

# Assessment of the Effectiveness of a Short-term Hearing Aid Use in Patients with Different Degrees of Hearing Loss

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The study presents evaluating the effectiveness of the hearing aid fitting process in the short-term use (7 days). The evaluation method consists of a survey based on the APHAB (Abbreviated Profile of Hearing Aid Benefit) questionnaire. Additional criteria such as a degree of hearing loss, number of hours and days of hearing aid use as well as the user's experience were also taken into consideration. The outcomes of the benefit obtained from the hearing aid use in various listening environments for 109 hearing aid users are presented, including a degree of their hearing loss. The research study results show that it is possible to obtain relevant and reliable information helpful in assessing the effectiveness of the short-term (7 days) hearing aid use. The overall percentage of subjects gaining a benefit when communicating in noise is the highest of all the analyzed and the lowest in the environment with reverberation. The statistical analysis performed confirms that in the listening environments in which conversation is held, a subjective indicator determined by averaging benefits for listening situations individually is statistically significant with respect to the degree of hearing loss. Statistically significant differences depending on the degree of hearing loss are also found separately for noisy as well as reverberant environments. However, it should be remembered that this study is limited to three types of hearing loss, i.e. mild, moderate and severe. The acceptance of unpleasant sounds gets the lowest rating. It has also been observed that in the initial period of hearing aid use, the perception of unpleasant sounds has a big influence on the evaluation of hearing improvement.

**Keywords:** hearing aid; APHAB (Abbreviated Profile of Hearing Aid Benefit); assessment of hearing aid benefit; hearing loss; evaluation of hearing aid use.

## 1. Introduction

Evaluating the quality of the hearing aid fitting process in terms of the obtained benefits is a complex issue. It is easy to determine the objective parameters of hearing aids such as gain (amplification), harmonic distortion, frequency response etc. Yet, these parameters do not always directly and decisively influence user's subjective assessment of the hearing aid fitting

success. Current trends in hearing aid technology introduce a number of advanced solutions that facilitate and improve especially speech recognition in a variety of difficult listening environments (AUBREVILLE *et al.*, 2018; LITTMANN *et al.*, 2016; ZHOU *et al.*, 2018) but their comparison or measurement is not fully possible. Most of the above-mentioned solutions aim at improving signal-to-noise ratio (SNR). There are such technologies available as noise reduction and

speech enhancement systems, directional microphones (including programmes corresponding to the properties of concha), etc. (AUBREVILLE *et al.*, 2018; KAÇOL, KOSTEK, 2016; KUKLASINSKI, JENSEN, 2017; ZHOU *et al.*, 2018). They are aimed at compensating for the loss of perceptual abilities of the hearing-impaired, which is most often associated with a deterioration of ability to hear quiet sounds and in most cases with a weaker ability to understand speech in more difficult listening environments such as: speech recognition in reverberant setting, in a group of people, from a distance, etc. Overall, modern hearing aids try to provide the best possible speech recognition and at the same time natural hearing to ensure comfort of staying in various listening environments. To achieve this aim there are such technological solutions applied as automatic recognition of acoustic conditions prevailing at a given moment and adaptive selection of individual systems as well as adjustment of their settings. Theoretically, application of all these technologies should improve the quality of hearing and satisfaction of hearing aid users. In daily life, both the potential hearing aid user and hearing care professional must make choices and compromise.

Technology solutions and their quality influence hearing aid prescription affordability. This, in turn, makes the best possible solution sometimes unachievable for the user. On the other hand, a wide choice of technologies offered in available hearing aids may make the instruments difficult to compare and evaluate objectively. It results from the fact that the quality and efficiency of the solutions offered in hearing aids, despite them being similar, depend on, *inter alia*, individual configuration and algorithms that manage them. Hearing care professionals usually do not have full insight and access to these mechanisms. Hence, it is difficult to objectively parameterize these systems and to determine their actual suitability for a given patient (SCHAFER *et al.*, 2015). Hearing care professionals should rely, in their daily practice, on manufacturer's indications, their own experience and feedback from the user. On the other hand, a person who has decided to acquire a hearing aid would like a solution which provides a sufficient recovery of hearing and speech recognition in all listening environments. The hearing aid professional is then faced with the task of choosing the solution which a patient could afford and which would at the same time improve the user's hearing in listening settings most important for them. The question how to evaluate whether the solution chosen in this way is optimum for a person, the obtained benefit is sufficient and acceptable for him/her remains open (KARCZEWSKA-NABELEK, 2007). It should be noted that in the case of a severe hearing loss, achieving sufficient benefits may not be possible even using the best and most advanced solutions.

Considering the above, the goal of the study was to evaluate the effectiveness of hearing aid fitting after its short-term use.

Adopted evaluation method should:

- assess the most typical listening environments faced by a hearing-impaired elderly person,
- in the assessment of hearing aid benefit take into account a degree of hearing loss, user's hearing aid experience, and type of instruments used,
- evaluate non-acoustic factors and aspects of hearing aid use,
- be easy to implement at many hearing centres and utilize existing human resources and typical audiology equipment,
- be implemented as a user-friendly computer application.

The assessment of the impact of hearing loss on the effectiveness of hearing aids is very important. Various studies have shown that the unaided APHAB (Abbreviated Profile of Hearing Aid Benefit) survey is correlated with audiometric data (COX *et al.*, 2003; LÖHLER *et al.*, 2016; 2017). The main goal of the work is examining the relationship between the degree of hearing loss and the short-term effectiveness of hearing aids that is aided APHAB.

It is worth emphasizing that usually the concept of short-term effectiveness assessment is understood as making such an assessment after 30–45 days from the first fitting of the hearing aids (MCARDEL *et al.*, 2005; SHI *et al.*, 2007). In this work data resulted from using the hearing aids for 7 days are to be evaluated. Therefore, another goal of the work is to check whether it is possible to obtain a reliable assessment of effectiveness, which after such a short period of time would allow predicting the effects of the future use of the hearing aid.

The results obtained by this research across a large group of people should allow the development of indicators determining the quality of hearing aid fitting and the benefits that hearing aid users can gain from a short-term use.

In this way, it will also be possible to create guidelines and recommendations that may be helpful in selecting specific solutions meeting the individual requirements and needs of the hearing-impaired.

