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A novel approach to initial hearing assessment

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Abstract:
Objective: justifying the possibility of using frequency-based hearing research via the web application 'Automated System for Initial Hearing Assessment'.
Materials and methods. The study was carried out at the Department of Otorhinolaryngology of the Samara State Medical University clinics in October 2019. It involved 91 patients 17 to 73 years old (average age 48±14.6 years). All study participants were divided into two age groups: Group I 17-59 years old), and Group II (over 60 years old). Patients were required to undergo two hearing assessment tests: using the Interacoustics AC-40 clinical audiometer and using our web application 'Automated System for Initial Hearing Assessment' (patent No. 2019664671).
Results. The maximum difference in average hearing thresholds between pure-tone threshold audiometry and the web application in Group I was 3.3 dB at a frequency of 2 kHz on the right and 3.2 dB at frequencies of 2 and 4 kHz on the left; in Group II, it constituted 4.7 and 3.5 dB at 1 and 2 kHz, on the right, correspondingly, and 7.2 dB at 4 kHz on the left. The presented data were evaluated using the Cohen's kappa coefficient, which confirmed high level of agreement between the results obtained using the clinical audiometer vs. our original web application.
Conclusion. Based on the obtained results, a conclusion was made about the possibility of using the original web application for the initial hearing express assessment in general practice in conditions of limited availability of audiological care.

Keywords: audiometry, initial hearing assessment, telemedicine, web application.

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Introduction

The problem of hearing loss is among the most important in contemporary health care, affecting over 5% of the world population, as stated by World Health Organization (WHO), including 432 million adults and 34 million children with hearing loss disabilities [1]. In recent years, the change in the demographic situation has somewhat shifted the emphasis towards people of working age and older age groups. The daunting task of timely detection and prevention of hearing loss is defined by the WHO as the priority strategy.

A possible solution of involving larger population fraction into hearing assessment could be the use of screening questionnaires, the sensitivity of which would help specialist physicians identifying hearing impairment based on the patient self-evaluation [2, 3]. Meanwhile, the anamnestic data, age, along with the cognitive and psychoemotional status of the subject, may affect the hearing assessment quality. The use of specialized techniques is often limited by the availability of audiological care and the lack of diagnostic equipment. The need for an intermediate assessment, clarifying the severity of hearing impairment, can be compensated for by using current mobile technology [4]. Applications, developed specifically for smartphones, allow for rapid hearing assessment and correct patient routing, while reducing examination time and material costs [5]. However, most applications are focused on the iOS or Android operating systems, which, in turn, limits their versatility. Besides, there are no applications combining hearing tests with both hearing risk factor assessment and ability to attach otoscopy images.

We have developed and patented the web application 'Automated System for Initial Hearing Assessment'. It includes three modules: a questionnaire about risk factors, frequency-based hearing research, and attachment of otoscopy images. It is also possible to send the collected data to a specialist physician for further interpretation of the results. The web application is available for use on any device with an Internet connection. It requires preliminary calibration – possibly, *via* biological method by determining the reference sound level relative to the hearing threshold of people with what is considered *the normal hearing range*.

Objective – justifying the possibility of using frequency-based hearing research *via* the web application 'Automated System for Initial Hearing Assessment'.

Materials and methods

In October 2019, on the basis of Samara State Medical University clinics, we carried out a single-stage cross-sectional study, in which 91 patients 17-73 years old participated (the mean age was 48±14.6 years). Among them, there were 38 men (41.7%) and 53 women (58.3%. Along with the standard pure-tone threshold audiometry, all participants were required to undergo an additional hearing assessment using the Automated System for Initial Hearing Assessment web application developed by us.

The study was carried out in compliance with the principles of the Declaration of Helsinki of the World Medical Association (2000) and the Rules of Clinical Practice in the Russian Federation, approved by Order of the Ministry of Healthcare of Russia No. 266 (2003), and also was approved by the Bioethics Committee at Samara State Medical University (the protocol No. 196 of October 31, 2018). Prior to the study, written voluntary informed consent for examination and processing of personal data was obtained from all prospective patients.

The inclusion criteria for the study were age exceeding 18 years and signed voluntary informed consent for examination and personal data processing. The exclusion criteria were inflammatory diseases of ENT organs (ear, nose, throat), external auditory canal obturation, and severe mental and cognitive disorders.

To objectify the data, study subjects were split among two age groups: Group I encompassing 55 people (23 men and 32 women) 17-59 years old (on average, 35±5.8 years) and Group II with 36 patients (15 men and 21 women) over 60 years old (on average, 68±2.4 years).

