthesis of measurement signals.

A computer software controls the playback of test acoustic signals. The characteristic feature of this solution is that the circuits which feed acoustic signals to the patient's headphones or to the bone vibrator are plugged into the acoustic output of the disk drive or to another acoustic output of the computer. The computer audiometer can be operated manually or automatically. In the automatic mode the computer software controls on its own the playback of test signals recorded on a disk. It does it by periodically changing the tracks being read. The tracks contain signals with successive measurement frequencies of various levels for threshold audiometry or speech-in-noise signals for speech audiometry.

III. SYSTEM DESCRIPTION

The computer-based hearing screening system is shown in Fig. 1. It consists of a personal computer (1) and a disk drive (2) coupled through its acoustic output with the acoustic amplifier (3), with the gain calibrated through the control (4) and with an optional voltmeter. Headphones (5a) or a bone vibrator (5b) are plugged into the amplifier output. The amplifier is an external device or it can be a part of the drive circuitry or computer card circuitry playing back the audiometric signals. The disk (6) with the program/test signals recorded on it is used for audiometric measurements. The installed software helps to carry out audiometric measurements by controlling the readout of signals from the disk (6) and record patient's responses and visualize and also archive the results from the audiometric measurements. The acoustic amplifier is made as a miniature electronic device and placed in the casing of the CD-ROM disk drive.

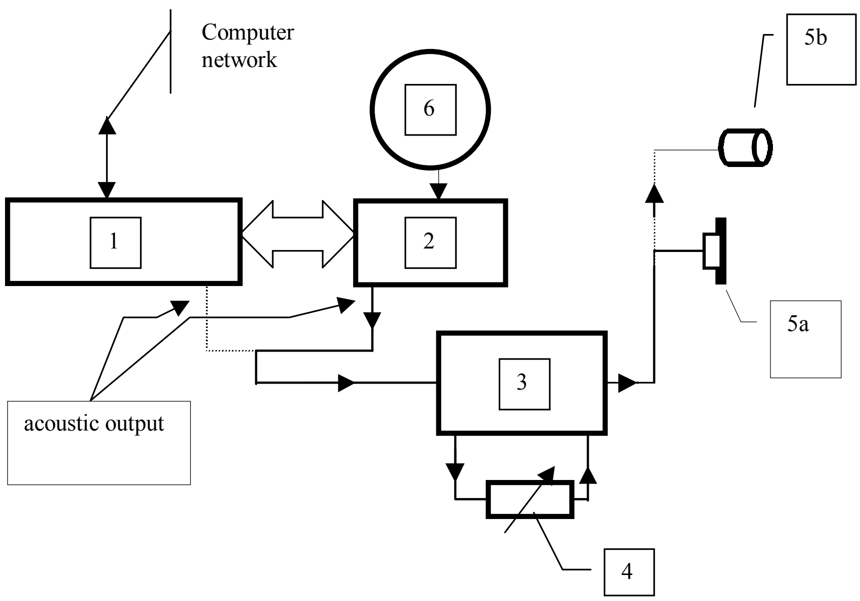


Fig. 1 Block diagram depicting a computer-based system for hearing screening

The software includes a user interface for the operator to communicate with the computer audiometer plus a set of procedures to control the readout of acoustic signals recorded on the CD-ROM disk and some routines to produce diagrams on the screen showing the characteristics of the threshold hearing level versus the acoustic stimulus frequency. The computer audiometer software and test signals can be also uploaded from the computer network, e.g. Internet as an installation package. The next option is such that the audiometer software and test signals are installed in the remote server and the PC connected to the network is using this software without a necessity of its local installation. The hearing sensitivity characteristics from the measurements can be stored in the archives of the computer database for future reference and comparison with the audiometric characteristics of the same patient taken before or with other patients' audiometric characteristics. In Fig. 2 a screen shot of the system is shown [3].

