

Upper Frequency Limit of Hearing – A New Screening Method or an Illusion?

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Received April 17, 2013; Revised June 18, 2013; Accepted July 03, 2013

Abstract The aim of this study was to develop a prototype generator with electro-acoustical connection, verify the parameters of the new apparatus, perform clinical trials in patients with normal hearing. A digital oscilloscope and artificial ear were used to check electrical and sound parameters. Sound intensity in the 0.5-20 kHz frequency range was 86.8 ± 9 dB SPL. This was followed by clinical trials involving 44 volunteers (17 men and 27 women) with an average age of 20. Before the experiment, each volunteer was examined by audiological tests to rule out damage to the auditory pathway. The upper frequency limit of hearing procedure consisted of binaural administration of constant-intensity signal with a frequency smoothly varying within the 20 kHz - 0.5 kHz range. The volunteer was told to release a signaling button when he heard the acoustic signal. At that moment, the generator stopped at a given frequency that was displayed on a digital scale unit. The test procedure was repeated three times in each subject and the arithmetic mean of three measurements was used in further analysis. The entire procedure, both technical and clinical, was conducted in an audiometric silent chamber, in which it was possible to control the acoustic conditions. Comparison of results of a prototype apparatus to the results obtained in previously research showed that the developed apparatus specifications meet their objectives. In clinical studies, the upper frequency limit of hearing results were as follows: in the group of 17 people only one person was below 75 percentile, two were at 75 percentile, ten at 50 percentile, and four were at 25 percentile. The results show that the modification of the apparatus involving the use of less expensive components has allowed to obtain the technical parameters and results comparable to the others authors and, therefore, the apparatus built by the authors of this paper may be used as a screening apparatus.

Keywords: *upper frequency limit of hearing, hearing loss, noise, digital generator*

Cite This Article: M. Bak, and K. Rosniak-Bak, "Upper Frequency Limit of Hearing – A New Screening Method or an Illusion?" *Journal of Biomedical Engineering and Technology* 1, no. 3 (2013): 31-35. doi: 10.12691/jbet-1-3-1.

1. Introduction

Until quite recently, noise was considered to be the only causal factor of occupational hearing loss. In the light of present knowledge, it has become evident that hearing loss due to noise can be aggravated by some ototoxic chemicals, and organic solvents in particular. These include among others: toluene, styrene, n-hexane, trichloroethylene. Their detrimental activity is associated both with the adverse impact on the peripheral portion of the hearing organ (styrene) and the central parts of the auditory pathway (n-hexane). Despite the frequent occurrence in the industry of combined exposure to physical and chemical agents (as in the case of noise and organic solvents), the exposure limit values and intensities are based on the isolated effects of the two exposures. However, the combined effects of these agents are more dangerous than the anticipated theoretical values [1-17].

For a long time, it has been known that noise causes hearing damage first of all at very high frequencies - above 8 kHz (similar effects are also valid for organic solvents). Unfortunately, pure-tone audiometry for

methodological reasons used to assess that high frequency fails to perform as required. Therefore, Morioka et al. developed a method of determining the upper limit frequency hearing loss that has proved to be a new successful clinical tool. The advantages of this method include: the possibility of obtaining a reliable result for each patient, regardless of the severity of hearing damage, and simple test procedure that does not required highly qualified personnel to operate the measuring set [18,19,20,21,22].

The aim of us current work was to develop a new version prototype apparatus able to determine the upper frequency hearing limit, review technical specifications of the new-developed apparatus, perform clinical studies in volunteers with normal hearing, and to compare the results with those obtained by Morioka et al.

2. Material

2.1. Technical Material

Work on the prototype was divided into two stages. The first stage was designed to develop and build a generator

of an electrical signal adjustable in the 0.5-25 kHz frequency range. The electrical characteristics of the generator were confirmed to correspond to the requirements. The second stage comprised measurements of the electro-acoustical connection intended to test its suitability for use in the upper frequency limit of hearing method. Unlike in the apparatus developed by the authors of that method who used Bruel & Kraejer microphones as the electroacoustic coupler, we have used brand-new Koss model HV-Pro headphones designed for standard high-frequency audiometry to reduce the cost of building the prototype system (the microphones used by Morioka are very expensive and constitute 2/3 of the cost of building the entire system).