Pure-tone threshold audiometry was carried out in a quiet room, using an Interacoustics AC-40 clinical audiometer (Denmark) and Sennheiser Urbanite XL i over-ear headphones, at the frequencies of 125, 250, 500 Hz; 1, 2, 4 and 8 kHz.

Further, the hearing was evaluated using a web application developed by us. For this purpose, we used the Samsung SM-J320F mobile device (Android 5.1.1 version). After filling out the general information and completing the screening questionnaire in the web application, each subject was proceeding to the hearing assessment. The study was conducted under identical conditions, using Sennheiser Urbanite XL i over-ear headphones at the same frequencies as did the pure-tone threshold audiometry. The participants in our study were changing the sound intensity, employing the plus and minus signs, and were identifying the weakest sound heard, using the mute button. The program recorded the result automatically, followed by a graphic image matching to the audiometry form.

Statistical analysis of collected data was carried out using special licensed software: IBM SPSS Statistics, version 1.0.0.1089. The distribution normality was assessed by the Kolmogorov–Smirnov test. The descriptive statistics for the normal distribution are presented in the tables as $M\pm\sigma$, where M is a sample mean and σ is its standard deviation. To verify the relationship between the data, obtained by the pure-tone threshold audiometry, and the results of hearing assessment *via* the web application, a non-parametric indicator was chosen: the Cohen's kappa coefficient. This statistic is applied the inter-rater reliability (in our study, these were the clinical audiometer and the web application), each of which classifies N items onto C mutually exclusive categories. The agreement is considered excellent if $\kappa > 0.75$, good if $0.4 < \kappa \leq 0.75$, or poor if $\kappa \leq 0.4$.

Results

We evaluated the average hearing thresholds (in dB) for left and right ears using pure-tone threshold audiometry and original web application. The total sample size was 182 ears of 91 participants in each age group.

I Group I (under 60 years old), hearing threshold values obtained by the pure-tone threshold audiometry at frequencies 0.125-8 kHz ranged from 10.5±1.2 dB to 9±1.3 dB on the right and from 10.3±0.9 dB to 9.3±1.0 dB on the left. When examining hearing *via* the web application, the hearing thresholds were slightly lower than identified on the audiometer: they varied from 9.6±1.2 dB to 7.5±1.5 dB on the right and from 8.9±0.8 dB to 7±0.9 dB on the left (*Table 1*). Patients under 60 years of age perceived high frequencies better in all considered cases. The maximum difference in average hearing thresholds between pure-tone threshold audiometry and the web application was 3.3 dB at 2 kHz on the right and 3.2 dB at 2 and 4 kHz on the left.

In patients of Group II, the average hearing thresholds for all frequencies were higher than in patients of Group I, which was associated with age-related changes in hearing, as well as with a large number of concomitant diseases. The values of pure-tone threshold audiometry varied from 13.7±2.6 dB to 21.5±6.2 dB on the right and from 13.7±2.6 dB to 20.3±5.2 dB on the left. When examining hearing *via* the web application, the average hearing thresholds had minimal differences and varied from 13.1±12.4 dB to 21.5±6.4 dB on the right, while on the left, the differences were most noticeable at high frequencies, and the average thresholds varied from 15.9±3.4 dB to 13.4 ± 2.8 dB (*Table 2*). The maximum differences were 4.7 dB at 1 kHz and 3.5 dB at 2 kHz on the right, as well as 7.2 dB at 4 kHz on the left.

We assessed the significance of the discrepancies in the values yielded by pure-tone threshold audiometry *vs*. the web application using the Cohen's kappa coefficient. Low consistency of the mean hearing thresholds was observed in Group II patients at frequencies of 1 and 4 kHz on the right ($\kappa=0.26$ and $\kappa=0.3$, respectively) and at a frequency of 4 kHz on the left ($\kappa=0.13$), which could be associated with a high-frequency hearing loss in this group and a greater sample variance. In other cases, we observed high consistency between the values of the pure-tone threshold audiometry *vs*. hearing testing *via* the web application in patients of Group I and Group II. The maximum values of the Cohen's kappa coefficient were 0.75 for Group I and 0.9 for Group II at a frequency of 0.125 kHz (*Table 3*).

Our data confirmed high level of agreement between the results obtained using the clinical audiometer *vs*. the original web application.

Discussion

Use of mobile devices for monitoring the population health, as well as for increasing the availability of medical care, is becoming increasingly important. Currently, there are various options for assessing hearing using mobile devices, but only a few of those have been clinically tested and can be used in medical practice. According to the published sources, the results of the hearScreen application for smartphones showed high sensitivity and specificity of the results when compared with a pure-tone threshold audiometry [6], and

demonstrated the possibility of using this application in primary health care. A similar study on the accuracy of frequency-based hearing testing, performed on a mobile device, was conducted using free Hearing Test application [7]. There was no significant difference between the results of the application and the hearing thresholds identified on the clinical audiometer, with the exception of 4 kHz frequency in patients over 60 years old, just as was established in our study. In total, 70.6% of the hearing thresholds at the studied frequencies exhibited a difference of below 5 dB.