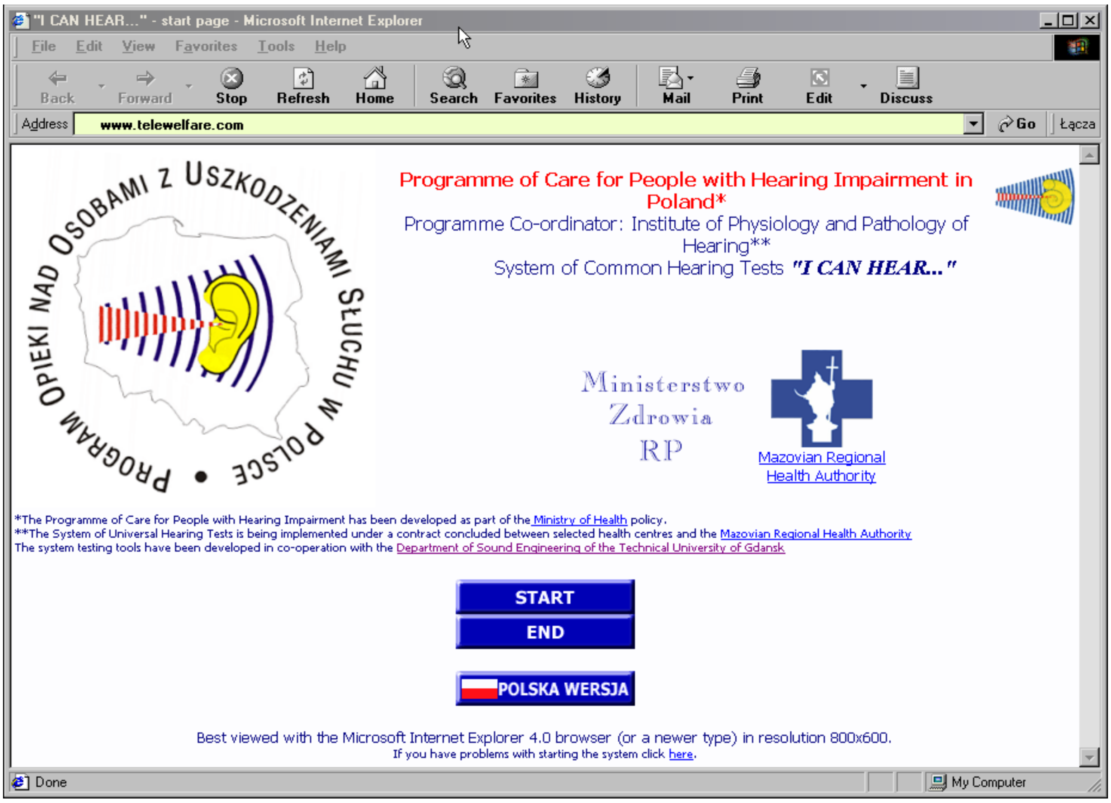


Fig. 2 Screen shot of a computer-based system for hearing screening

IV. SYSTEM CALIBRATION

It is obvious that any device that would serve as an audiometer should be calibrated first. It should be however remembered that research shows that about 44% of audiometers used in practice make errors when showing the level and in about 30% of audiometers frequency errors were found. In 3% of the audiometers tested errors were found in terms of the times of rising and falling of sound [5].

The calibration procedure is two-fold. First, at the system provider side the calibration test signal, e.g. a tone at a frequency of 1000 Hz and control at 0 or –20 dB compared to the maximal control available in the computer is generated. The idea of the calibration procedure is to adjust the computer amplifier to a level of say 60 dB SPL. Next, using the internal potentiometer the calibrator is programmed, so that it "memorizes" the given value of voltage (Fig. 3). During the initial calibration the output of amplifier is connected to the voltmeter, and the headphones of the computer audiometer are coupled with an artificial ear and acoustic analyzer. Through the analyzer, measurements of the level of acoustic pressure are made. In the conditions described above gain controller is set to ensure that the headphone produces acoustic pressure at a level that will match the audiometric zero. Next, the computer audiometer plays back signals recorded on the disk at the level of 0 dB, which match other measurement frequencies. In these conditions, the sound level meter of acoustic pressure coupled with the artificial ear may show values different from the audiometric zero, caused by the deviations resulting from the specific frequency characteristics of the signal channel and the headphones. These deviations are compensated for. The deviations from the audiometric zero, which are measured for the particular frequencies different from 1 kHz, in the process of calibration will be recorded in the computer memory and then used for automatic equalization of the transfer characteristics of the audiometric channel while the computer audiometer is being used.