## 2. Overview of the methods of evaluating the effectiveness of hearing aid fitting process

Methods of evaluating the efficiency of hearing aid fitting process can be divided into objective and subjective (COX, 1999; HOJAN, 2014; HUMES, 1999; MENDEL, 2009). The objective assessment is most often associated with the concept of verification, while

the subjective evaluation with the concept of validation. Verification of the acoustic parameters of hearing aid enables to check whether the acoustic signal that reaches the hearing aid user's tympanic membrane has characteristics compliant with the requirements of a chosen fitting method. Validation, in turn, is the assessment of benefits obtained from the hearing aid use for which questionnaires such as the Abbreviated Profile of Hearing Aid Benefit (APHAB) or through scales such as the Client Oriented Scale of Improvement or the COSI (DILLON *et al.*, 1997) are utilized.

Measurements of hearing aid effectiveness may concern many aspects, including compensation for hearing loss, acceptance, gain, or satisfaction with hearing aid fitting. Over the last few decades, new questionnaires which address these aspects have been developed. In addition, there are methods of assessing the efficiency of hearing aid fitting process which use tonal signals and various types of verbal tests as a research material.

Due to the fact that the APHAB questionnaire was selected and used in this research it will be described in more detail in this study.

APHAB is a closed-ended, self-assessment questionnaire completed by a hearing aid wearer. It was developed in 1995 as a more 'user-friendly' tool in clinical applications than PHAB due to a decreased number of elements (COX, ALEXANDER, 1995; TYLOR, 2007). It consists of 24 items (statements) scored in four 6-item sub-scales:

- EC (Ease of Communication) – communication abilities in quiet, effort involved in communication under relatively favorable conditions;
- RV (Reverberation) – communication abilities under reverberant listening conditions, describes speech recognition in moderately reverberant settings;
- BN (Background Noise) – communication abilities in the presence of background noise, describes speech recognition in the presence of multi-talker babble or other competing noise (environmental noise);
- AV (Aversiveness of Sounds) – the degree of acceptance of unpleasant sounds, describes negative reactions to environmental noise (COX, ALEXANDER, 1995; HOJAN, 2014; TYLOR, 2007).

The benefit obtained from hearing aid use can be assessed by analyzing the mean percentage values for individual sub-scales (EC, RV, BN, AV) (COX, ALEXANDER, 1995; HOJAN, 2014; LÖHLER *et al.*, 2017) as well as calculating the mean value for three (EC, RV, BN) (COX *et al.*, 2005; JOHNSON *et al.*, 2010; LÖHLER *et al.*, 2017) or four sub-scales (so-called *Global Score*) (HOJAN, 2014).

In our study the following denotations representing benefit for individual sub-scales were adopted:

APHAB<sub>EC</sub>, APHAB<sub>RV</sub>, APHAB<sub>BN</sub>, APHAB<sub>AV</sub>, and for Global Score respectively: APHAB<sub>3</sub> and APHAB<sub>4</sub>. It should be noted that APHAB<sub>3</sub> is an indicator determined by averaging benefits for listening situations individually related to conducting conversations in the environment of EC, RV, BN and APHAB<sub>4</sub> denotes averaging benefits for all four situations, including the one associated with the acceptance of unpleasant sounds, i.e. AV.

The Abbreviated Profile of Hearing Aid Benefit (APHAB) is widely used to assess the effectiveness of hearing aids. It is also noteworthy to mention that this questionnaire is also used for other purposes, e.g. as a tool for evaluating fittings protocols (SHI *et al.*, 2007), for comparison of the effectiveness of various technological solutions in the field of hearing aids (WOOD, LUTMAN, 2004; VALENTE, MISPAGEL, 2008) and for evaluating other questionnaires (MCARDEL *et al.*, 2005).

### 3. Method

As mentioned in the previous section, there are many methods for evaluating the benefits and effectiveness of hearing aid fitting.

To evaluate the most common listening situations experienced by the elderly hearing-impaired person as well as the benefits derived from hearing aid use, it was decided to include the APHAB inventory into this study. This choice was determined by a wide variety of listening environments referred to in the questionnaire. Additionally, due to the fact that the questionnaire has a closed-ended structure, this enables to perform various comparisons. It is possible to compare, for instance, the effectiveness of two different types of hearing aids or settings for the same person. In the case of a large number of subjects, it is possible to determine the overall trend for one specific type of hearing aid or the entire family of hearing aid technology.

One of the goals of the study was to assess the short-term benefits obtained from hearing aid use so that it could easily be implemented at hearing aid dispensing centres. For this purpose, a web-based application was developed that includes the above-mentioned areas for assessing the efficiency, effectiveness and hearing aid benefits. It systematizes and organizes the way of collecting and filing the results. The application was prepared using the Moodle platform. ICT infrastructure makes the application accessible from all above mentioned centres. It is planned to make this tool available for general use in the future. The application contains two types of surveys that are closely related to the respondent's subsequent visits. The surveys arrange and indicate the steps to be taken at the subject's follow-up appointments. Therefore, they should be filled out in the right order. The content of Questionnaire No. 1 is illustrated in Table 1.



Table 1. Illustration of the questionnaire used during the subject's first visit.

|  |                          |                                 |   |                                 |   |                          |                          |
|--|--------------------------|---------------------------------|---|---------------------------------|---|--------------------------|--------------------------|
| Subject's ID   |                          |                                 |   |                                 |   |                          |                          |
| Is the patient a hearing aid user?   |                          | Yes<br><input type="checkbox"/> |   |                                 | No<br><input type="checkbox"/>          |                          |                          |
| Name of used hearing aid   |                          |                                 |   |                                 |   |                          |                          |
| How long has the patient been using hearing aids (years)?  |                          | N/A<br><input type="checkbox"/> | less than 1<br><input type="checkbox"/> | 1–2<br><input type="checkbox"/> | more than 2<br><input type="checkbox"/> |                          |                          |
| Right Ear – arithmetic mean of hearing loss (for f: 0.5, 1, 2 and 4 kHz)                                 |                          |                                 |   |                                 |   |                          |                          |
| Left Ear – arithmetic mean of hearing loss (for f: 0.5, 1, 2 and 4 kHz)                                  |                          |                                 |   |                                 |   |                          |                          |
| Recognition of one syllable words under free-field conditions without hearing aid (unaided) (65 dB, 1 m) |                          |                                 |   |                                 |   |                          |                          |
| Recognition of one syllable words under free-field conditions with hearing aid (aided) (65 dB, 1 m)      |                          |                                 |   |                                 |   |                          |                          |
| <b>APHAB</b> (Abbreviated Profile Of Hearing Aid Benefit) – assessment without hearing aid               |                          |                                 |   |                                 |   |                          |                          |
|  | Always<br>(99%)          | Almost always<br>(87%)          | Generally<br>(75%)                      | Half-the-time<br>(50%)          | Occasionally<br>(25%)                   | Seldom<br>(12%)          | Never<br>(1%)            |
| 1. When I am in a crowded grocery store, talking with the cashier, I can follow the conversation.        | <input type="checkbox"/> | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. ...   | <input type="checkbox"/> | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/> | <input type="checkbox"/> |
| ⋮  | ⋮                        | ⋮                               | ⋮                                       | ⋮                               | ⋮                                       | ⋮                        | ⋮                        |
| 24. ...  | <input type="checkbox"/> | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/>        | <input type="checkbox"/>                | <input type="checkbox"/> | <input type="checkbox"/> |
| Other remarks, suggestions, observations of the subject:   |                          |                                 |   |                                 |   |                          |                          |

