ABS-0182

Using Ecological Momentary Assessments (EMA) to understand hearing aid experiences in everyday life in order to facilitate hearing aid fine-tuning

Karolina SMEDS[1]; Dina LELIC[2]; Daniel PARKER[3]

[1] ORCA Europe, WS Audiology, Sweden

[2] Scientific Audiology, WS Audiology, Denmark

[3] Applied Audiological Research, WS Audiology, Denmark

ABSTRACT

We have for a long time focused on ensuring successful real-life hearing for hearing aid users. In previous research, we have learned about everyday signal-to-noise ratios and classified listening tasks that people perform in real life. During Ecological Momentary Assessments (EMA), this classification has been used to study people's auditory reality. This knowledge about the average hearing aid user has been valuable in hearing aid design. However, hearing aid users can have individual and specific needs. New interactive technology has given hearing aid users a chance to create their own hearing aid programs while in a specific listening situation. Here we report on a different interactive approach, where a 2-week EMA trial was used to learn about hearing aid users' good and difficult listening experiences. While reporting on these experiences, hearing aid data were logged. Contrasts in hearing aid data between good and difficult situations could be identified. For a subset of participants, hearing aids were fine-tuned based on the acquired data. A week-long follow-up EMA period showed that the data-driven fine tuning was successful for all but one test participant. In conclusion, moments of hearing aid data combined with subjective reports of real-life listening experiences offer valuable insights for a data-driven hearing aid fine-tuning process.

Keywords: EMA, Hearing Aids, Data-Driven Fine-Tuning

1 INTRODUCTION

Ecological Momentary Assessment (EMA) has become an increasingly popular research tool in hearing research. EMA involves repeated sampling of test participants' experiences in their natural environment. The method aims to minimize recall bias and maximize ecological validity (1). By using EMA in hearing research, we have learned about people's auditory reality, perceived hearing difficulties, and hearing device use and benefit (2).

1.1 Auditory reality and hearing aid preference

Our own EMA work has focused on studying people's auditory reality and understanding hearing aid preference in everyday listening situations. In a literature study, Wolters et al. (3) investigated common listening situations that people encounter, and in the Common Sound Scenarios (CoSS) framework these situations were categorized into seven "task categories". In subsequent EMA studies, we have learned about how often these situations occur in peoples' everyday life, how important they are to hear well in, and how difficult it is to hear in the situations (4).

We have also used EMA to evaluate people's preferred hearing aid settings in everyday life using direct paired comparisons (4). The advantage of using EMA was that evaluations were made in the participants' everyday listening situations. Two hearing aid settings were implemented in two hearing aid programs, and the participants indicated their preferred program in the moment when they were prompted to report. The EMA questionnaire was implemented on a smartphone using Google forms. Switching between hearing aid programs was done using a traditional remote control, and there was no connection between the smartphone and the hearing aids.

Later, we developed a proprietary smartphone app that could administer the EMA protocol. With the new app, the smartphone and the hearing aids were connected. In a subsequent study, the app was evaluated (5) using similar research questions as in our previous work. For the auditory reality investigations, the new app provided information about the environment, such as sound levels (registered by the hearing aid microphones) and sound classes (as detected by the hearing aid's sound-classification system). For the hearing aid program preference, the new app could provide randomized and blinded paired comparisons. From this and similar studies, we have acquired knowledge about the average hearing aid user's auditory reality and hearing aid setting preference. However, hearing aid users can have individual and specific needs. Below, we describe the traditional hearing aid fitting process and how individual needs are usually dealt with.

1.2 Traditional hearing aid fitting

When fitting hearing aids, the end goal is that each client will get hearing aids with the settings that are the most appropriate. Traditionally, a combination of methods is used to reach this goal. Early in the process, a theoretical, prescriptive approach is used. A prescription makes it possible to calculate initial hearing aid settings based on characteristics related to the client, most commonly the audiogram. The audiogram data are combined with psychoacoustical theories and large data sets to calculate the initial hearing aid settings, which should be appropriate for an average hearing aid user with the stated audiogram. Subsequently, the fitting process enters an empirical phase, where the client uses the hearing aids in everyday life. During this period, the client likely experiences situations when the hearing aids function well and others where they do not. When the client comes back to the hearing care professional (HCP), there is a focus on the situations where the hearing aids did not work well, and the hearing aids are fine-tuned to alleviate the problems experienced in these situations.