In the user procedure no costly artificial ear or sound level meter are required. After the program for screening audiometry is activated it asked to perform the following steps:

1. Shut out any unnecessary sources of sound, e.g. close the window, etc.
2. Connect the headphones and calibrator to the computer as shown in the picture (Fig. 4). In automatic equalization of the computer audiometer transfer characteristics, the recorded value of the deviation matching a signal of a specific frequency is added to the level of the same frequency signal being played back.

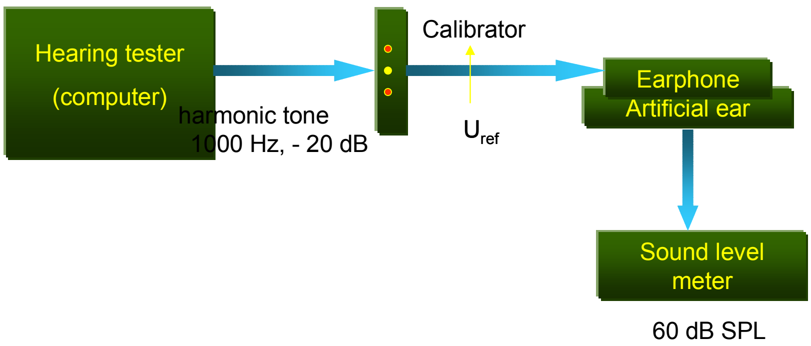


Fig. 3 Calibration procedure (part I)

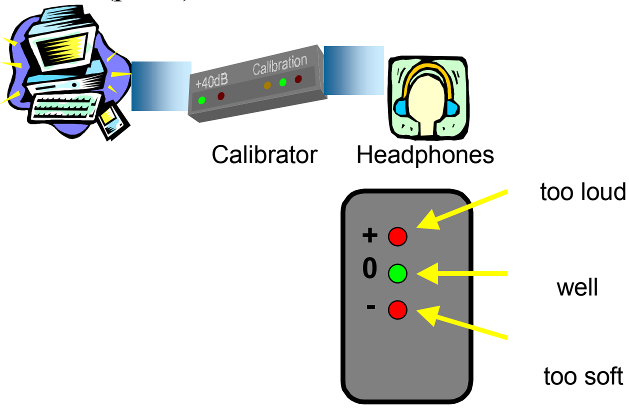


Fig. 4 Calibration procedure (part II)

V. SYSTEM OPERATION

Three modes of operation are envisioned in the system. First, a questionnaire form is filled in by the system operator or the person (an adult) performing tests himself/herself. The next step are audiometric tests. According to the standard ASHA (American Speech-Language-Hearing Association) proposed in 1985, the idea of an audiometric screening test should be such that the child being examined should hear in both ears 3 tones at frequencies of 1000 Hz, 2000 Hz and 4000 Hz at levels of 20 dB HL. Therefore such tests are performed. The last phase is speech-in-noise tests.

The main advantage of speech audiometry is that, contrary to tone audiometry, it measures not just the receiving and conduction features of hearing but also the entire mechanism of hearing and perception.

Speech audiometry basically involves two types of thresholds. The first one is the speech detection threshold (SDT). It is defined as the lowest level of signal for which speech is heard 50% of the time. The second type of threshold is the speech recognition (SRT) defined as the lowest level at which speech is recognized 50% of the time (see Fig. 5) [4]. This kind of tests is organized in such a way that noisy speech patterns are played-back to the examined subject and he/she is asked to select a picture on the computer screen corresponding to the perceived word. The computer program counts accurate and wrong answers, calculates the statistics and on this basis provides the assessment of the subject's hearing ability.

