

Article

App-Based Self-Adjustment—User Behavior and Adjustment Practices of Cochlear Implant Users in Everyday Life

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Abstract: This study evaluated the effectiveness and usage of a smartphone application for adjusting the hearing impression of cochlear implants or hearing aids in everyday contexts. Building on previous laboratory research that demonstrated subjective auditory perception improvements through personalized settings, this research aimed to confirm these findings in real-life scenarios. Additionally, it analyzes user behavior and adaptation practices. Over a period of six months, 15 participants, including both bimodal and bilateral cochlear implant recipients, employed a self-adjustment app in their everyday lives. This application enabled them to modify the auditory experience through two distinct user interfaces and store their configurations as accessible programs. The collected data indicated that all participants were able to operate the app, and 13 of 15 participants successfully used the app throughout the whole study. In contrast to our previous findings, the acoustic environment did not affect frequency settings but did influence the choice of user interface. Bimodal users more frequently adjusted the settings for each ear independently compared to bilateral users. Most participants stated that they would also use the app outside of this study.

Keywords: cochlear implants; self-adaption; self-adjustment; user behavior; adaption practices; smartphone application



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1. Introduction

A cochlear implant (CI) is a prosthetic device for the inner ear that directly stimulates the auditory nerve, bypassing damaged inner hair cells and generating audible sensations, even in cases of profound deafness. Current CI systems generally provide effective speech perception in quiet environments [1–3]. However, challenges arise in more complex acoustic environments, such as those with background noise or reverberation, where many users face difficulties in understanding speech [4–6]. One of the critical factors influencing speech perception is the adjustment of the sound processors. The correct determination of threshold levels and upper stimulation limits is a pivotal aspect in this adjustment process [6]. Typically, the fitting process for a hearing aid (HA) or a CI is highly individualized. An initial fitting is typically performed by an expert. Subsequent fine-tuning is based on the expert’s expertise and the user’s feedback. The fine-tuned HA or CI is then worn by the user in various real-life listening scenarios. Further appointments for fine-tuning are commonly necessary, and this iterative process continues until a satisfactory setting is achieved for the user [7,8]. As a result, this fitting process may span several sessions, and the final configuration is heavily influenced by the expert’s experience and the time spent with the patient [9].

One potential solution to these problems is allowing users to adjust their hearing aid (HA) and cochlear implant (CI) settings themselves. This self-adjustment in everyday situations could enable users to tailor the sound to specific hearing environments, thereby enhancing their auditory experience. The concept of self-adjustment has been explored

by various research groups. Notably, Gößwein et al. [7] investigated this approach for hearing aids, while Vroegop et al. [6] and Botros et al. [10] examined its application for cochlear implants. They showed that self-adjustment led to a higher satisfaction in different acoustic environments but not to higher speech intelligibility. In both studies, users began with an expert baseline setting and could amplify or attenuate specific frequency ranges of the input signal using a software tool. Building on these findings, Kliesch et al. [9] introduced a self-adjustment function for bimodal users via an app in 2023, leveraging the latest generations of cochlear implants and hearing aids with integrated Bluetooth. The primary aim of that study was to evaluate the usability of two distinct UIs, one featuring a traditional equalizer and volume control, while the other one employed a 2D surface approach. Regardless of the UI type, both interfaces allowed users to modify the sound parameters of the CI and HA. The study also aimed to compare hearing outcomes based on patient adjustments. Previous data showed that in 80% of all tested conditions, participants preferred their self-adjusted settings over the expert fitting [9]. The current study examined how the findings obtained under laboratory conditions correspond to data and subjective impressions collected in real-life situations. Additionally, it analyzed user behavior and individual adaptation practices in daily life. A total of 15 study participants, including both bimodal and bilateral cochlear implant users, were provided with a self-adjustment app that they integrated into their daily lives over a period of six months. Data on app usage, adjustments, and prevailing daily life situations were collected and analyzed throughout the study period. Two of the fifteen participants withdrew from this study early, as they did not perceive any personal benefit from the opportunity for self-adjustment in their daily lives.

2. Materials and Methods

2.1. Study Participants

A total of 15 postlingually deaf participants, with either bimodal or bilateral implants, were included in the study. A slightly reduced sample size of 15 participants was selected, as this was an observational study. However, careful attention was paid to ensuring that the participants accurately represented the broader population of CI users. Particular attention was paid to diversity in terms of fitting (bimodal, bilateral), duration of CI or HA use, age, and progression of hearing loss. A summary of participants' demographic data is presented in Table 1 and in detail in Table A3. To be eligible, bilateral participants needed to have implants from Advanced Bionics, primarily from the HiRes series, although older models like the Clarion II were also compatible. Bimodal participants were required to have a conventional hearing aid, with no specific requirements regarding the make or model. However, to ensure compatibility with the hearing aids used in this study, participants needed to have ear molds with tube inlets. Additionally, participants were required to use the HiRes Optima or HiRes 120 coding strategy on the CI side. The specific configurations for each ear are detailed in Table 2. Hearing thresholds on the HA side were required to be better than or equal to 80 dB HL from 250 Hz to 1 kHz (see Figure 1). Additionally, all participants were required to be over 18 years old and have experience using smartphones, defined as regularly using at least one app per day. The selection process began with a review of the internal patient database, applying the above criteria. Patients who met all criteria and expressed interest in this study were invited to an initial appointment, where they were informed about this study and subsequently enrolled. Suitable candidates were contacted until the required number of participants was reached.