There are several difficulties associated with this fine-tuning process. First, clients need to remember the situations in which there were difficulties during the home-trial period. Next, they need to be able to describe both the situation and the perceived problem. Then, the HCP needs to understand both the description of the listening environment and the description of the problem and transform the described difficulty into actionable fine-tuning adjustments. However, it is not always easy for the client to accurately describe real-life moments of hearing difficulties or for the HCP to transfer these verbal descriptions into meaningful hearing aid adjustments (6).

From modern hearing aids, we can retrieve both data that describe the listening environment and data that show the hearing aid settings in that environment. Ideally, these data could help the HCP in the fine-tuning process. However, to be helpful, these hearing aid data need to be tied to subjective evaluations of the situations.

1.3 Good and difficult listening experiences

Lelic et al. (7) found a way of using EMA to tie hearing aid data to subjective experiences. They investigated if contrasts between good and difficult listening experiences could be identified in objective hearing aid data. Sixteen participants were instructed to report, using the provided EMA app, when they experienced a listening situation that was either difficult or exceptionally good. When the participants started an EMA survey, they first indicated if it was a difficult or good situation by pressing on a sad or happy emoji. Then they described the listening environment and activity in their own words. If a difficult situation was indicated, the participants were also asked to describe why it was difficult.

While the participants answered the questionnaire, hearing aid data were logged at a time resolution of two seconds. The collected data included information about the acoustic environment, such as the sound level, the hearing aid detected sound classes, as well as presence of speech and transient sounds. Further, the app logged information about the hearing aid settings, such as the gain in each compression channel, hearing aid program, and whether certain adaptive features were active or not.

On a group level, the results showed that difficult listening situations were characterized by higher sound levels and more frequent activation of high-level noise reduction and directional microphones. The hearing aids also classified the situation as Party more frequently for the difficult situations. However, for 14 out of the 16 participants, Lelic et al. found individual contrasts that deviated from the group data for at least one hearing aid parameter. The authors suggested that this type of hearing aid data, together with the subjective evaluations, could be used when fine-tuning hearing aids. The rest of this paper will report on a pilot study, where a subset of the participants in the Lelic et al. study received hearing aid fine-tuning based on their momentary reports.

2 METHODS

Eight participants from the original study had their research hearing aids fine-tuned based on their reports and the collected hearing aid data. The fine-tuning was done immediately after the initial two-week trial period. After the fine-tuning session, the participants used the hearing aids for another week, where they again reported difficult and good situations using the EMA app. After the one-week period, an exit interview was conducted to understand experiences with the fine-tuned hearing aids.

2.1 Participants

From the original study, all participants who had at least as many difficult reports as good ones were included (4 people). In addition, participants who had a larger number of good than difficult reports were included if they had more than 5 reports of difficult situations (4 people). There were 5 females and 3 males who completed the current study, and their average age was 65 years (ranging from 55 to74 years).

2.2 Hearing aids

The participants were fitted with Widex EVOKE 440 receiver-in-canal hearing aids. For details related to the baseline fitting, see reference (7). Central to the study, a MATLAB script was used to modify the hearing aids by enabling an extended logging functionality, called the Eventlog.

2.3 EMA app setup

The EMA app setup is described previously (7). The logged hearing aid parameters included:

- Sound level in 15 frequency bands with center frequencies 125, 250, 350, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3200, 4000, 6000, and 8000 Hz
- Speech detection in the input signal (binary variable – yes or no)
- Transient activity in the input signal (binary variable – yes or no)
- Detected sound class corresponding to those available in the test HAs (8)
- Insertion gains in 15 frequency bands (listed above)
- High-level noise reduction activity (binary variable – yes or no)
- Low-level noise reduction activity (binary variable – yes or no)
- Wind noise reduction activity (binary variable – yes or no)

Once the participant started the study app, the Eventlog was simultaneously initiated and recorded one sample of hearing aid data every two seconds for a maximum of 70 samples. Additionally, volume control use during the entire hearing aid wear time was recorded, although these data were not published in the original work of Lelic et al.

2.4 Fine-tuning strategy

An experienced audiologist (the third author) performed the fine-tunings. Before each fine-tuning session, the participant's field data were analyzed, and potential fine-tuning adjustments were considered. When the participant arrived, the audiologist showed the summary graphs of the collected hearing aid data together with subjective reports of difficult situations. The participant could verbally supplement the descriptions retrieved through the app. The audiologist then performed the fine-tuning based on the data-driven dialogue. In most cases, the fine-tuned hearing aid settings were implemented in a new hearing aid program to not disrupt the good listening experiences. This was particularly important for participants who had submitted a substantial number of good reports.