The speech-in-noise tests address both school children (tests employing words) and pre-school children (tests employing pictures). 20 words or words with accompanying pictures are presented in noise to the subject in a random order. The subject is asked each time to select the corresponding word or picture.

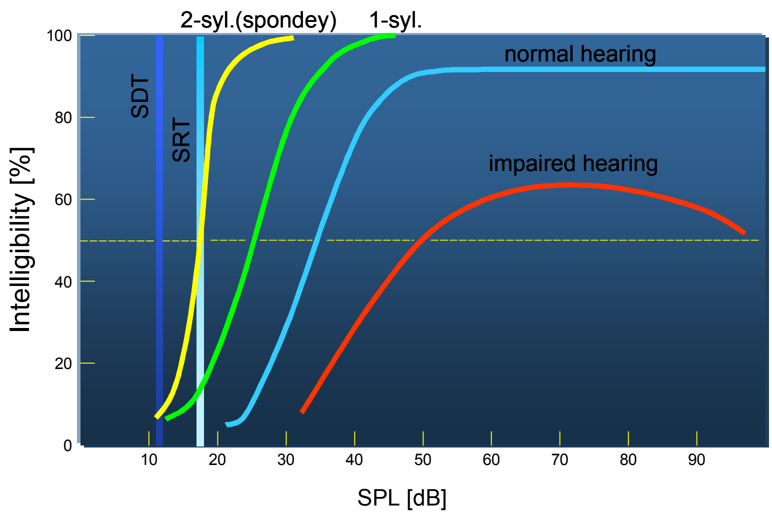


Fig. 5 Speech-in-noise hearing thresholds

The sample statistics of the processed results obtained from questionnaires may be seen in Fig. 6. In addition, in Fig. 7 scores from the pilot tests are presented. They correspond to the three-tone testing. Three tones and three silence passages are sent to each ear, so that maximum score is 12.

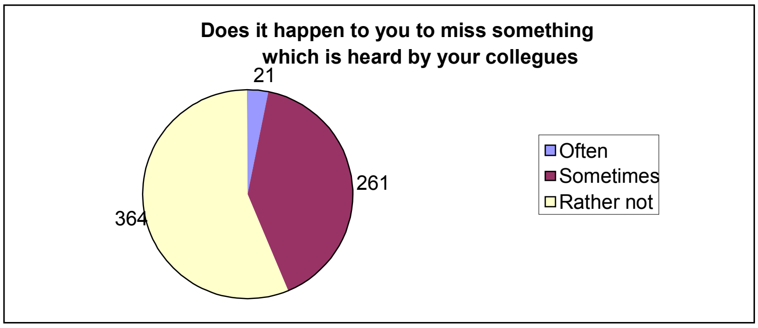
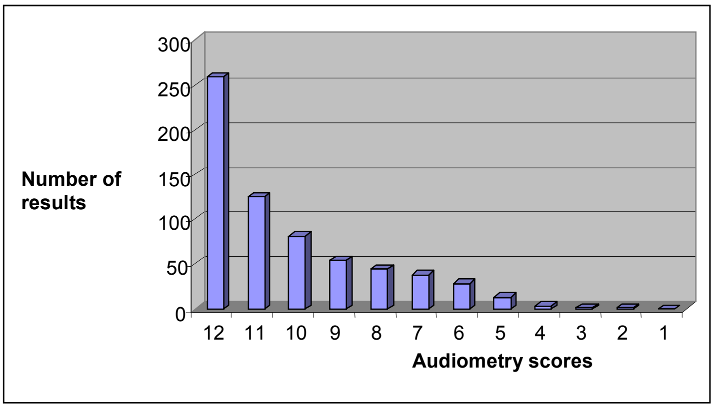


Fig. 6 Exemplary questionnaire processing



CONCLUSION

This paper showed that mass hearing screening tests using state-of-the-art telecommunications and multimedia technologies would enable to discover existing hearing impairment problems in children, and at the same time show reasons for slower progress of learning in some school children. In Poland, it is envisioned that 4 hundred thousands children would be tested every year with the "I can hear..." system.

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