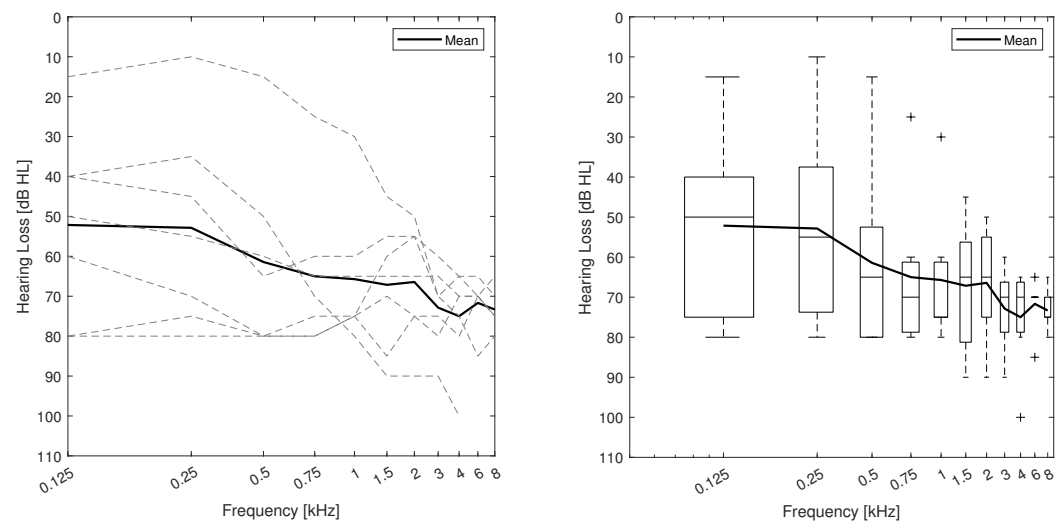


Figure 1. (left) Audiograms of all 7 bimodal participants for the HA side (dashed lines), as well as the mean (continuous line). (right) Audiograms for all 7 bimodal participants presented as boxplots, displaying the 25th and 75th quartiles, the median values, outliers (indicated by +), and the mean (represented by a continuous line).

Table 1. Short overview of the demographics of all 15 participants given in years.

	Mean (Years)	Min (Years)	Max (Years)
Age at study inclusion	60.3	41	74
Duration of CI use (first supplied side)	7.3	0.02	22.2
Duration of HA use (first supplied side)	29.7	10.5	56.8
Duration of hearing impairment (first side)	36.5	13.8	67.8
Duration of profound hearing loss (first side)	15.8	0.1	67.8

Table 2. Supply per side for each participant.

Subject ID	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
left	CI	CI	HA	CI	CI	CI	CI	CI	HA	CI	CI	HA	CI	HA	CI
right	HA	HA	CI	CI	HA	CI	CI	CI	CI	CI	CI	CI	CI	CI	CI

2.2. Hardware

In this study, the hearing aid used was the Phonak Naída™ (Phonak, Stäfa, Switzerland) Link M, while the cochlear implant side utilized the Advanced Bionics Naída™ (Advanced Bionics, Valencia, CA, USA) CI M processor. Both devices operated internally at a sampling rate of 22,050 Hz and employed a short-time Fourier transform (STFT) filterbank with Hanning windows. The frequency adjustments made during the self-adjustment process (see Section 2.3.2) were applied to 20 Bark bands, as detailed in [9]. For participants who did not own an iPhone (Apple, Cupertino, CA, USA), an iPhone was provided for the duration of this study, specifically from the 7, 8, or SE generation.

2.3. Smartphone Application

In the present study, a smartphone application specifically designed for the Apple iOS 15 or later platform was utilized. The application was not officially listed on the App Store at the time of this study but was rolled out to the iPhones using Apple's provided testing environment, Testflight Version 3.2.2 or later. This approach had the advantage of enabling updates on the fly to be deployed during the chronic phase without requiring manual re-installation. After pairing the app with the CI or HA via Bluetooth,

the study participants could use the app to switch between different hearing programs and create new ones using the self-adjustment feature. Additionally, the app performed background tasks that collected and stored parameters related to the participant's current hearing or acoustic environment. This functionality was supported by the AutoSense OS™ 3.0 Operating System running on Naída™ devices, which analyzes ambient noise every 0.4 s. Based on this analysis, the app automatically activated the optimal combination of settings, programs, and features to provide the best possible hearing experience [11].