At the very beginning of the first visit all standard hearing aid fitting procedures are performed. They comprise, among others, medical history, otoscopy, audiometric test and hearing aid fitting. With regard to the hearing aid benefit measurement, an expanded interview is conducted. It is supplemented with the questions from the APHAB questionnaire. The part of the questionnaire which refers to the subject's unaided hearing performance in various daily life situations is completed. Once the subject has been fitted with a hearing aid, speech audiometry is performed without and with the instrument. Finally, this person is counseled on how to operate, use any features and take care of his/her hearing aid. It is recommended that the user wears his/her hearing aid for seven consecutive days, at least four hours a day. The upper limit of use is not determined and depends only on the hearing aid user.

It is standard practice to see the user after the 7-day hearing aid use for a follow-up appointment. The goal of the visit is to determine the short-term benefits obtained from using the hearing aid. For this purpose, an interview with the user is conducted using Questionnaire No. 2 (see Table 2). One of the most important elements of this follow-up check is reading the data from the instruments and saving them in the electronic program for hearing aid operation. Based on this, Questionnaire No. 2 is completed with the actual

duration of hearing aid use, which can be identified precisely hour by hour. This is an important parameter which will be taken into account while assessing the benefits obtained from hearing aids. It turns out that in some cases there is a discrepancy between the hearing aid use declared by the user and the actual state. Due to this, it is possible to assess the subjective benefits obtained by the user with respect to the objective parameter which is the duration of hearing aid use. The next step is to re-test the recognition of one-syllable words under free-field conditions and complete the second part of the APHAB questionnaire. This time the questions involve aided hearing in various listening environments. Percentage differences in responses given during the first (Questionnaire 1) and second visit (Questionnaire 2 – see Table 2) constitute the assessment of hearing improvement in the above mentioned situations.

One of the goals of this method was also to evaluate non-acoustic indicators and aspects of hearing aid use. Therefore, the last part of the questionnaire contains additional questions, mainly aimed at gathering information on the user's general opinion about the comfort of hearing aid use. The preliminary studies show that during the initial period of hearing aid use, an increased perception of loud sounds in noise is most cumbersome for the hearing aid user (POREMSKI *et al.*, 2017). HOUBEN *et al.* (2011) showed that although

Table 2. Illustration of the content and structure of the questionnaire used during the subject's follow-up visit after 7 days.

|   |                                      |                                      |                                     |                                 |  |                          |                          |
|---|--------------------------------------|--------------------------------------|-------------------------------------|---------------------------------|--|--------------------------|--------------------------|
| Model of a hearing aid that the patient is testing on Right Ear                                   |                                      |                                      |                                     |                                 |  |                          |                          |
| Tube type used in a hearing aid on Right Ear  | N/A<br><input type="checkbox"/>      | standard<br><input type="checkbox"/> | slim<br><input type="checkbox"/>    | RIC<br><input type="checkbox"/> |  |                          |                          |
| Size of Right Ear ventilation   |                                      |                                      |                                     |                                 |  |                          |                          |
| Model of a hearing aid that the patient is testing on Left Ear                                    |                                      |                                      |                                     |                                 |  |                          |                          |
| Tube type used in a hearing aid on Left Ear   | N/A<br><input type="checkbox"/>      | standard<br><input type="checkbox"/> | slim<br><input type="checkbox"/>    | RIC<br><input type="checkbox"/> |  |                          |                          |
| Size of Left Ear ventilation  |                                      |                                      |                                     |                                 |  |                          |                          |
| How long has the patient been testing hearing aid (days)?   |                                      |                                      |                                     |                                 |  |                          |                          |
| Reading Data Logging. Actual duration of hearing aid use (number of hours)                        |                                      |                                      |                                     |                                 |  |                          |                          |
| Recognition of one syllable words under free-field conditions with hearing aid (aided)            |                                      |                                      |                                     |                                 |  |                          |                          |
| <b>APHAB</b> (Abbreviated Profile Of Hearing Aid Benefit) – assessment with hearing aid           |                                      |                                      |                                     |                                 |  |                          |                          |
|   | Always<br>(99%)                      | Almost always<br>(87%)               | Generally<br>(75%)                  | Half-the-time<br>(50%)          | Occasionally<br>(25%)                    | Seldom<br>(12%)          | Never<br>(1%)            |
| 1. When I am in a crowded grocery store, talking with the cashier, I can follow the conversation. | <input type="checkbox"/>             | <input type="checkbox"/>             | <input type="checkbox"/>            | <input type="checkbox"/>        | <input type="checkbox"/>                 | <input type="checkbox"/> | <input type="checkbox"/> |
| 2. ...  | <input type="checkbox"/>             | <input type="checkbox"/>             | <input type="checkbox"/>            | <input type="checkbox"/>        | <input type="checkbox"/>                 | <input type="checkbox"/> | <input type="checkbox"/> |
| ⋮   | ⋮                                    | ⋮                                    | ⋮                                   | ⋮                               | ⋮  | ⋮                        | ⋮                        |
| Additional questions regarding hearing aid use and non-acoustic aspects                           |                                      |                                      |                                     |                                 |  |                          |                          |
| Was hearing in noise comfortable?   | <input type="checkbox"/>             | <input type="checkbox"/>             | <input type="checkbox"/>            | <input type="checkbox"/>        | <input type="checkbox"/>                 | <input type="checkbox"/> | <input type="checkbox"/> |
| Was hearing loudness with hearing aid adequate?   | <input type="checkbox"/>             | <input type="checkbox"/>             | <input type="checkbox"/>            | <input type="checkbox"/>        | <input type="checkbox"/>                 | <input type="checkbox"/> | <input type="checkbox"/> |
| Was the hearing aid comfortable to use?   | <input type="checkbox"/>             | <input type="checkbox"/>             | <input type="checkbox"/>            | <input type="checkbox"/>        | <input type="checkbox"/>                 | <input type="checkbox"/> | <input type="checkbox"/> |
| What were the reactions of people around you to the fact that you were wearing the hearing aid?   | Positive<br><input type="checkbox"/> |                                      | Neutral<br><input type="checkbox"/> |                                 | Negative<br><input type="checkbox"/>     |                          |                          |
| Are you generally satisfied with the tested hearing aid?  | Yes<br><input type="checkbox"/>      |                                      | No<br><input type="checkbox"/>      |                                 | I don't know<br><input type="checkbox"/> |                          |                          |
| Did the hearing aid improve the comfort of your life and speech understanding?                    | Yes<br><input type="checkbox"/>      |                                      | No<br><input type="checkbox"/>      |                                 | I don't know<br><input type="checkbox"/> |                          |                          |
| Do you plan to buy the hearing aid?   | Yes<br><input type="checkbox"/>      |                                      | No<br><input type="checkbox"/>      |                                 | I don't know<br><input type="checkbox"/> |                          |                          |
| Other remarks, suggestions, observations of the subject:  |                                      |                                      |                                     |                                 |  |                          |                          |