3 RESULTS

The following fine-tuning actions were the most common: adding pre-defined hearing aid programs available in the fitting software, creating a personalized hearing aid program, or adjusting the overall gain or the gain in a particular frequency range.

3.1 Group results

Seven of the participants thought the fine-tuning adjustments were helpful. One person (participant 8, Table 1) was not content with the fine-tuned hearing aids. The number of positive and negative reports as well as participant comments from the exit interview are presented in Table 1. During the second field-trial period, some participants focused mainly on the difficult situations, which had been the focus of the fine-tuning session.

Table 1 – Summary of the number of submitted reports by each participant during the first field-trial period, the fine-tuning actions, the number of reports during the second field-trial period and comments given after the second field-trial period.

Partic-ipant	**Before Fine-Tuning**		**Fine-tuning actions**	**After Fine-Tuning**		
	Good reports	**Difficult reports**		**Good reports**	**Difficult reports**	**Comments after fine-tuning**
6	25	7	Party program (P2) Social program (P3)	8	5	Thinks it works better than before. It was fun trying the 2 programs. With one program he could hear more of what was going on around him and with other the person in front of him. Selected program based on intention. In many cases he could use the Universal program, but in other occasions he chose to use the special programs. There were no situations where he had a lot of difficulty after he tried one of the special programs.
13	61	10	Microphone set to omni-directional mode (P2)	52	2	Has been testing mostly the omni program, which has really improved her speech understanding, localization, and separation of sounds. Even in dance classes, with loud music, she could hear the instructor with the omni program, which she could not do with the Universal program.
15	25	10	Comfort program (P2)	16	14	Her hearing experience has improved. She really likes the Comfort program, uses it 1-2 hours a day, mainly in situations with many people. It helps with both comfort and speech understanding. She has been turning down the volume less often and is reporting good situations that were previously uncomfortably loud. She still has some speech understanding difficulties, mostly where there is poor acoustics.
16	14	12	-5 dB (250-2500 Hz) (P2) Comfort program (P3)	12	1	Switched to Comfort program in the kitchen to reduce noise. Switched back to program 2 or Universal so she could understand her husband. It has gone much better this week since the adjustments. She has used all 3 programs, depending on the situation. She used Comfort in the store and on the golf course, which made it much more comfortable. Has not experienced the same speech understanding difficulties as during the first 2 weeks.
4	2	17	+5 dB overall gain Transport program (P2) Social program (P3)	0	2	He was overall happy with the fine-tuning. Overall gain was perfect. Liked the Transport and Social programs when they were appropriate. He tried the Transport program in a train. He tried the Social program in shopping mall, supermarket and at a party/ wedding event where it helped him.
10	3	4	+5 dB for soft sounds (1000-2500 Hz) and -3 dB (350-500Hz) Urban program (P2) Party program (P3)	1	5	She confirmed that the adjustments in gain improved her speech understanding in meeting situations, and on Skype. Substantially better but not optimal. Also, the reduction of gain in the low frequencies reduced the "reverberant" sound quality that she was experiencing a lot in the beginning. The special programs did not help much in difficult situations.
14	4	5	-5 dB overall (P2) -3 dB for loud sounds (P3) -3 dB for loud and normal sounds (800-2000 Hz) (P4)	5	2	She reported good situations when watching TV and understanding speech in groups – situations that were difficult before. She reported two difficult situations, both because the sound level was too high. As observed in objective data, she had not tried to decrease the volume in these two situations.
8	7	10	Comfort program (P2) Party program (P3)	3	8	The fine-tuning was not successful. The Party program only helped when the sound level was not very high. The Comfort program dampened all sounds too much. This participant had many difficulties in very loud situations because it was too loud.

3.2 Fine-tuning examples

Below, two fine-tuning examples are given. A large amount of hearing aid data was collected during each EMA report. Here, examples of data that informed the fine-tuning process are presented. The participants' identifying numbers are the same as in reference (7). Hence, it is possible to look at Table 2 in that publication to see individual hearing aid data.

3.2.1 Participant 13

Participant 13 (female, 61 years) submitted 71 reports during the first field-trial period. Ten were in difficult situations. She described the difficult situations in the following way: 1. The sound is muffled, 2. Surrounding sounds from different directions are a "mish-mashed", 3. When there are more inputs from different directions at one time, it is difficult to separate words.

