DETERMINATION OF SUBJECTIVE TINNITUS CHARACTERISTICS BY MEANS OF SOUND SYNTHESIS CONTROLLED BY THE TOUCH SCREEN INTERFACE

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ABSTRACT

Determination of Tinnitus (defined as a phantom auditory sensation) characteristics concerning sound type, level, bandwidth or frequency are one of the steps in the measurement protocol. A novel technique to measure Tinnitus parameters is proposed. It is based on a computer application designed as an auditory display for easier identification of the perceived Tinnitus. The proposed method utilizes sound synthesis employing a special graphical user interface to facilitate sound generation and identification. The method was verified during preliminary tests organized with participation of people suffering from Tinnitus and compared with the classical audiometry-based measurements. The obtained results are presented and discussed in the paper.

1. BACKGROUND – PSYCHOACOUSTIC MEASUREMENTS OF TINNITUS PARAMETERS

The measurement of the psychoacoustic parameters of tinnitus should be included in the tinnitus therapy to arrive at relevant diagnostic information, select a treatment and quantitatively substantiate its effects. Due to the limited diagnostic value, the clinical relevance of these measurements depends on the form of treatment or therapy applied. As indicated by Henry & Meikle and Schechter & Henry [1] [2], in the case of tinnitus therapy using masking sounds, the key is to measure and document the impact of masking stimuli on the perception of tinnitus. For this purpose, it is helpful to measure the minimum masking level (MML). Other parameters, such as loudness, pitch matching and residual inhibition may also be useful in the classification of subjective tinnitus [3]. Jastreboff [4] also believes that measurements of the tinnitus parameters are generally important in terms of individual consultations with patients undergoing TRT therapy (Tinnitus Retraining Therapy). Tyler et al. [5] points out that measurement of the tinnitus parameters is justified if it is used in a treatment plan. Jastreboff and Hazell [6] also state that these parameters are not associated with the subjective intensity with which tinnitus is felt or with its severity. They show the changes that are connected with reducing the perception of tinnitus, and help during consultation with patients. Psychoacoustic measurements are also valuable in assessing and verifying patients' subjective reports on the state of their tinnitus.

A method for determining the loudness and pitch of tinnitus that may be carried out with a clinical audiometer is described by Henry [7] [8]. Another method used to assess the Tinnitus frequency bases on a idea of Vernon and Fenwick [9] and is called a two-alternative forced-choice (2AFC). According to its creators, it is more accurate than the previous methods, however this method is often criticized in the literature. The procedure involves emission of two tones of different frequencies. The patient decides which of the presented tone is closer to the frequency of Tinnitus.

Patients often have difficulty in determining the pitch of the tinnitus they hear in relation to the frequency of the tone fed [10] [11]. Their task is to assign a tone that is as close as possible to the tinnitus heard. In this case, tones one octave below and one octave above are given to make this comparison simpler. The final determination of the pitch of the tinnitus should be made when feeding a tone with a loudness as close as possible to the perceived tinnitus. This is why, in accordance with the procedure described by Vernon and Meikle [12], one should use the lowest available level resolution of the audiometer.

The studies conducted by the authors of this paper used the method described by Vernon and Meikle [12], however, a modified procedure has been used in which the test sequence was reversed. This happens to be in accordance with the instructions given by Schwartz [36]. To be more exact, we first tried to find a tone whose frequency was as close as possible to the pitch of the perceived tinnitus, and only later did we determined its loudness. It was decided to follow this sequence since each loudness equalization between the tone and tinnitus - even when their pitches were found to be different - significantly prolonged the process of obtaining the relevant tinnitus parameters.

As described by Henry [7], the next step after obtaining the pitch and loudness of the tinnitus is to determine its nature - namely whether it sounds more like a tone or more like noise. The tests conducted by the authors showed that most patients had reported their tinnitus as tonal, which had also been found by other researchers [13].

Henry [7] [8] suggested that the noise presentation should begin with the narrowest band for the frequency corresponding to the tinnitus pitch obtained with pure tone if there exists a device that enables the continuous adjustment of the fed noise bandwidth. If the similarity of the noise is better than that of the tone, its bandwidth should be gradually extended until the best match is obtained.

Another psychoacoustic parameter which may be useful in evaluating tinnitus treatment is measuring the minimum masking level (MML). This is the minimum level of broadband noise at which the patient's individual tinnitus is inaudible. MML is a commonly-used measuring method, applied by many clinics dealing with tinnitus and regarded as correlating with the effectiveness of treatment [14] [15] [16].