many noise reduction algorithms in consumer products are preset for the end-user, the question remains open whether these settings can be improved for the individual user. This is especially relevant in the case of hearing aid technologies and the hearing-impaired persons. This may discourage him/her from wearing the hearing aid despite the obvious benefits obtained in other listening environments. Other factors preventing subjects from accepting their hearing aids are the lack of full control over the loudness of the recognized sounds and the comfort of use. The questionnaire also includes questions to people in the immediate vicinity of a subject and, above all, their response to the change in the person's perceptual abilities. Finally, there is a ques-

tion that concerns the person's plans to acquire a hearing aid and consequently his/her permanent improvement in hearing and speech recognition. The aim of this question is to see how short-term hearing aid benefits can affect the decision of using a hearing aid on a regular, daily basis. The questionnaires also provide room for additional comments and suggestions from the subject.

According to the methodology described above, each subject filled out two questionnaires – the first one was completed prior to hearing aid use and the second one after 7 days. Only those data were taken into account that had shown at least four hours of a hearing aid utilizing during the day. The benefit derived from

Table 3. Differences between hearing aids characteristics used in the study.

| Technology level of hearing aids  | A                                      | B  |
|---|--|--|
| Number of channels available  | 8                                      | 12   |
| Number of acoustic environments encountered in daily life in which hearing aid settings are automatically adapted | 2<br>Calm situation<br>Speech in noise | 3<br>Calm situation<br>Speech in noise<br>Comfort in noise |
| Real ear microphone characteristic  | No                                     | Yes  |

hearing aid use is calculated as the difference in responses obtained during the first and the second visit. In each of the four listening environments: EC (Ease of Communication) – ease of communication with ambient noise in a quiet environment, BN (Background Noise) communication in the presence of background noise, RV (Reverberation) – communication in reverberant environments, AV (Aversiveness of Sounds) – perception of loud sound events, unpleasantness of environmental sounds), thus the respondent answered six questions. An adequate percentage weight is assigned to each answer (see Tables 1 and 2). Then the benefit calculated in this way was averaged in each listening setting.

The degree of hearing loss was taken into consideration while analyzing the data. The degree of hearing impairment was determined according to WHO definition as the average hearing threshold for frequencies 500, 1000, 2000, 4000 Hz for the better ear (World Health Organization [WHO], 1991, p. 2). A total of 275 subjects with different levels of hearing loss (i.e. monoaural, binaural, symmetrical and unsymmetrical) and using different hearing aids participated in the study. To ensure proper comparability of data for this analysis, only the results of test participants with binaural symmetric hearing loss of the same degree were further considered as other cases were under-represented in the data obtained. An additional selection criterion was the use of hearing aids of one manufacturer belonging to the same family but with two technological levels (A and B). Overall, 109 cases were further analyzed. Below in Table 3 the differences between the A and B hearing aids are outlined. The other hearing aid characteristics such as gain, fitting range, adaptive directional microphone, noise reduction, speech enhancement, etc. are the same in both types of hearing aids analyzed, however they are individually selected according to the degree of hearing loss.

Data of 109 adult subjects were analyzed in this study, including 82 men (average age: 66.1, standard deviation: 9.2) and 27 women (average age: 65.3, standard deviation: 12.7). All participants provided a voluntary and informed written consent for participation in the study. The hearing loss range of the participants ranged from mild to severe. All of participants had symmetrical, sensorineural hearing loss. Of

all 109 subjects, 28 had grade 1 (mild) hearing loss. Among this group there were six women (average age: 58.2, standard deviation: 5.0) and 12 men (average age: 65.0, standard deviation: 6.5). 73 of all subjects had grade 2 (moderate) hearing loss. This group included 18 women (average age: 66.1, standard deviation: 14.1) and 55 men (average age: 66.9, standard deviation: 10.4). Eight of all subjects had grade 3 (severe) of hearing loss. There were three women (average age: 74.7, standard deviation: 5.7) and five men (average age: 62.8, standard deviation: 1.5) with severe hearing loss. All test participants filled in APHAB questionnaires themselves and in addition they were able to adjust hearing aid settings manually without any help.

As already mentioned, participants have used two types of technology level of hearing aids (type A and type B). 49 of all subjects had used type A hearing aids. Among them there were 16 women (average age: 68.0, standard deviation: 11.1) and 33 men (average age: 65.5, standard deviation: 7.7). 60 of all subjects had used type B hearing aids. There were 11 women (average age: 61.4, standard deviation: 14.3) and 49 men (average age: 66.5, standard deviation: 10.2).

The data obtained as a result of the conducted research were analyzed based on the assumed significance level  $\alpha = 0.05$ . GNU R software was used for statistical analyses.

#### 4. Analysis of results

The results of the APHAB questionnaire, general satisfaction with tested hearing aids and the degree of hearing loss were analyzed. The obtained results have been presented in the form of a box and whiskers diagram. This is to show data variation and their distribution. In the further discussion of the results, the average values were taken into account, because they correlate directly with the results obtained and the criteria for the evaluation of results taken. The charts include auxiliary lines to illustrate the average values of the achieved benefit from the use of hearing aids in various acoustic environments. This is useful in assessing the trend (comparison) of the changes in benefit depending on the degree of hearing loss or the type of hearing aids used.