When looking at her hearing aid data, we could see that she had reported difficult situations when the directional microphone was particularly active (Figure 1). Based on this and her subjective reports, the suggested solution was to provide the participant with an extra program where the microphone was locked in omni-directional mode.

In the week following the fine-tuning, the participant reported 54 situations. Only two of these were difficult. One was a phone conversation at the office, which was perceived as very loud, and one was in the back seat of a car, were it was difficult to hear the conversation from the front of the car.

After the last field-trial week, she reported that she had mainly used the second program where the microphone was in omni-directional mode. This was confirmed by the objective hearing aid data, which showed that program 2 was used 70% of the time. This program had improved her speech understanding, localization, and separation of sounds.

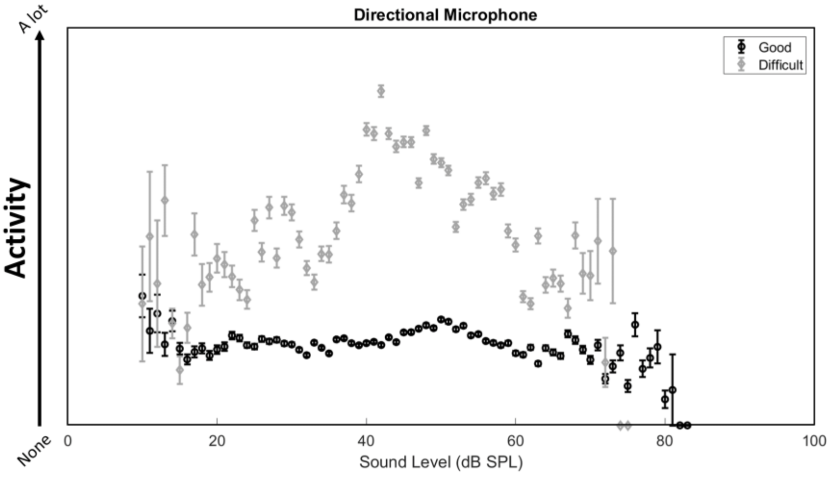

Figure 1 – Hearing aid data for participant 13 showing the directional microphone activity in good and difficult situations.

3.2.2 Participant 4

Participant 4 (male, 55 year) submitted 19 reports during the first field-trial period. Only two were of exceptionally good situations and 17 situations were reported to be difficult. The subjective reports of hearing difficulties included: 1. When there is traffic noise, 2. When a soft-spoken person talks, and 3. When many people are around, with multiple conversations outside and in living rooms.

His hearing aid data revealed that he particularly struggled when the detected hearing aid sound class was Urban or Traffic (Figure 2). The Urban sound class is flagged in situations with varied and diverse sounds and the Traffic sound class is flagged in situations with low-frequency noise. This is in line with the difficult environments that the participant described. Further, he had increased the volume control in some situations and for the most part reported difficult situations when the volume control was at the default (Figure 3), which indicated that he might need more amplification. The suggested solution was to increase the overall gain by 5 dB. In addition, two new programs were provided, Transport and Social. The Transport program is optimized for situations with low-frequency sounds, such as car noise. The Social program is optimized for situations characterized by multiple conversations at the same time.