In therapies that use sound stimulation (e.g. noise stimulation) a parameter known as residual inhibition can be measured. This defines a temporary reduction or total elimination of tinnitus perception as a result of sound stimulation [17] [18] [19]. Residual inhibition measurement is also used in other work we have conducted, which involves the synthesizer design and, in particular, in the study of the influence of ultrasonic noise on the perception of tinnitus [20]. Our work was based on a new method of diagnosing and treatment of tinnitus, which can be called as an “ear dithering” [21] [22].

The aim of the research study is to determine the usefulness and effectiveness of using an auditory display in the form of a sound synthesizer in the diagnosis and screening of tinnitus. When diagnosing tinnitus, a series of tests is carried out to determine the source, location and the causes of the tinnitus. One of the most important is the interview that requires the patient to identify and describe their tinnitus listening experience. For the follow-up inquiry, sounds that resemble the patient's tinnitus experience as closely as possible are presented to the patient. For the most part, the sound is generated by an audiometer, or sample sounds are played with other media. However, to enhance the patients’ ability to identify their Tinnitus and at the same time to reduce errors that often occur in this screening process, we propose an auditory display in a form of sound synthesizer to enable better communication with the patient. The synthesizer application provide auditory feedback of what happens when the patient touches the screen. The proposed and designed synthesizer application is illustrated in the next Section. The description of the measurement methods is provided in Section 3 and the results of tests conducted with patients are presented in Section 4. The paper concludes with some comments regarding the usefulness of the developed application and the benefits of the proposed approach for Tinnitus measurement.

2. AUDIOTORY DISPLAY APPLIED TO TINNITUS MEASUREMENTS

A computer-based tool which has been developed at the Multimedia Systems Department, Gdansk University of Technology can be used in a relatively easy way to make an attempt to sound synthesis, which corresponds to perceived Tinnitus and helps to determine the frequency and characteristics of Tinnitus.

The idea of the tool for the synthesis of Tinnitus was based on a relatively simple mechanism of the sound generator, which has the following features: (1) simple tone generation at any frequency and amplitude, (2) white noise generating and filtering, (3) AM modulation of any sound, (4) any digital sound filtering.

The difficulty of implementing such a synthesis is related to developing the user interface that would allow to make the synthesis without requiring user knowledge and skills in the domain of audio processing. The interface should attract the attention of the user and should have a intuitive operation [23]. Such assumptions have been used while designing the user interface for Tinnitus diagnosis.

The central element of Tinnitus synthesizer interface is a rectangular color space with axes marked at the bottom and on the left side (Figure 1). The lower axis represents frequency of sound, while the vertical axis represents amplitude of sound. Amplitude as a function of frequency, i.e. amplitude spectrum is displayed in the window. There are three icons located on the right side of the panel. Each icon represents a different type of sound: a simple tone, white noise and recorded samples of sound. The user can select an icon and drag it to the above-described area. Moving icons horizontally will change sound frequency, while the vertical movement changes its amplitude. The designated area is assigned to each frequency band of different colors: cool colors to low frequencies, and warmer colors represent higher frequencies. The color intensity represents the amplitude of sound (intensity) - the higher the sound level, the greater the intensity of color (more saturated). In case of simple tones the user modifies their frequency, whereas in the case of noise and digital recorded sounds the user can adjust the frequency band to which the sound is limited in the frequency domain. In this case, a sound object can not only be moved, but also can change its width corresponding to the width of the frequency band to which the sound is filtered.

Moreover, people suffering from Tinnitus can often specify whether the sound has constant characteristic or is periodically changed. Very often, such a change at the time of the perceived sound is described by patients as a pulsing sound. This effect can be achieved by amplitude modulation (AM). Therefore, when the user double clicks a sound object the window appears, where it can be set the speed, "throbbing" and its intensity (depth). To facilitate the scaling, the slider was described by relevant labels such as slow, fast or weakly, strongly.