A Maxim MAX 038 specialized chip was used as the signal source [23]. The chip is a precision, high frequency generator that makes it possible to obtain an output signal of 0.1 Hz to 20 MHz, depending on the values of capacitance and resistance elements connected to it. The manufacturer offers the possibility to obtain sine wave, rectangular or sawtooth output with a frequency specified above. Because the test procedure requires that the acoustic signal changes over time, digital potentiometers have been included. A digital frequency meter was used to indicate the hearing limit. Koss HV-Pro headphones were used as the electro-acoustical connection. According to the manufacturer's specifications, their passband bandwidth is up to 25 kHz. Real view to prototype is on Picture 1 and schematic diagram of the apparatus is shown in Figure 1.



Picture 1. Real view of prototype

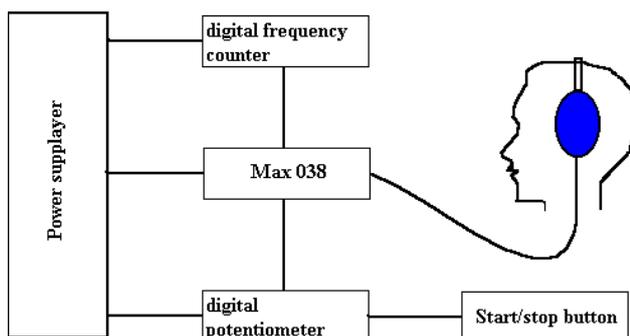


Figure 1. Schematic diagram of the apparatus

2.2. Clinical Material

The participants of the experiment included 44 volunteers (17 men and 27 women) with mean age 22 ± 4 years, with normal hearing. Education level of all volunteers was similar. Each volunteer had been informed about the aim of the experiment. The Bioethical Commission of the Nofer Institute of Occupational Medicine granted its consent to perform the experiments.

The inclusion criteria were as follows:

- good general condition of health,
- no alcohol or drug addiction,
- no exposure to noise during the 24 hours preceding the experiment,
- normal tympanic membrane image,
- normal tympanogram with ipsilateral reactions from stapedial muscles at 500, 1000, 2000 and 4000 Hz frequency bands (assessed on a Madsen model Zodiac 901 Impedance Audio Meter, Taastrup, Denmark),
- normal hearing as assessed by pure tone audiometry: hearing threshold within 20 dB HL for each frequency within the 250–8000 Hz range (assessed on an Interacoustic AC40 Pure Tone Audiometer, Assens, Denmark),
- normal transient evoked otoacoustic emission (TEOAE) with signal to noise ratio not worse than 6 dB at two or more 1000, 2000, 3000, 4000 and 5000 Hz octave bands (assessed on an Otodynamics ILO-96, London, United Kingdom unit for TEOAE testing).

3. Methods

3.1. Technical Methods

The prototype was tested at the laboratory of the Department of Physical Hazards, Nofer Institute of Occupational Medicine (NIOM) Lodz, Poland. Measurements were performed in two stages.

First, the electrical performance of the developed generator was checked using a Hitachi digital oscilloscope provided with a Hitachi probe. The oscilloscope makes it possible to measure signals in the range 0-25 MHz. In the second stage, acoustic measurements were performed using the following measuring set:

- Bruel & Krajer Artificial Ear type 4152, Ser. No. 1540966
- Bruel & Krajer Condenser Microphone type 4144 Ser. No. 473933
- KOSS type HV-PRO Headphones (air conduction type)
- Hewlett-Packard Analyzer model 3569.

The Bruel & Krajer condenser microphone type 4144, Ser. No. 473933 can measure sound intensity in the 0-20 kHz range, so the measurements are limited to this value, although technically the generator is able to provide an electrical signal at the output frequency up to 25 kHz. During measurements, ambient air temperature was 21.5°C, relative humidity 28%. The measurement was performed using a linear filter in each 1/3 octave frequency bands from 500 Hz to 20 kHz. The whole procedure was conducted in audiometric silent booth, in which it was possible to control the acoustic conditions.