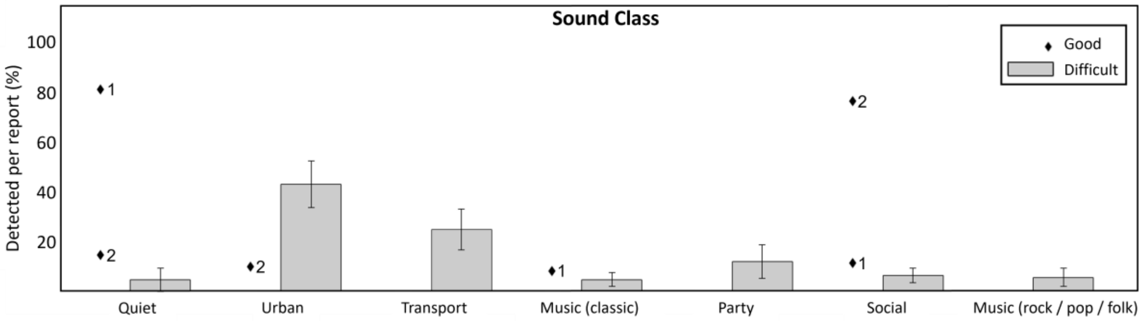

Figure 2 – Hearing aid data from participant 4 showing the sound classes which were flagged while the participant was reporting. For all samples during one reported situation (judged to be either good or difficult), the percentage of samples (vertical axis) in the different sound classes (horizontal axis) was calculated. For the difficult situations, the bars represent the mean of these percentages, and the error bars the standard error of the mean. For the good reports, the individual percentages are depicted by the diamonds. The numbers next to the diamonds indicate which of the two good reports the data belong to. The Quiet sound class was mainly detected during the first report, and the Social sound class was mainly detected during the second report.

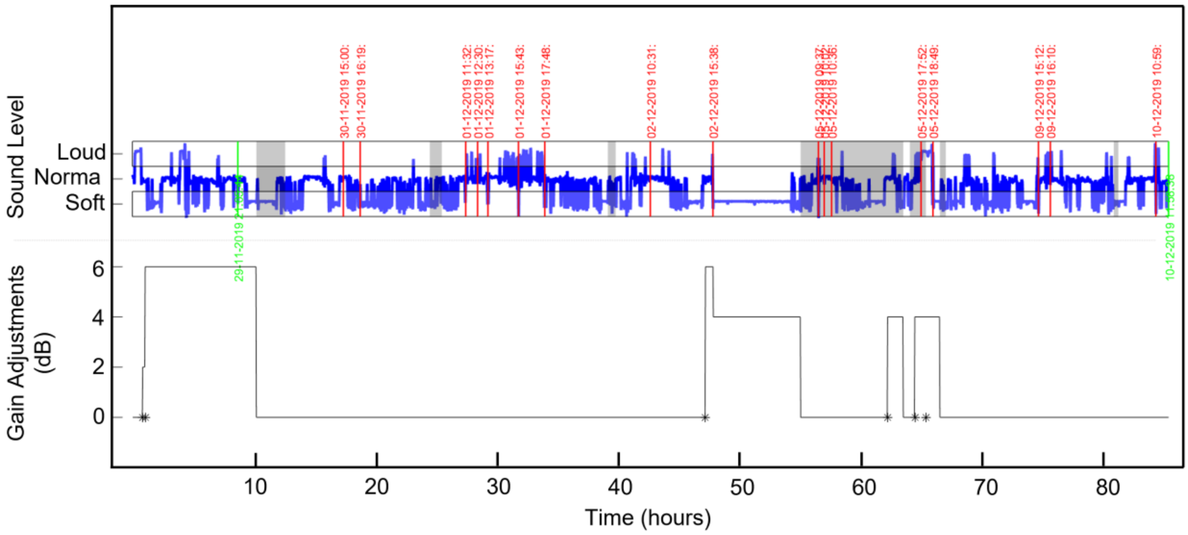

Figure 3 – Hearing aid data for participant 4 showing the participant's use of the volume control during the two-week trial. In the top row, the registered sound levels are shown and below is the self-selected volume control setting. The time stamps of his 17 reported difficult situations are marked on top in red, and the time stamps of the two reported good situations are marked below the level graph in green.

In the week following the fine-tuning, the participant reported only two difficult situations: conversation over a mobile phone with wind noise present, and a one-to-one conversation with wind noise present. Hence, both situations related to difficulties in wind noise and were different from the difficulties he expressed during the first two weeks of the trial.

After the last field-trial week, he commented that he had used the Transport program when he was outdoors. Here the program had helped a lot. Speech was heard more clearly, and the program did not muffle the sounds. He visited a big shopping center with lots of people and found that the Social program gave a clear improvement in speech understanding.

4 DISCUSSION

The work of Lelic et al. (6) showed that by using EMA and an Eventlog, which logged hearing aid parameters, subjective evaluations of good and difficult listening situations could be meaningfully linked to data collected from the hearing aid at the time of reporting. It was suggested that this information could be useful for hearing aid fine-tuning. In the current paper, we have presented a pilot study where a subset of the participants from the first study had the research hearing aids fine-tuned based on the momentary data they submitted.

Generally, the data-driven fine-tuning process worked well. Seven out of the eight participants were happy with the fine-tuned hearing aid settings. The one participant who was not satisfied would likely have benefitted from at least one additional follow-up session to improve his hearing aid fit. However, iterative fine-tuning until reaching the most appropriate hearing aid settings was beyond the scope of this study. The goal was to investigate whether hearing aid data coupled with subjective reports had the potential to be used for fine-tuning.