First, the results were analyzed showing the short-term benefit depending on the type of hearing aids used. Figure 1 presents a summary of overall, averaged scores (*Global Score*) usually presented as an arithmetic mean of the percentage benefit from hearing aid use in all listening situations that are assessed, i.e. EC, BN, RV and AV, denoted as APHAB<sub>4</sub>. Contrarily, APHAB<sub>3</sub> takes into account only those situations that are directly related to communication or conversation (EC, BN, RV) and omits the situations (AV) in which the acceptance of unpleasant sounds is evaluated.

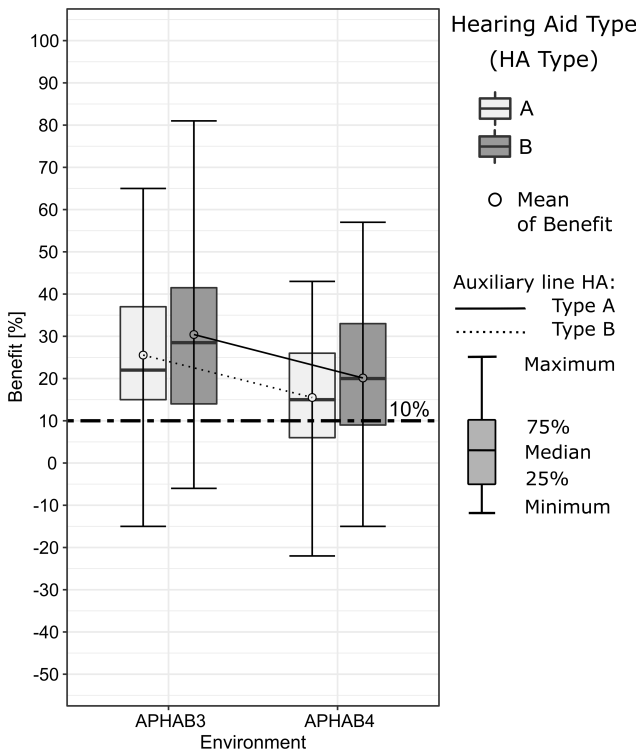


Fig. 1. Benefits obtained during short-term use of hearing aids with different technology levels, presented in the form of global indicators for three and four environments respectively (HA refers to hearing aid).

The following criteria for the classification of results were adopted: a benefit of  $\leq 0\%$  means deterioration of hearing, i.e. ineffective hearing aid use. A benefit of  $< 10\%$  is considered to be small, though positive. The next two ranges were created taking into account the criteria of other authors who, depending on the configuration of the results, propose the application of the criteria at the level of 10% in the case of global indicators (APHAB<sub>3</sub> and APHAB<sub>4</sub>) and 22% for individual indicators (APHAB<sub>EC</sub>, APHAB<sub>RV</sub>, APHAB<sub>BN</sub>, APHAB<sub>AV</sub>) (COX, 1997; HOJAN, 2014).

It is interesting to observe how the technology level of hearing aids affects the benefit achieved. It can be observed that users of type B hearing aids get better results than type A hearing aids, both for APHAB<sub>3</sub> and APHAB<sub>4</sub>. In order to check whether these results differ significantly, a statistical analysis was performed.

The assumption of the normality of variables was checked using the Shapiro-Wilk test. These variables have a normal distribution, therefore, the ANOVA test was used to check the statistical significance of differences, which did not result in a statistically significant result. Thus, it may be concluded that despite the differences in the benefit achieved for both types of hearing aids, they are not statistically significant (see Table 4).

In addition, it can be seen that the benefit of using the hearing aid in situations related only to conducting conversations in different environments (APHAB<sub>3</sub>) is clearly greater than in the APHAB<sub>4</sub> indicator, which also takes into account the acceptance of unpleasant sounds. Analyzing the whole set of data obtained in the course of the carried out study, it may be concluded that for the APHAB<sub>3</sub> indicator, over 87% of users (counted together for A and B type devices) gain a benefit of over 10%, which means effective provisioning of hearing aids.

Taking into account the APHAB<sub>4</sub> indicator, the percentage of users with sufficient benefit from the use of hearing aids decreases to a total of 67%. It can be seen, therefore, that the overall benefit from the use of hearing aids will particularly be influenced by the assessment of the acceptance of unpleasant sounds. For a more detailed analysis of the data, the results obtained during short-term use of hearing aids with different technology levels for each environment are presented in Fig. 2.

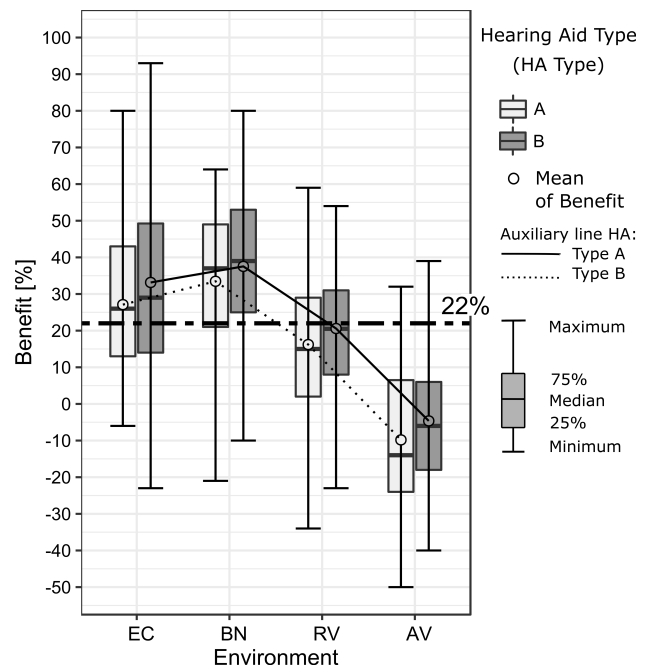


Fig. 2. Benefits obtained in various listening environments during short-term use of hearing aids with technology levels of A and B (HA – as denoted in Fig. 1).

Similarly to the previous investigation, a statistical analysis was carried out to check whether the differ-

Table 4. Results of the statistical analysis for determining the significance of the differences obtained when using the A and B type hearing aids.

| Environment | Statistical test    | <i>p</i> -value   |
|-------------|---------------------|-------------------|
| APHAB3      | ANOVA               | <i>p</i> = 0.1712 |
| APHAB4      | ANOVA               | <i>p</i> = 0.1226 |
| EC          | ANOVA               | <i>p</i> = 0.1636 |
| BN          | ANOVA               | <i>p</i> = 0.3237 |
| RV          | ANOVA               | <i>p</i> = 0.3094 |
| AV          | Mann-Whitney U Test | <i>p</i> = 0.9282 |

ences visible in the benefits achieved by the users of the A and B type hearing aids are statistically significant. The EC, BN and RV variables have a normal distribution, therefore the ANOVA test was used. In the case of an AV variable that does not have a normal distribution, the non-parametric Mann-Whitney test was employed for the statistical analysis. The conducted analysis showed, as before, that the differences between the results obtained in the A and B hearing aids are not statistically significant. Table 4 summarizes the results of statistical analysis collected for the differences between the results obtained by the users of A and B type hearing aid devices.