2.3.1. Organization of Programs

Figure 2a displays the home screen of the application along with the drop-down list of all available programs, from which users could select their preferred program. The program selection applied to both sides, whether for a hearing aid (HA) or a cochlear implant (CI). Upon the initial setup of the application, participants had access to seven preset programs in addition to the automatic program. These preset programs were included: Speech in quiet, Speech in noise, Speech in loud noise, Speech in car, Comfort in noise, Comfort in echo, and Music. These seven programs corresponded to the different ambient sound classes of the AutoSense OS™ 3.0 operating system [12], providing participants with a versatile selection of programs right from the start. At any time, the participant had the option of creating a new program from within the AutoSense OS™ 3.0 program (see Section 2.3.2). The newly created program was based on the current parameter settings of the classifier at the time the user started the creation. In the course of self-adjustment, these parameters could then be adapted to personal preferences. Newly created programs were automatically added to the program list and were available to the participant at any time. In contrast to the preset programs, the user could also delete self-created programs. It was also possible to modify own programs or preset programs, with the exception of the AutoSense OS™ 3.0 program. Participants could create as many custom programs as they wanted.

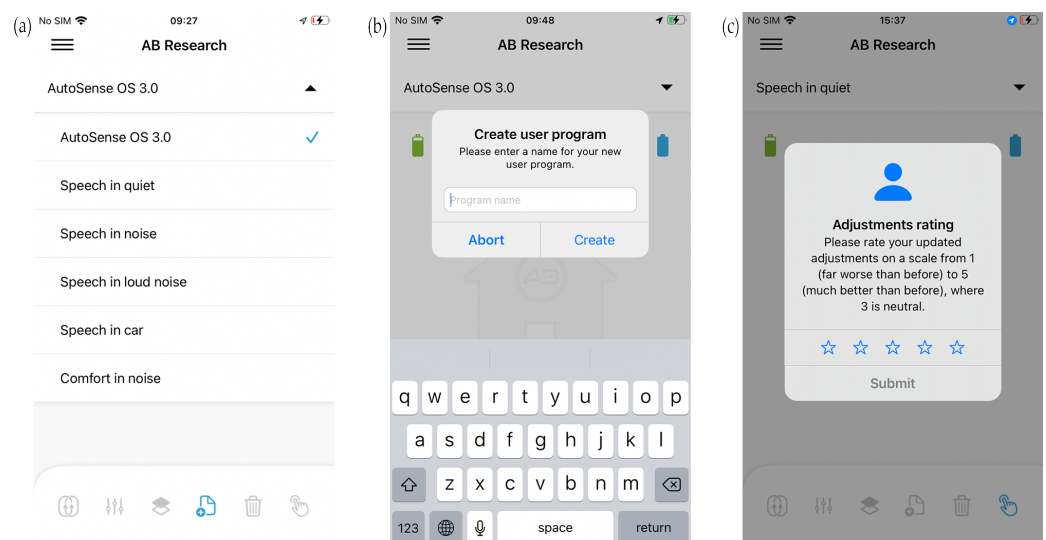


Figure 2. (a) App environment for program selection; (b) naming a new program; (c) evaluation process of a saved adjustment.

2.3.2. Self-Adjustment

The application's self-adjustment function to change the daily listening experience is based on methods for modifying frequency-dependent gain parameters as described by Kliesch et al. [9]. For this study, both the EQ user interface (EQ UI) and the 2D user interface (2D-Surface UI) were integrated into the self-adjustment workflow. These UIs empowered users to make frequency-specific adjustments, including modifications to bass, midrange, treble, and overall volume. All changes were applied to an initial expert setting, which was created during the first study appointment (see Section 2.5). Furthermore, in this study,

users had the ability to adjust beamforming strength, noise reduction, and wind noise reduction based on the AutoSens OS 3.0 program parameters at the moment the participant initiated the program creation for the first time. One of the two user interfaces (UIs) provided in this study was a classic equalizer and volume control interface (EQ UI), while the other followed a tactile 2D-Surface concept (2D-Surface UI) for manipulating frequency-specific sound parameters. The EQ UI, shown in Figure 3a, allowed participants to adjust three frequency ranges: low (centered at 172 Hz), medium (centered at 861 Hz), and high (centered at 4.5 kHz), along with overall volume. Adjustments could be made for both the HA and CI simultaneously or independently, if the two pointers for each slider were decoupled. Each slider offers a range of ± 10 dB, and in combination with the volume control, total gain adjustments of ± 20 dB were possible. The 2D-Surface UI, depicted in Figure 3b is based on concepts developed by Dreschler et al. [13], Gößwein et al. [7], Rennie et al. [14] and further refined in the work of Kliesch et al. [9]. In this interface, participants adjust sound parameters by moving a point within a square. As with the EQ UI, adjustments can be made simultaneously or independently for both the HA and CI if the points for the left and right sides are decoupled. Moving the point along the x -axis selects different gain–frequency curves focused on specific frequency ranges, while moving it along the y -axis allows for boosting or cutting these frequencies. Unlike the EQ UI, which utilizes three band-pass filters, the 2D-Surface UI combines a high-pass and a low-pass filter, with a gain range of ± 20 dB. In addition to the frequency adjustments, three additional sliders were incorporated, as shown in Figure 3c. These sliders allowed participants to adjust beamforming, noise reduction (HA only), and wind noise reduction. This expanded functionality enabled participants not only to amplify or attenuate specific frequency ranges but also to control the intensity of individual signal processing steps.