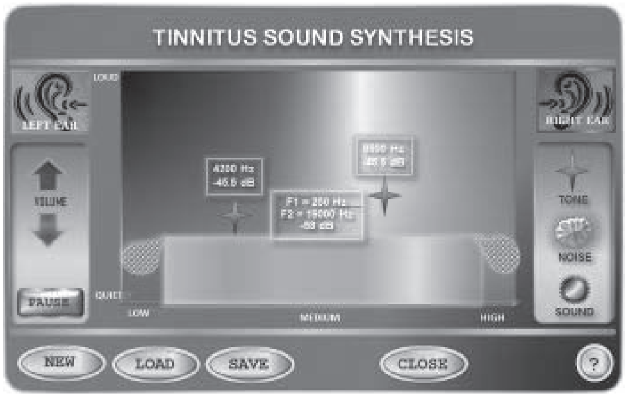

Fig. 1. The user interface for Tinnitus sound synthesis

The user during the Tinnitus synthesis may use different sound sources, and any number of them. For the case of recorded sound samples a database of usually perceived sounds is available, which usually refers to patients with Tinnitus (e.g. beeping, buzzing, ringing, the sound of shells, etc.). Only filtering was made available in the current version of the module. An implementation of the algorithm to transpose the sound spectrum is also considered ultimately. The synthesized sound can be stored to disk as a simple WAVE file format, as well as a project file that can be re-loaded for further modification.
It is recommended to monitor the synthesis result by listening to it, especially in cases of subjective Tinnitus. If Tinnitus occurs subjectively inside the head or in both ears, then the process of synthesis could be much more difficult.

3. DESCRIPTION OF THE MEASUREMENT METHOD

The tests of the effectiveness of synthesizer application involved people who had suffered from tinnitus of varying etiology. Before the main part of the study begins, the participants are interviewed and are given audiometric tests, such as: air and bone tone audiometry, otoacoustic emissions (DPOAEs) and tympanometry with designation of stapes responses. Then, using a description of the tinnitus listening experience, the tests towards Tinnitus identification follows. They consist of two stages:

I. Presenting simple tones available in the audiometer or narrowband noises with different frequencies. The audiometer is operated by a qualified person who, based on the subject's responses, presents sample sounds that resemble the perceived tinnitus as closely as possible. In this step, in addition to cooperating with the person conducting the test, the participant is asked to evaluate subjectively the resemblance of the generated sound to their own tinnitus on a scale of 0 to 10, or based on a percentage scale, that is, from 0% to 100%. The duration of the test is also one of the parameters to be assessed.

II. The participants determine the tinnitus parameters themselves using the synthesizer touch interface. The participants can choose from simple tones in the entire audible range (16 Hz–20 kHz) and white noise, which may be limited by band. These stimuli can be combined or used separately. Just as in the first stage, the participants also have to determine the subjective resemblance of the generated noise to their tinnitus.

Evaluating the effectiveness of the synthesizer in determining tinnitus acoustic parameters involves comparing the results obtained with the audiometer and the synthesizer. The comparison measures are the duration of the various test stages and the subjective evaluation of tinnitus patterns obtained with the two methods. We also calculated the relative percentage of duration reduction that can be achieved with the synthesizer.

4. TEST RESULTS AND ANALYSIS

Seven patients were examined employing two methods for their Tinnitus evaluation, i.e. audiometry- (stage I) and synthesizer-based tests (Stage II). The results are shown in Table 1.

In assessing the usefulness of the proposed method of synthesis of Tinnitus sound this Section focuses on the assessment of statistical significance employing the Wilcoxon test at the $\alpha = 0.05$ significance level. The calculations were performed with the STATISTICA10 program.

Figs. 2 and 3 show a graphic illustration of the distribution of patients' answers participating in the study using a box –and-whisker plot, indicating spread of answers.

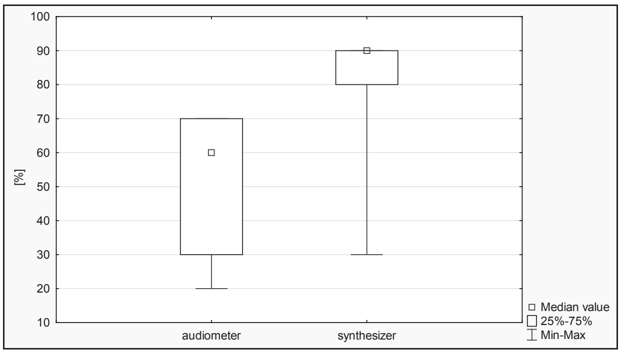

Fig. 2. Evaluation of the resemblance of the generated noise to the patient's Tinnitus.

As shown in Fig. 2, the similarity of the noise generated by the use of the synthesizer is higher in comparison with the noise generated by the audiometer with smaller dispersion of answers. This means that the identified sound more closely resembles the sound of the patient's Tinnitus. Calculating the Wilcoxon test for the above comparison indicates that there is a statistically important difference in the assessment of the similarity of the generated noise to the perceived tinnitus patient's own level with a *p*-value of 0.027.