3.2. Clinical Methods

The test procedure consisted of binaural administration of constant-intensity signal with a frequency smoothly varying between 25 kHz and 0.5 kHz. The volunteer was informed that, from the very beginning of the test procedure, the signaling button must be kept depressed. He/she was told to release the button only when a sound was heard in the headphones. At that moment, the generator stopped at a given frequency, the value of which was displayed on a digital scale. The test procedure was repeated three times in each subject, and the arithmetic mean obtained from all three measurements was used in further analysis. The entire procedure, both technical and clinical, was conducted in silence in the audiometric booth, in which it was possible to control the acoustic conditions.

4. Results

4.1. Technical Results

Figure 2 shows the relationship between sound pressure level and frequency for the right-hand earphone. The average value of sound intensity in the frequency range 0.5-20 kHz was 86.8 ± 9 dB SPL.

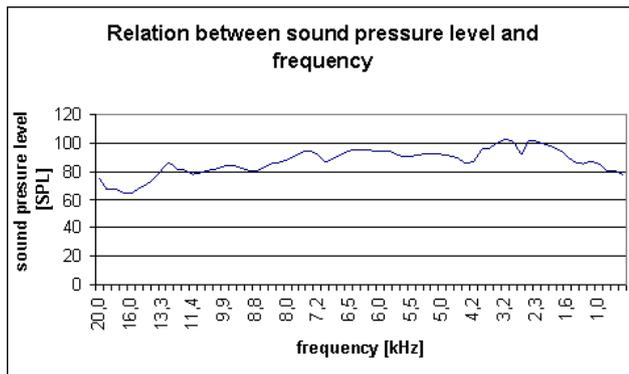


Figure 2. Relationship between sound pressure level and frequency for the right-hand headphone

4.2. Clinical Results

Figure 3 shows the mean upper limit of hearing in each group. The highest value was recorded in the group of men (16.2 ± 1.0); in women, the corresponding value was (15.8 ± 0.8), and for the combined group of men and women, the value was 15.9 ± 0.9 kHz.

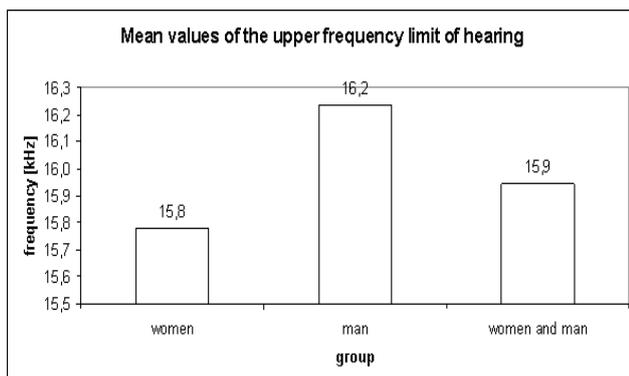


Figure 3. Mean values of the upper frequency limit of hearing in each group

5. Discussion

Technological processes are inextricably linked with the generation of harmful agents. Current advances in technology allow, where applicable, the encapsulation process. However, no robot or machine can replace human hands and his creative mind. Not being able to completely eliminate the human element from the technological processes, a series of regulations has been developed, intended to protect the health and life from the harmful effects of exposure to physical, chemical and biological agents occurring in the workplace. There is a rule pertaining to noise, according to which there is no damage to the hearing if the energy carried by the acoustic wave does not exceed a certain value over time. By keeping working time and the intensity of noise at safe levels, the workers can be protected from hearing loss. Besides, in addition noise monitoring at the workplace, it is possible to monitor the hearing status by pure tone audiometry. Unfortunately this method, although very popular, has several limitations. The most serious is the lack of a method for objective assessment of hearing and the inability to diagnose the individual components of the auditory pathway (except for the difference between air and bone conduction). A person subjected to this type of testing is expected to hear the sound generated by the apparatus (the receiving part of the auditory pathway), to become aware that the sound is the thing in question (nerve centers of the auditory pathway and associative fields), and then generate a button press motor reflex signal (central and peripheral motor centers). In the event of damage to just one part of that auditory pathway, this method is not able to ensure a comprehensive diagnosis and detect the culprit organ or process. Besides, people with slight hearing loss, in an attempt to reap financial benefits from being diagnosed with occupational disease of the hearing organ, can successfully feign excessive hearing loss. A number of methods for complete diagnostics of all components of the auditory pathway include: impedance audiometry and testing of otoacoustic emissions, auditory evoked potentials from the brainstem or late positive potentials. Diagnosing with the aid of that method requires expensive equipment and highly skilled personnel, which limits the feasibility of its application to the academic and scientific research units.