Most fine-tuning adjustments were implemented in an extra program. The use of several programs seemed to work well. It is probably beneficial not to introduce several programs to first-time hearing aid users at the first fitting visit since it can be difficult to know when to use the various programs. However, when a certain situation is described as difficult after a home-trial period and a special program is created for that situation, it becomes easier to understand when to use the program.

The now suggested fine-tuning strategy is thought to be used by HCPs when fine-tuning their clients' hearing aids. In modern hearing aids, there is often a possibility for clients to fine-tune their hearing aids themselves by, for instance, creating own programs for certain situations using machine-learning algorithms and paired comparisons (9). The two strategies are complementary and might be preferred by different client groups.

In addition to the difficult situations, the participants in this study were asked to report the situations they experienced as exceptionally good. The purpose of this design was to better understand how the hearing aids could be personalized to improve the difficult listening situations while not compromising on the good ones. However, it was inspiring that many participants reported such a high number of exceptionally good listening experiences. Encouraging hearing aid users to focus also on good listening experiences may strengthen the realization that hearing aids positively impact everyday life. This, in turn, can lead to increased satisfaction with and appreciation of the hearing aids (10, 11).

5 CONCLUSIONS

In conclusion, EMA data constituting self-reported subjective experiences and objective hearing aid data offered valuable insights that could be used for data-driven fine-tuning.

ACKNOWLEDGEMENTS

We want to thank Jakob Nielsen who enabled this study by setting up the logging functionality. Jakob Nielsen, Ole Hau and Jesper Theill contributed to the interpretation of the logged hearing aid data. Christina Johansson Folgeroe helped define the fine-tuning guidelines. Finally, we want to thank the test participants who contributed to this research.

REFERENCES

1. Shiffman S, Stone AA, Hufford MR. Ecological momentary assessment. Annu Rev Clin Psychol. 2008;4:1-32.
2. Holube I, von Gablenz P, Bitzer J. Ecological Momentary Assessment in Hearing Research: Current State, Challenges, and Future Directions. Ear Hear. 2020;41 Suppl 1:79S-90S.
3. Wolters F, Smeds K, Schmidt E, Christensen EK, Norup C. Common Sound Scenarios: A context-driven categorization of everyday sound environments for application in hearing-device research. J Am Acad Audiol. 2016;27(7):527-40.
4. Smeds K, Gotowiec S, Wolters F, Herrlin P, Larsson J, Dahlquist M. Selecting scenarios for hearing-related laboratory testing. Ear Hear. 2020;41 Suppl 1:20S-30S.
5. Jensen NS, Hau O, Lelic D, Herrlin P, Wolters F, Smeds K. Evaluation of auditory reality and hearing aids using an Ecological Momentary Assessment (EMA) approach. In: Ochmann M, Vorländer M, Fels J, editors. 23rd International Congress on Acoustics (ICA); September 9-13, 2019; Aachen, Germany:

Berlin, Germany : Deutsche Gesellschaft für Akustik; 2019.

6. Jenstad LM, Van Tasell DJ, Ewert C. Hearing aid troubleshooting based on patients' descriptions. Journal of the American Academy of Audiology. 2003;14(07):347-60.
7. Lelic D, Nielsen J, Parker D, Marchman Ronne F. Critical hearing experiences manifest differently across individuals: insights from hearing aid data captured in real-life moments. Int J Audiol. 2021:1-9.
8. Kuk F, Schmidt E, Jessen AH, Sonne M. New technology for effortless hearing: A “Unique” perspective. Hearing Review. 2015;22(11):32-6.
9. Balling LW, Mølgaard LL, Townend O, Nielsen JBB, editors. The Collaboration between Hearing Aid Users and Artificial Intelligence to Optimize Sound. Seminars in Hearing; 2021: Thieme Medical Publishers, Inc.
10. Saunders GH, Dillard LK, Frederick MT, Silverman SC. Examining the Utility of Photovoice as an Audiological Counseling Tool. J Am Acad Audiol. 2019;30(5):406-16.
11. Lelic D, Parker D, Herrlin P, Wolters F, Smeds K. Focusing on positive listening experiences improves hearing aid satisfaction in experienced hearing aid users. Journal of Hearing Science. 2022;12(1).