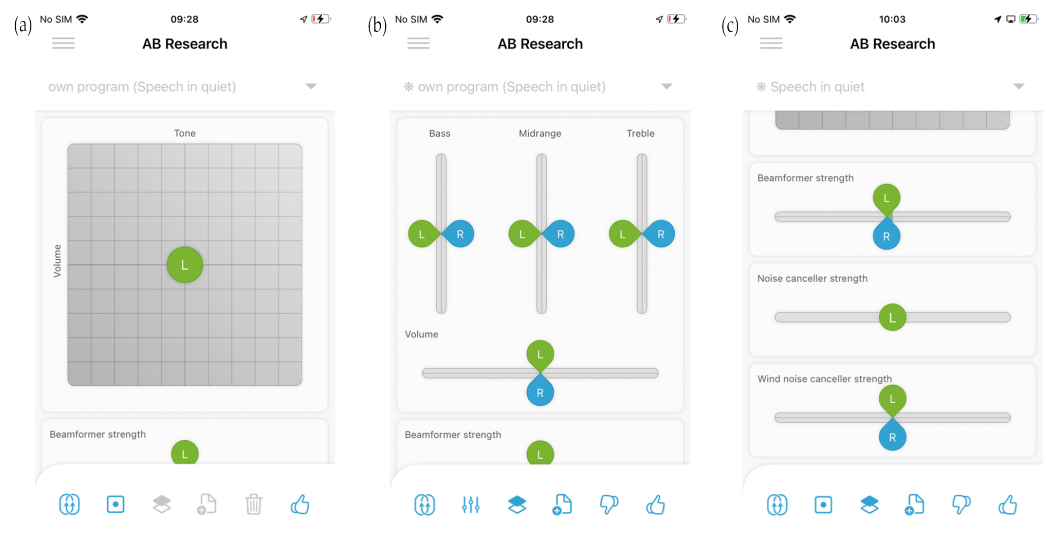


Figure 3. App environment for creating and modifying programs: (a) 2D Surface user interface, (b) EQ Surface user interface, (c) slider to make changes to the strength of each signal processing step. Note: “L” refers to the left side, and “R” refers to the right side.

During the adjustment process, the participant had the option to switch between the two UI’s at any time. However, changing the UI resulted in the loss of previously made settings, as the parameter sets were not transferable between the UI’s. Consequently, the sliders/points and their associated parameters were reset to their initial settings. To prevent this, a default UI could be set in the general settings of the application. In the event of a new adjustment, this UI would be displayed from the start. At any point of the adjustment process, the participant had the option to save the settings made or to cancel the customization and discarding all applied changes. In the case of modifying an existing program, the participant had to choose whether to irreversibly overwrite the old parameter

set or to create a new program with updated settings. The participant had the option to assign a unique name to each newly created program. The naming procedure is illustrated in Figure 2b. Once assigned, the program was displayed in the program list on the home screen under the designated name. Each time a setting was saved, the participants had to rate their settings. Figure 2c shows the evaluation process and the associated question: “Please rate your updated adjustments on a scale from 1 (far worse than before) to 5 (much better than before), where 3 is neutral”. This evaluation of the adjustment could not be skipped. In the event of discarding an adjustment, no rating was required.

2.4. Study Procedure

The present study was designed as a prospective observational study in which all participants were equipped with identical hardware and software to ensure comparable basic conditions for using the application. In an initial study appointment, an experienced audiologist created the expert fitting for the CI and HA using the regular fitting software Target CI 1.5 by Phonak, Stäfa, Switzerland (see also Section 2.5) and participants were instructed on how to use the application. To reinforce their understanding, participants were required to make a self-adjustment in three different natural environments, saving each adjustment as a new program. The first adjustment took place in the study room, which was characterized by low reverberation and little external noise. The second adjustment was performed in the entrance hall of the CI aftercare center, a large hall with strong reverberation and soft background music. The third adjustment was made outdoors on a busy street in front of the building, occasionally exposed to weather-related challenges such as wind. In all three scenarios, the study investigator engaged in conversation with the participant during the self-adjustment, allowing them to experience the impact of their changes. At the end of the initial study session, each participant selected their preferred user interface (2D Surface or EQ) for subsequent self-adjustments. They were also encouraged to incorporate the app into their daily routines, without specific usage instructions, to ensure that the data collected reflected their voluntary, everyday use. Throughout the study’s six-month duration, data on daily hearing situations and app usage were continuously monitored and stored. At the end of this study, during a second session, participants were discharged, and the provided hardware and software were returned.