After documenting the adverse synergistic effect of noise and organic solvents on the organ of hearing, researchers have attempted to find a new method for the early detection of hearing loss [24,25,26,27]. They proposed a screening method to determine the upper limit of hearing in people subjected to the combined exposure to noise and organic solvents. They built an apparatus to produce, by means of electro-acoustical connection, a constant-intensity signal with frequency continuously variable from 0.5 to 25 kHz. As a result, they obtained a standard (percentile) curve showing the relationship between age, years of exposure and the resultant upper limit of hearing. The calibration curve begins with the age group 20 years, i.e. people entering the profession and, therefore, not exposed to harmful agents (in that instance, noise and organic solvents). They have demonstrated that this method allows the detection of hearing loss in the case of combined exposure to noise and solvents in workers whose upper limit of hearing is below the 75 percentile.

Unfortunately, the authors of that method of determining the upper frequency limit of hearing, in the apparatus of their design failed to apply components which would be suitable for building a measuring system that would be appropriate for implementing of their method as a screening tool. As a source of sound in the electro-acoustical connection, they used Bruel & Krajer microphones that: 1) were, by their definition, detector components, and 2) were very expensive. Although reports about the possibility of their use as a signal source have been accessible, such application has never been recommended the manufacturer. Taking into account the price of two microphones, the possible violation of the warranty, and the necessity to use other highly specialized components, the method in this form fails to meet the specifications of a screening method. By its definition, a screening method in medicine is "a kind of strategic testing to be carried out among asymptomatic people for early detection and treatment intended to prevent serious sequelae of a disease in the future"; a medical screening method is also required to be inexpensive, reproducible and should not require involvement of personnel with high skills or unique knowledge.

As the result of modifying the Morioka method, it has become possible to use the widely available specialized electronic components, while high frequency audiometry headphones normally constitute an essential part of audiometric equipment.

Comparison of results of a prototype apparatus to the results obtained by the authors of the method of upper frequency limit of hearing has shown that the technical specifications of the new apparatus meet the requirements of the screening method. The authors of the present study has examined a group comprising both men and women. Because Morioka had not defined a standard curve for women, the results used in further comparative analysis were limited to those obtained from the male members of the study group. Morioka et al. studied 20- to 50-year old people with a selective history of employment in the conditions of occupational exposure. According to their observations, 20 year olds had just begun their occupational careers and were not exposed to noise and organic solvents. In the experiment, the authors assume that people aged 20 years had no occupational exposure sufficient to cause hearing loss. Therefore, the results for the Morioka's and present author's 20-year-old participants have been assumed to be comparable.

In the group 20-year-old participants, the upper frequency limit of hearing results were as follows - in the group of 17 people only one person was under 75 percentile, two people were at the level of 75 percentile, ten at 50 percentile and four at the level of 25 percentile.

6. Conclusions

The results show that, despite differences in the construction, the specifications have been preserved. And the results obtained for 20-year-old patients are comparable. Further research is necessary to complete the verification of the new apparatus. It would be necessary to repeat the complete Morioka's experiment in the full range of age, with male subjects exposed simultaneously to noise and organic solvents. The next step would be to

use the apparatus as a diagnostic tool for screening testing of hearing loss. Then it would be advisable to determine the upper limit of hearing loss in women who are also subjected to the same occupational exposures.

Acknowledgements

The Authors would like to thank prof. Malgorzata Pawlaczyk-Luszczynska (MSc, PhD ENG) and Adam Dudarewicz (MSc), for their help in implementing the technical part of the experiment.

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