Despite the fact that the differences obtained with two types of hearing aids (A and B) are not statistically significant, the benefits of using them differ significantly depending on the acoustic environment in which the hearing aid user is staying. The best result was obtained in the case of communication in noisy environments (BN) and the worst result concerns the acceptance of unpleasant sounds (AV). Assuming the 22% level as a borderline result indicating the effective supply of hearing aids, the percentage of users benefiting from the combined use of A and B type devices during the first 7 days can be given. Thus, about 64% of users benefited from hearing aid use when conducting a conversation in a calm listening environment (EC), 78% of hearing aid users reported benefit in noisy environments (BN), whereas in reverberation conditions (RV) 42% of them. However, only 8% of users accepted unpleasant sounds (AV) in the first period of use of the hearing aids.

Due to the fact that the analysis of the results for types A and B hearing aids does not give statistically significant differences, in the further part of the work, the analysis of the results was carried out without taking into account the type of hearing aids. This approach means that the analyzed AV variable, due to the increase in quantity, assumes a normal distribution, which consequently allows employing the MANOVA (multivariate analysis of variance) test for statistical analysis in the further part of the study.

One of the aims of the study carried out was to assess the impact of the degree of hearing loss on short-

term benefits from the use of hearing aids. Therefore, Fig. 3 presents the results obtained using global indicators.

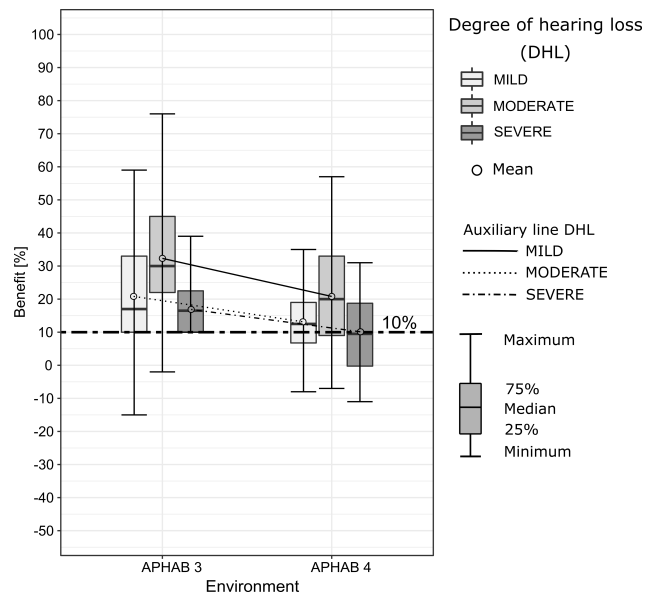


Fig. 3. Benefit of short-term use of hearing aids for users with different degrees of hearing loss, determined by using global indicators (DHL – degree of hearing loss).

It can be observed that the greatest benefit from short-term use of the devices concerns users with moderate and then with a mild degree of hearing loss. The least benefit refers to the users with significant (severe) hearing loss. This is understandable due to the lower perceptual abilities that are the result of damage to the hearing organ. It can be seen, as in previous analyses, that the benefits are reduced when the acceptance of unpleasant sounds (APHAB<sub>4</sub>) is taken into account in their assessment. In listening situations related to conducting a conversation, for the APHAB<sub>3</sub> indicator sufficient benefits are gained by 75% of users with the mild and severe degree, and over 93% with the moderate degree. When the assessment also takes into account the acceptance of unpleasant sounds then all the indicators fall and the percentage of benefits decreases significantly below 75%. This is illustrated by the analysis presented in Fig. 4.

Analyzing the above results for individual environments, it can be noticed that in the case of mild hearing loss, they benefit the most from communication in calm EC situations (53% of users) and in noisy BN (60% users). The percentage of receiving profits in the reverberation is 25% and the unpleasant sounds accept only about 7%. The result is surprising especially because the benefits in noise are greater than in a quiet environment. The same applies to other hearing loss. This is most likely due to the fact that modern hearing aids are able to effectively enhance speech (speech enhancement) in the presence of background of noise and thus improve the perception of speech in these



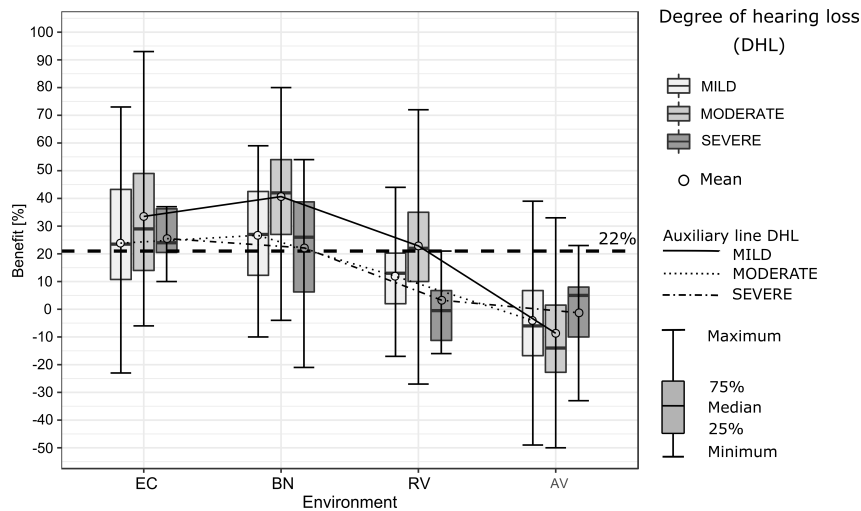


Fig. 4. Benefit of short-term use of hearing aids for users with different levels of hearing loss, determined separately for four environments (DHL – as denoted in Fig. 3).

situations. Contrarily, new hearing aid users are often overwhelmed by the sudden ability to hear every day noises, especially in quiet environment. Moreover, the lower result in EC calm situations is most likely due to the fact that in the case of mild to moderate hearing loss, communication in a calm environment does not cause too much trouble. Good effects of the use of hearing aids by users with mild hearing loss are important because it occurs that in Poland most people with such hearing loss do not decide to use hearing aids, most probably due to the fact that they do not feel significant deterioration in hearing and understanding speech (another factor may be related to that they are not entitled to a refund).