2.5. Expert Fitting

For the participants’ cochlear implants, all configurations, including the primary map utilized by the participants, were exported from their personal processors and transferred to the Advanced Bionics Naída™ CI M processor used in this study. This approach ensured that the hearing experience closely resembled their everyday perception. Participants were asked whether the new program sounded familiar, and adjustments were made if they were not satisfied. This final setting represented the expert fitting for the patients’ CIs. For the hearing aids, if a participant privately used a Phonak Naída™ Link M, their data were transferred to the study device, with only minor adjustments made, if requested. If a different hearing aid was used, the settings from the private device were not exported. Instead, a new expert setting was created using the Target CI 1.5 fitting software for the study device. This fitting was performed using data from the AudiogramDirect functionality and the Adaptive Phonak Digital Bimodal (APDB) formula. The APDB formula was specifically tailored for bimodal CI users, especially those with limited hearing on the HA side, where the CI often plays a dominant role in speech understanding [15]. Cochlear implants are good at encoding higher frequencies (1–8 kHz) but can only deliver limited temporal fine structure in the lower-frequency range. The APDB fitting formula enhances the audibility of low-frequency information through the HA, complementing the CI by providing temporal cues that aid speech understanding in noisy environments [9,16]. Additionally, the volume boost and automatic gain control (AGC) functions were synchronized between the CI processor and the HA [9,16]. To achieve the best bimodal benefit, the loudness of the new HA fitting was matched to the loudness of the CI side. This loudness adjustment

was performed informally through conversation with the participant, without further measurements, and in consultation with subject. Subsequent fine-tuning was performed if necessary. These expert settings for both the CI and HA also served as the baseline from which participants made adjustments using the smartphone application.

2.6. Data Acquisition

Throughout this entire study, user interactions with the app and acoustic environments from the participants' everyday lives were continuously collected and stored in a cloud-based system. This approach offered the advantage of immediate data availability for the study team, facilitating prompt analysis and allowing precise tracking of the times when data were collected and stored. In cases where an internet connection was unavailable during data collection, the data were temporarily stored locally on the smartphone and uploaded once the connection was restored. Special attention was given to the necessary prerequisites to ensure accurate data tracking. For example, occasional gaps in the classification parameters of the Auto Sens OS 3.0 program were observed, which occurred when there was no Bluetooth connection between the hearing device and the smartphone. A detailed list of the tracked parameters, user actions, storage timestamps, and any requirements for data collection can be found in Table 3.

Table 3. Overview of all recorded parameters and user actions as well as their storage duration and possible requirements for storing the data.

Parameters/Actions	Storage Timestamp	Requirements
program creation	save new program	none
program modification	overwrite program	none
current program change	change program	none
self-adjustment gains	save new program overwrite program	none
used user interface	save new program overwrite program	none
program rating	save new program overwrite program	none
current classification parameters of the Auto Sens OS 3.0 program	start creating a new program start overwriting a program current program change every minute	The app had to be running in the background and the Bluetooth connection had to be active to track the environmental situations every minute

3. Results

3.1. User Behavior

Throughout the study period, almost all participants actively used the application and regularly made individual adjustments in the context of their daily lives. Participants with IDs MHH14 and MHH15 discontinued this study prematurely, citing that they did not find the application beneficial in their everyday experiences. The exact number of days each participant was included in this study can be found in Table A1 in Appendix A. The number of different datasets collected from the participant's daily lives can be found in Table 4.

Table 4. Overview of the amount of data collected.

Action	Quantity [n]
program creation	213
program modification	266
current program change	5536
Auto Sens OS 3.0 classification	559,312

3.1.1. Everyday Life Situations

The evaluation of the data on the acoustic environments from all study participants is shown in Figure 4. The analysis revealed that the “speech in quiet” scenario accounted for 39% of participants’ daily situations. Similarly, acoustic environments such as “speech in noise” (24%) or “noise” (18%) occurred with comparable frequency. Conversely, situations such as “music”, “reverberant speech”, and “in car” collectively represented only about 19% of all observed everyday scenarios. However, an analysis of individual participant datasets, as shown in Figure 5, highlighted the highly personalized nature of everyday life situations. For example, a significant disparity was evident between participants MHH01 and MHH04: while MHH01 frequently chose or found themselves in quiet situations with speech, MHH04 more often selected or experienced environments with both speech and background noise.