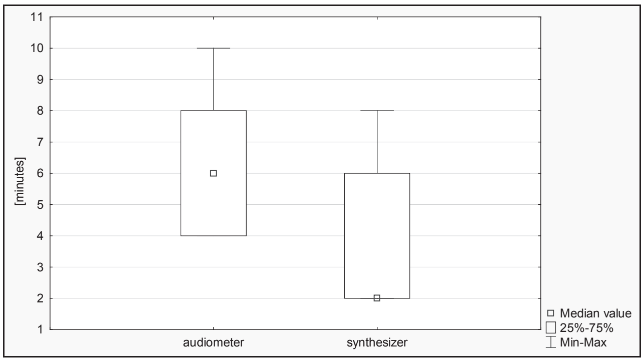

Fig. 3. Comparison of time needed for evaluation of patient's Tinnitus employing audiometer and synthesizer.

Figure 3 shows the difference between examination time while employing audiometer and synthesizer. It may be observed that the determination of the perceived noise pattern is faster by more than half when using the synthesizer. Calculating the Wilcoxon test for the above data indicates that there is a statistically important difference in the assessment of time needed for evaluation of patient's Tinnitus employing audiometer and synthesizer with a p-value of 0.017.

5. CONCLUSIONS

The tests reveal capabilities, limitations, advantages and disadvantages of both methods for the determination of tinnitus. They show that determining tinnitus using an audiometer takes over two times longer in most cases and is also less accurate than with the synthesizer prepared for this purpose. The lower accuracy of the results is directly related to the limitations of the audiometer. Most diagnostic audiometers provide only a limited set of frequencies (125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000), hence to determine Tinnitus one most often has to compromise and choose a pitch that has not been indicated by the patient.

The more complex the description of the perceived tinnitus, the harder it is to determine the sound parameters of the patient's perception, and this takes more time regardless of the method. The synthesizer, however, with its greater capacity for modeling the acoustic parameters of the sound, represents it more precisely. Let us take patient/participant no. 5, aged 79, who was able to model his listening experience according to three components, and who gave the results 70 percentage points more than he gave the results obtained with the audiometer.

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7. REFERENCES

[1] Henry, J. A., Meikle, M. B. Psychoacoustic measures of tinnitus. Journal of the American Academy of Audiology, 11, 138–155, 2000.

[2] Schechter, M. A., & Henry, J. A. Assessment and treatment of tinnitus patients using a ''masking approach.''.: Journal of the American Academy of Audiology, 13, 545–558., 2002.

[3] Nodar R.H. Tinnitus reclassified: new oil in an old lamp.: Otolaryngology Head Neck Surg., 1996, 114:582-585.

[4] Jastreboff P. Tinnitus as a phantom perception: theories and clinical implications. In J. Vernon, A. Moller (Eds), Mechanisms of Tinnitus. Boston : Allyn&Bacon, 73-93, 1995, 73-95.

[5] Tyler R.S., Haskell G.B., Gogel S.A., Gehringer A.K. Establishing a Tinnitus Clinic in Your Practice. American Journal of Audiology, 17, 25-37, 2008.

[6] Jastreboff P., Hazell J., Tinnitus Retraining Therapy - Implementing the Neurophysiological Model. Cambridge University Press, 2004.

[7] Henry J. A. Audiological assessment. In J. B. Snow, Jr. (Ed.), Tinnitus: Theory and management. Lewiston, NY: BC Decker., 2004.

[8] Henry J.A., Dennis K.C., Schechter M.A. General Review of Tinnitus:Prevalence, Mechanisms, Effects, and Management. Journal of Speech, Language, and Hearing Research, 48, 1204–1235, 2005.

[9] Vernon J.A., Fenwick J.,. Identification of tinnitus: a plea for standardization. : J. Laryngol. Otol., Suppl. 9, pp. 45-54, 1984.

[10] Graham, J. T., Newby, H. A. Acoustical characteristics of tinnitus: An analysis. Archives of Otolaryngology, 75, 82–87, 1962.

[11] Vernon, J. A., Johnson, R. M., Schleuning, A. J., Mitchell, C. R. Masking and tinnitus. Audiology and Hearing Education, 6(Summer), 5–9, 1980.