It should be noted that it is important to use the web application correctly: the study should be carried out in a quiet room and with headphones in a working condition in order to ensure the most accurate outcome. In a study by K. Khoza-Shangase and L. Kassner [8], the differences between the results obtained *via* the uHear™ app and a pure-tone threshold audiometry were significant at all frequencies, which was most likely associated with a violation of the requirements for mobile hearing diagnostics.

Table 1. Average hearing thresholds based on pure-tone threshold audiometry and web application in patients under 60 years old (Group I), M±σ

Frequencies (air conduction, kHz)	Right ear		Left ear	
	pure-tone threshold audiometry	web application	pure-tone threshold audiometry	web application
0.125	10.5±1.2	9.6±1.2	10.3±0.9	8.9±0.8
0.25	10.7±1.2	9.3±1.2	10.5±0.9	8.6±0.9
0.5	11.9±1.2	9.7±1.0	11.6±0.9	9.3±0.9
1	10.5±1.2	8.4±1.2	8.9±0.8	5.9±0.8
2	11.5±1.3	8.2±1.0	9.2±1.0	6±0.9
4	10.8±1.3	8.9±1.0	10±1.0	6.8±0.9
8	9±1.3	7.5±1.3	9.3±1.0	7±0.9

Table 2. Average hearing thresholds according to pure-tone threshold audiometry and web application in patients over 60 years old (Group II), M±σ

Frequencies (air conduction, kHz)	Right ear		Left ear	
	pure-tone threshold audiometry	web application	pure-tone threshold audiometry	web application
0.125	13.7±2.6	13.1±2.4	13.7±2.6	15.9±3.4
0.25	11.5±2.2	10.3±2.2	11.8±2.2	12.5±2.6
0.5	12.5±1.8	11.2±2.3	10.9±2.3	9±2.3
1	13.7±2.4	9±2	10.3±2.6	7.8±2
2	12.8±2.7	9.3±2.4	11.2±2.9	6.5±1.9
4	18.7±4.7	15±4.3	15±3.2	7.8±2
8	21.5±6.2	21.5±6.4	20.3±5.2	13.4±2.8

Table 3. Cohen's kappa coefficient (κ) in the study groups

Frequencies (air conduction, kHz)	Group I		Group II	
	Right ear	Left ear	Right ear	Left ear
0.125	0.75	0.69	0.9	0.77
0.25	0.7	0.58	0.77	0.47
0.5	0.5	0.56	0.46	0.54
1	0.56	0.41	0.26	0.65
2	0.46	0.46	0.46	0.4
4	0.61	0.48	0.3	0.13
8	0.67	0.58	0.57	0.5

Audiological care in Russia is at a fairly high level; however, the number of patients in need of hearing diagnostics is rapidly growing: it exceeds the number of specialist physicians, as a result of which a high percentage of people are not subjected to such care. Hearing testing in geographically remote areas is somewhat problematic and is often possible solely by checking whispering and speaking, which is not a reliable and indicative way of hearing assessment [9]. The mobile versions of hearing assessment available in Russia are either borrowed from foreign colleagues or have a marketing focus. The 'Automated System for Initial Hearing Assessment' web application developed by us is based on Russian national clinical guidelines and can be used by any patient independently, as well as under the supervision of medical personnel, without need for special training.

Of course, no application could entirely replace specialized medical equipment for audiometry. However, when a doctor does not have access to a clinical audiometer, or it is necessary to assess hearing acuity fast, our original web application is sufficiently reliable (based on statistically confirmed data) for the initial hearing assessment in patients. Moreover, additional features of the original web application, such as its cross-platform use, the presence of a questionnaire, the ability to attach otoscopy images, sending the data, as well as data evaluation by a specialist physician, provide sufficiently comprehensive patient anamnesis and allow developing the algorithm for correct patient routing.

Conclusion

The main hypothesis about high level of agreement between hearing measurements taken simultaneously by two different techniques (on a clinical audiometer and via our original web application), was confirmed.

correspondence of data between two hearing measurements taken at the same time in different ways - on a clinical audiometer and using the web application we developed, was confirmed.

Taking into account the analyzed statistical data, it can be concluded that the cross-platform web application 'Automated System for Initial Hearing Assessment' is appropriate for initial hearing express diagnostics in adults in general clinical practice and in conditions of limited availability of audiological care.

Conflict of interest

The authors declare no conflict of interest.

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