In the case of moderate hearing loss, the gain from the use of hearing aids is the highest among all other conversational situations (EC, BN, RV) but it is one of the worst for situations related to the acceptance of unpleasant AV sounds. The percentage of users benefiting in individual environments is approximately: 67% for EC, 86% for BN, 52% for RV and only 8% for AV.

For people with severe hearing loss the results are different. In this case, an efficient benefit is achieved at approx. 75% in EC and 62% in BN. In other situations, short-term use of hearing aids does not bring sufficient benefits. For the data presented in Figs 3 and 4 showing the benefits of short-term use of hearing aids for users with varying degrees of hearing loss, a statistical analysis was performed. Its aim is to check the relationship between the degree of hearing loss and the profit from the use of hearing aids determined using the APHAB questionnaire. For this purpose, a multivariate analysis of variance (MANOVA) was used for all presented variables (EC, BN, RV, AV, APHAB<sub>3</sub>, and APHAB<sub>4</sub>). All the multivariate tests carried out (i.e. Wilks' Lambda, Hotelling-Lawley Trace, Pillai's Trace and Roy's Largest Root) yielded statistically signifi-

cant results at  $p \leq 0.0089$ . That is why, it was possible to conduct a one-way analysis of variance (ANOVA) for individual variables. BN, RV and APHAB<sub>3</sub> are variables, i.e. environments for which at a later stage of the ANOVA analysis statistically significant differences between the compared groups were obtained. Therefore, Tukey's test was additionally performed for these groups, which allowed for distinguishing hearing loss in the given environment, whose pairs of averages differ significantly. In this way, it was found that in the case of variable BN, statistically significant differences were found between moderate-mild ( $p = 0.0062$ ) and severe-moderate ( $p = 0.0395$ ). In the case of the RV variable, statistically significant differences were found between the mean for severe-moderate hearing loss ( $p = 0.0381$ ). In the case of APHAB<sub>3</sub> variable, statistically significant differences were found between the mean for moderate-mild ( $p = 0.0097$ ) and severe-moderate ( $p = 0.0483$ ).

As may be seen in the above charts, in some cases the dispersion of the obtained responses is large in relation to the average value. This is probably due to the fact that, firstly, the APHAB questionnaire used serves to judge the subjective hearing of the user, and thus the evaluation is dependent, among others, on the individual user's expectations and attitude toward hearing loss and hearing aids. However, it cannot be ruled out that out of 109 respondents, individual cases of negative evaluation may have occurred, when the devices have not been optimally adjusted due to, for example, residual dynamics or UCL threshold, hearing preferences or the used ear mold, etc.

## 5. Conclusions

The presented method of evaluating the effectiveness of hearing aid use after a short period of time,

due to its implementation in the form of a web-based application, allows a systematic and organized assessment of the benefits gained from the hearing aid use. The data collected in this way can easily be gathered and analyzed.

The assessment of hearing aid use is carried out for individual subjects, but the analysis of the obtained results can be performed with regard to whole groups of subjects who can be arranged according to the degree of hearing loss, duration of hearing aid use, hearing aid use experience, type of hearing aid, type of individual earmolds, etc. Conducting the assessment with the subject may serve as a tool for a more objective evaluation of aided hearing and make it easier for the person to choose from various available solutions after a short period of hearing aid use. Information obtained in this way can be used by hearing care professionals to adjust the settings of the instruments to enhance subjects' satisfaction.

The presented preliminary results of the research show that it is possible to obtain relevant and reliable information helpful in assessing the effectiveness of short-term hearing aid use. The analyzed results were obtained in a group of 109 subjects. Considering the total number of subjects, it can be concluded that a 10% improvement in speech recognition in all listening environments (APHAB<sub>3</sub>) after a short-term use of hearing aids was achieved in over 75% of the subjects. It has been observed that in the initial period of hearing aid use, the perception of unpleasant sounds has a big influence on the evaluation of aided hearing improvement. Wrong adjustment of hearing aid acoustic parameters in this regard may discourage the user from using the hearing aids and obscure the potential benefits that could be obtained from a long-term use. Therefore, when fitting the hearing aids on the first visit, special attention should be paid to careful selection of the acoustic parameters responsible for the perception of unpleasant sounds. An increasing adaptation to unpleasant sounds occurs over time, after a longer period of hearing aid use. The process of auditory adaptation will be the subject of further research with the use of survey outcomes from subjects' subsequent visits.

Analyzing the benefit of hearing aid use in each of the listening environments separately, it was noticed that in a quiet environment the highest percentage of people obtaining a benefit were those with moderate hearing loss. The worst results were obtained by the subjects with mild hearing loss. This is probably due to the fact that people who can hear sufficiently are able to communicate quite well in quiet without hearing aids. In general, it can be stated that in all situations related to conversation, the biggest benefit is obtained by the hearing aid users with moderate hearing loss.

The overall percentage of subjects gaining a benefit when communicating in noise is the highest of all the

analyzed. This is quite a surprising conclusion as it shows that the subjects subjectively indicate a greater benefit from hearing aids when communicating in noise than in quiet.

The situation is different for the evaluation of benefit when communicating in reverberant rooms. The overall percentage of subjects gaining a benefit in this environment is the lowest of all the analyzed situations that concern conversation. It can be concluded then that while modern hearing aids are good at improving speech recognition in noise, reverberation is still a big challenge for both hearing aid manufacturers and users. The above conclusions coincide with the preliminary studies carried out in a group of 70 subjects by the authors of this paper (POREMSKI *et al.*, 2017).

The conducted statistical analysis confirms that in listening environments in which conversation is held, the subjective APHAB<sub>3</sub> benefit is statistically significant with respect to the degree of hearing loss. Statistically significant differences depending on the degree of hearing loss are also found separately for noisy BN as well as reverberant RV environments. However, it should be remembered that this study is limited to three types of hearing loss, i.e. mild, moderate and severe as there were insufficient amount of data provided for potential hearing aid users with a profound hearing loss.

Currently, work is underway to obtain results for a much larger group of subjects. Acquiring such outcomes should allow the future development of data pointing to potential opportunities as well as limitations of specific solutions which improve hearing. Due to this, it would be possible to prepare reference data which could help to compare the life of a person starting to wear hearing aids with people using the aids successfully and predict person's benefits from hearing aid use in the future. This can also be confirmed by the results of other researchers (MCARDEL *et al.*, 2005). They show that mean scores at 2 months and 6 months after the hearing aid intervention did not differ significantly, suggesting that the initial improvement in communication ability as measured by the global score of the APHAB was maintained for at least 6 months after the use of hearing aids. It is therefore worth investigating when the obtained results do not change. This will be the subject of further research carried out by the authors.