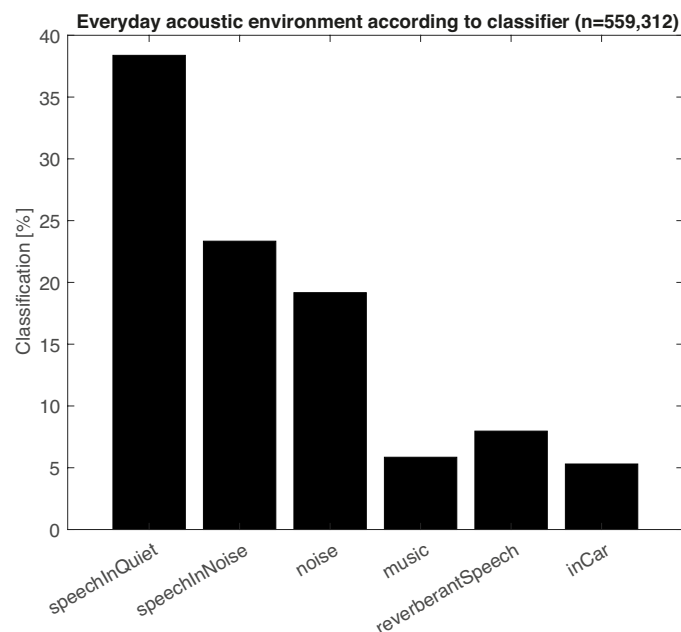


Figure 4. General overview of the everyday acoustic environment of the participants.

3.1.2. Self-Adjustment Situations

To investigate the potentially increased need for personalized adjustments in certain everyday situations, the prevailing acoustic environments at the time of self-adjustment were analyzed and are presented in Figure 6. It was found that 38% of all self-adjustments occurred in quiet situations with speech and approximately 29% in situations with speech with background noise. These two conditions accounted for nearly two-thirds of all observed everyday situations where self-adjustments were performed. However, the pattern in this distribution mirrored the general distribution of acoustic situations in daily life, as shown in Figure 4. To account for the inherent bias introduced by this natural distribution, an adjustment was made by factoring out the general distribution of acoustic scenarios. Specifically, inverse factors based on the data in Figure 4 were applied to the self-adjustment data in Figure 6. The adjusted data, shown in Figure 7, revealed a more homogeneous distribution. A detailed analysis using a two-sided binomial test showed that self-adjustments were made significantly more frequently in the “speech in noise” situation ($p < 0.01$) and significantly less frequently in the “noise” situation ($p < 0.05$).