[12] Vernon J, Meikle M. Tinnitus masking: unresolved problems. London: In Evered D, Lawrenson G, editors. Coba Foundation Symposium. p. 239-256, 1981.

[13] Lockwood, A., Salvi, R. J., Burkard, R. Tinnitus. : The New England Journal of Medicine, 347, 904-910, 2002.

[14] Jastreboff P. J., Hazell J. W. P., Graham R. L. Neurophysiological model of tinnitus: dependence of the minimal masking level on treatment outcome. Hearing Research, 80,216-232, 1994.

[15] Vernon, J., Griest, S., Press, L. Attributes of tinnitus and the acceptance of masking. American Journal of Otolaryngology, 11, 44–50, 1990.

[16] Vernon, J. A., Meikle, M. B. Tinnitus masking. In R. S. Tyler (Ed.), Tinnitus handbook. San Diego, CA: Singular, pp. 313–356, 2000.

[17] Vernon J. Relief of tinnitus by masking treatment.In G. M. English (Ed.). : Otolaryngology, Philadelphia: Harper & Row pp. 1–21, 1982.

[18] Vernon, J. A., Meikle, M. B. Measurement of tinnitus: An update. In M. Kitahara (Ed.), Tinnitus. Pathophysiology and management. Tokyo: Igaku-Shoin.pp. 36–52, 1988.

[19] Vernon J. A. Current use of masking for the relief of tinnitus. In M. Kitahara (Ed.). : Tinnitus. Pathophysiology and management. Tokyo: Igaku-Shoin.pp. 96–106, 1988.
[20] Poremski T., Kostek B. Tinnitus Therapy Based on High-Frequency Linearization Principles. Archives of Acoustics, vol. 37, No. 2, 1-13, 2012.
[21] Czyżewski A., Kostek B., Skarżyński H. Technika komputerowa w audiologii, foniatrii i logopedii. Warszawa : AOW, EXIT, 2002 (in Polish).
[22] Czyżewski A., Klejsa A.,. Tinnitus Diagnosis and Therapy Method Employing Ultrasound Dithering. Nymphaio, Greece, World Scientific Publishing , 2006.
[23] Czyzewski A., Kosikowski Ł.,Kostek B., Kotus J., Suchomski P. New Tools for Hearing Loss Screening and Tinnitus Diagnosing. : 47 Audio Eng. Soc. Conference, Chicago, 2012.

Interview			Stage I			Stage II			Comparison between Stages I and II	
Participant no.	Age	Type and location of tinnitus (info from interview)	Tinnitus audiometric parameters [Hz|dB SPL]	Evaluation of the resemblance of the generated noise to the participant's noise Tinnitus [%]	Test duration [min.]	Tinnitus parameters obtained with the synthesizer [Hz|dB SPL]	Evaluation of the resemblance of the generated noise to the participant's tinnitus [%]	Test duration [min.]	Score boost for the resemblance of noise generated from the synthesizer in relation to the audiometer [percentage points]	Relative test duration reduction [%]
1	51	Squeal, in the head	RE: 6k|65.5 LE: 4k|59.5	**70**	**4**	RE: 2724|35.5 LE: 2655|32.4	**90**	**2**	**20**	**50**
2	67	High whistle, in LE and RE	RE: 4k|34.5 LE: 4k|34.5	**60**	**6**	RE: 6172|79 LE: 6251|76.7	**90**	**2**	**30**	**67**
3	77	Hum of bees, in the head	RE: 3k|70 LE: 3k| 65	**30**	**4**	RE: 1929|56.7 LE: 1954|57.3	**80**	**2**	**50**	**50**
4	61	High metallic sound	RE: 8k|33 LE: 8k|43	**70**	**6**	RE: 7103|37.2 LE: 7103|44.9	**90**	**2**	**20**	**67**
5	79	Low-frequency hum and squeal, in LE	LE: 2k|40	**20**	**5**	LE: 82|88.4 361|65.5 1281|39	**90**	**4**	**70**	**20**
6	61	Murmur, squeal, in RE and LE	RE: 8k|68 LE: 8k|63	**60**	**10**	RE: noise 8.7–10.4|48.8 LE: noise 8.9–10.4|46	**90**	**8**	**30**	**20**
7	36	Squeal, in RE	RE: 4k|79.5	**30**	**8**	RE: 5572|72	**30**	**6**	**0**	**25**

Table 1. Comparison of the results of determining tinnitus acoustic parameters using the audiometer and the synthesizer. *Key: RE – right ear, LE – left ear*