## References

- AUBREVILLE M., EHRENSPERGER K., MAIER A., ROSENKRANZ T., GRAF B., PUDER H. (2018), *Deep denoising for hearing aid applications*, arXiv:1805.01198 [eess.AS] [accessed June 2018].
- COCHRAN W.G. (1952), *The chi-square goodness-of-fit test*, Annals of Mathematical Statistics, **23**, 315–345.



3. COX R.M. (1997), *Administration and application of the APHAB*, The Hearing Journal, **50**, 32, 35–36, 38, 40–41, 44–45, 48.
4. COX R.M. (1999), *Measuring hearing aid outcomes: Part 1*, Journal of the American Academy of Audiology, **10**, Editorial.
5. COX R.M., ALEXANDER G.C. (1995), *The abbreviated profile of hearing aid benefit*, Ear and Hearing, **16**, 176–186.
6. COX R.M., ALEXANDER G.C., GRAY G.A. (2003), *Audiometric correlates of the unaided APHAB*, The Journal of the American Academy of Audiology, **14**, 361–371.
7. COX R.M., ALEXANDER G.C., GRAY G.A. (2005), *Hearing aid patients in private practice and public health (veterans affairs) clinics: are they different?*, Ear and Hear, **26**, 513–528.
8. DILLON H., JAMES A., GINIS J. (1997), *Client Oriented Scale of Improvement (COSI) and its relationship to several other measures of benefit and satisfaction provided by hearing aids*, Journal of the American Academy of Audiology, **8**, 27–43.
9. HOJAN E. (2014), *Hearing prosthetics* [in Polish: *Protektyka słuchu*], Wydawnictwo Naukowe UAM, Poznań.
10. HOUBEN R., DIJKSTRA T.M.H., DRESCHLER W.A. (2011), *Differences in preference for noise reduction strength between individual listeners*, Proceedings of the 130th Convention of the Audio Engineering Society, Paper No: 8447, London.
11. HUMES L.E. (1999), *Dimensions of hearing aid outcome*, Journal of the American Academy of Audiology, **10**, 26–39.
12. JOHNSON J.A., COX R.M., ALEXANDER G.C. (2010), *Development of APHAB norms for WDRC hearing aids and comparisons with original norms*, Ear and Hearing, **31**, 47–55.
13. KARCEWSKA-NABELEK A. (2007), *Predicting hearing aid acceptance and beyond*, Archives of Acoustics, **32**, 3, 505–510.
14. KĄKOL K., KOSTEK B. (2016), *A study on signal processing methods applied to hearing aids*, Signal processing algorithms, architectures, arrangements, and applications, SPA 2016, pp. 219–224, Poznan, Poland, 21–23.09.2016.
15. KUKLASIŃSKI A., JENSEN J. (2017), *Multichannel Wiener filters in binaural and bilateral hearing aids – speech intelligibility improvement and robustness to DoA errors*, Journal of the Audio Engineering Society, **65**, 1/2, 8–16, doi: <https://doi.org/10.17743/jaes.2016.0060>,
16. LITTMANN V., BEILIN J., FROELICH M., BRANDA E., SCHÄFER P.J. (2016), *Clinical studies show advanced hearing aid technology reduces listening effort*, The Hearing Review, April 2016, <http://www.hearing-review.com/2016/03/clinical-studies-show-advanced-hearing-aid-technology-reduces-listening-effort/> [accessed June 2018].
17. LÖHLER J., AKCICEK B., WOLLENBERG B., KAPPE T., SCHLATTMANN P., SCHÖNWEILER R. (2016), *The influence of frequency-dependent hearing loss to unaided APHAB scores*, European Archives of Oto-Rhino-Laryngology, **273**, 3587–3593.
18. LÖHLER J., GRÄBNER F., WOLLENBERG B., SCHLATTMANN P., SCHÖNWEILER R. (2017), *Sensitivity and specificity of the abbreviated profile of hearing aid benefit (APHAB)*, European Archives of Oto-Rhino-Laryngology, **274**, 3593–3598.
19. MCARDEL R., CHISOLM T.H., ABRAMS H.B., WILSON R.H., DOYLE P.J. (2005), *The WHO-DAS II: measuring outcomes of hearing aid intervention for adults*, Trends in Amplification, **9**, 127–143.
20. MENDEL L.L. (2009), *Subjective and Objective Measures of Hearing Aid Outcome*, from AudiologyOnline: [www.audiologyonline.com/articles/subjective-and-objective-measures-hearing-891](http://www.audiologyonline.com/articles/subjective-and-objective-measures-hearing-891) [accessed 7.07.2017].
21. POREMSKI T., SZYMAŃSKI P., KOSTEK B. (2017), *Short-term evaluation of the effectiveness of hearing aids employing the web-based survey*, Proceedings of XVII International Symposium on Sound Engineering and Tonmeistering, Warsaw, Poland.
22. SCHAFER P.J. et al. (2015), *Evaluation of an objective listening effort measure in a selective, multi-speaker listening task using different hearing aid settings*, Conference Proceedings of IEEE Engineering in Medicine and Biology Society, August 2015, pp. 4647–4650, Milan, Italy, doi: 10.1109/EMBC.2015.7319430.
23. SHI L.-F., DOHERTY K.A., KORDAS T.M., PELLEGRINO J.T. (2007), *Short-term and long-term hearing aid benefit and user satisfaction: A comparison between two fitting protocols*, Journal of the American Academy of Audiology, **18**, 482–495.
24. TYLOR B. (2007), *Self-report assessment of hearing aid outcome – An overview*, from AudiologyOnline: <http://www.audiologyonline.com/articles/self-report-assessment-hearing-aid-931> [accessed 6.07.2017].
25. VALENTE M., MISPAGE K.M. (2008), *Unaided and aided performance with a directional open-fit hearing aid*, International Journal of Audiology, **47**, 329–336.
26. WOOD S.A., LUTMAN M.E. (2004), *Relative benefits of linear analogue and advanced digital hearing aids*, International Journal of Audiology, **43**, 144–155.
27. World Health Organization (1991), *WHO Report of the Informal Working Group on Prevention of Deafness and Hearing Impairment Programme Planning*, Geneva, Switzerland.
28. ZHOU T., ZENG Y., WANG R. (2017), *Single-channel speech enhancement based on psychoacoustic masking*, Journal of the Audio Engineering Society, **65**, 4, doi: <https://doi.org/10.17743/jaes.2017.0003>.