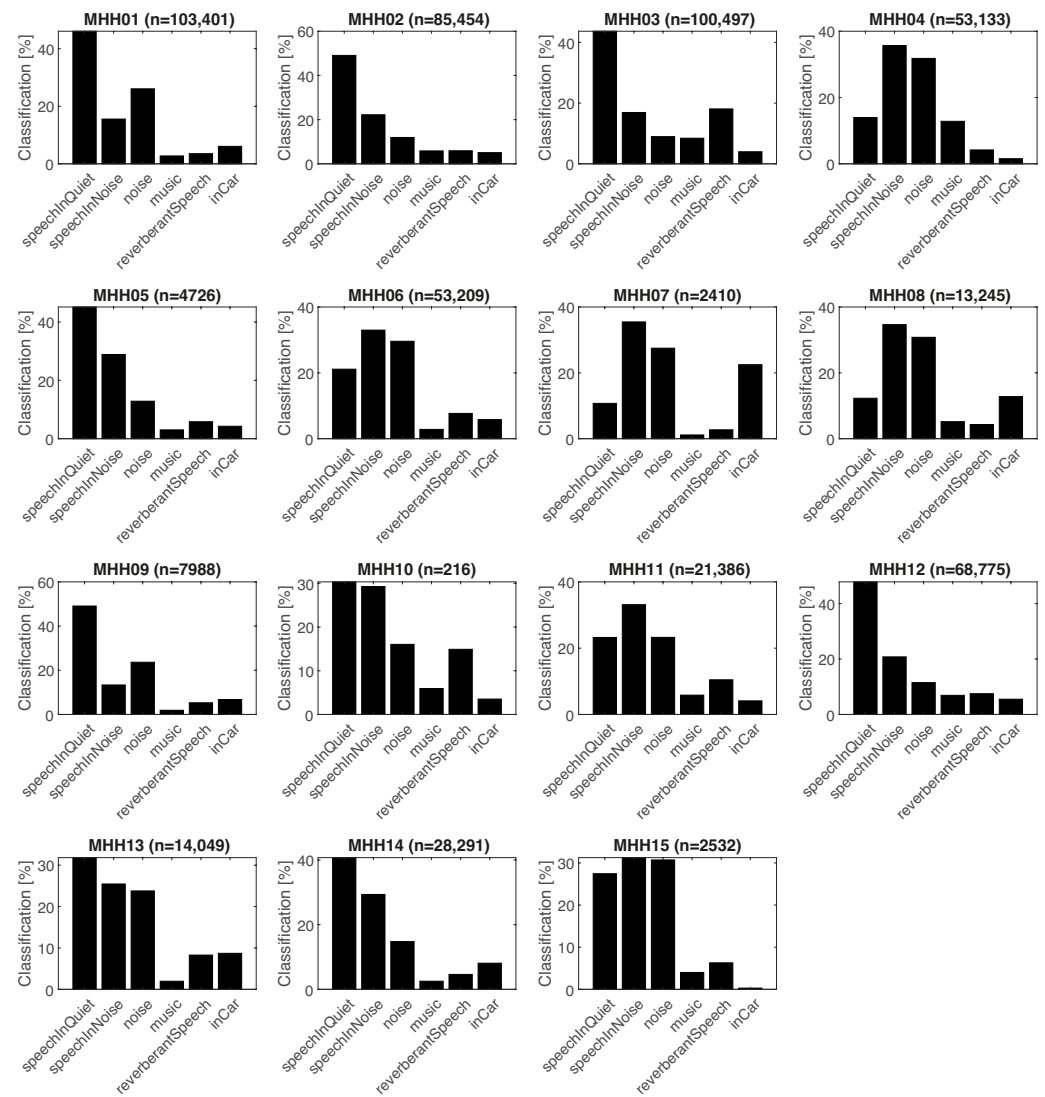


Figure 5. Overview for each individual participant of the acoustic environment situations in which they most frequently found themselves.

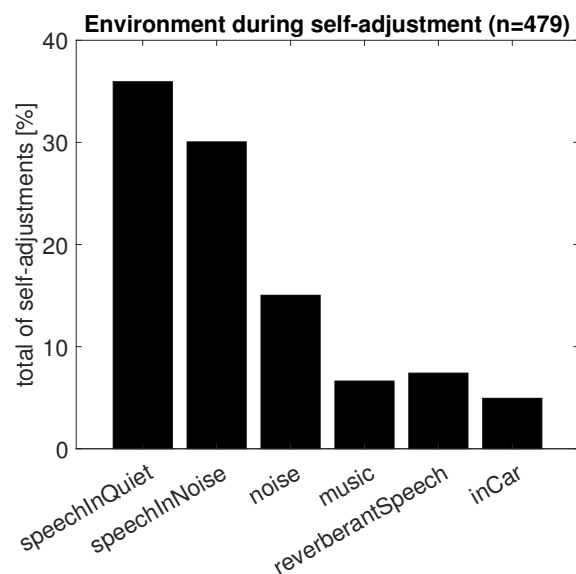


Figure 6. The environment during self-adjustment of all participants.

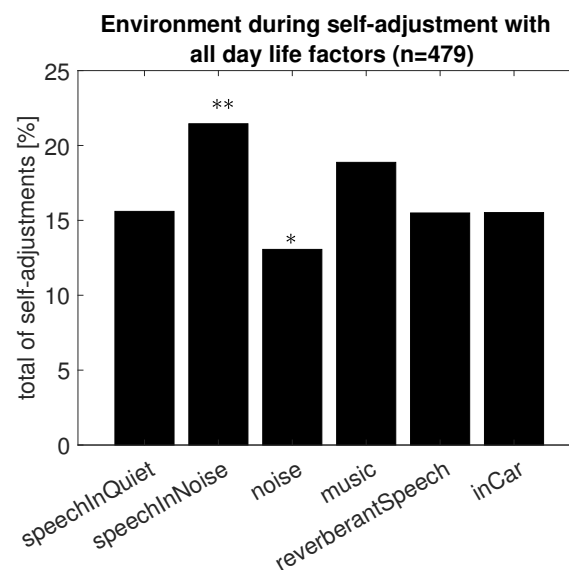


Figure 7. The environment during self-adjustment for all participants, taking into account the frequency of acoustic situations in everyday life presented in Section 3.1.1. * Significant at a level of $p < 0.05$; ** significant at a level of $p < 0.01$.

3.1.3. App Usage During the Study Period

The following section examines app usage throughout the entire study period in more detail. While all participants used the app consistently during this study, a decline in usage was observed over time. App usage can be divided into two main functions: making self-adjustments and switching between programs. As shown in Figure 8, self-adjustments were predominantly made at the beginning of this study and then declined significantly over time. In contrast, the function to switch programs and access user-created programs was used consistently throughout the study period, showing only a minimal decline. In Figure 9, only program changes to a program previously created by the participant were taken into account.

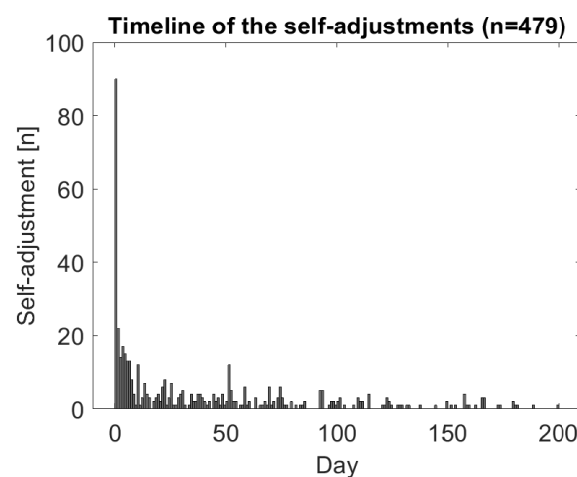


Figure 8. Frequency of a self-adjustment plotted over study duration in days.

3.2. Adjustment Practices

The following section evaluates the adjustment practices during self-adjustments.

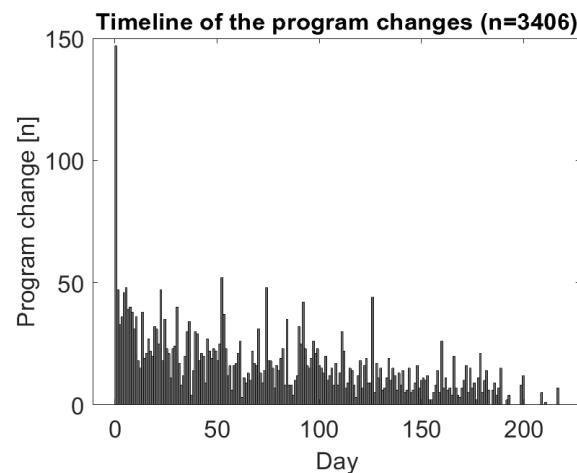


Figure 9. Frequency of a program change plotted over study duration in days. Only program changes to a program previously created by the participant were taken into account (see Figure 4).

3.2.1. Used User Interface

From Table A2 in Appendix A, it was inferred that a total of 12 out of 15 participants chose the 2D-Surface UI as their standard user interface during the first study session. Consequently, only three participants initially selected the EQ UI as default for their self-adjustments. During this study, it was observed that seven participants switched between the UIs during self adjustments, while eight participants performed all their adjustments using their default user interface. Based on this information, Figure 10 illustrates the ratio between the usage of the two user interfaces. It shows that 68.5% of all 479 self-adjustments were carried out using 2D Surface UI, while only 31.5% were performed using EQ UI.

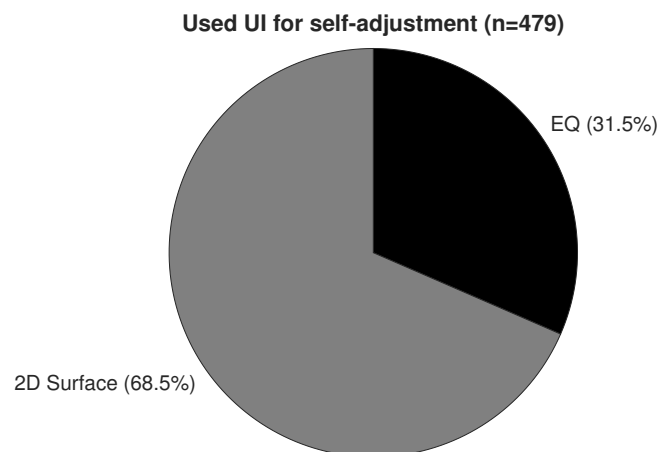


Figure 10. The ratio between the use of EQ and 2-D Surface UI for self-adjustments.

An analysis of the selected user interface in the context of the prevailing acoustic environment at the time of self-adjustment is illustrated in Figure 11. A chi-square test for independence reveals a significant relationship between the selected user interface and the acoustic situation, at a significance level of $p < 0.01$.

3.2.2. Gains of Self-Adjustment

The following section examines whether there was a correlation between the sound settings made and the prevailing acoustic environment at the time of self-adjustment. Figure 12 presents the resulting gains for each filter band based on the acoustic situation. In this evaluation, the settings for both the left and right sides of each program were considered, resulting in a total number of settings (n) that was twice the number of the underlying programs. The analysis revealed that, on average, there were no significant

differences between the acoustic situations, suggesting no strong correlation between the prevailing acoustic environment and the self-adjustment. However, it is important to note the wide range of gains within each frequency band, indicating a high level of individualization in the adjustments made by the participants.

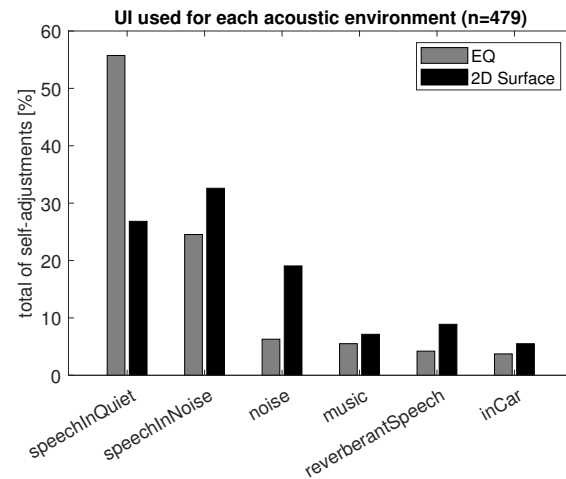


Figure 11. Overview of the UI used in each acoustic environment.

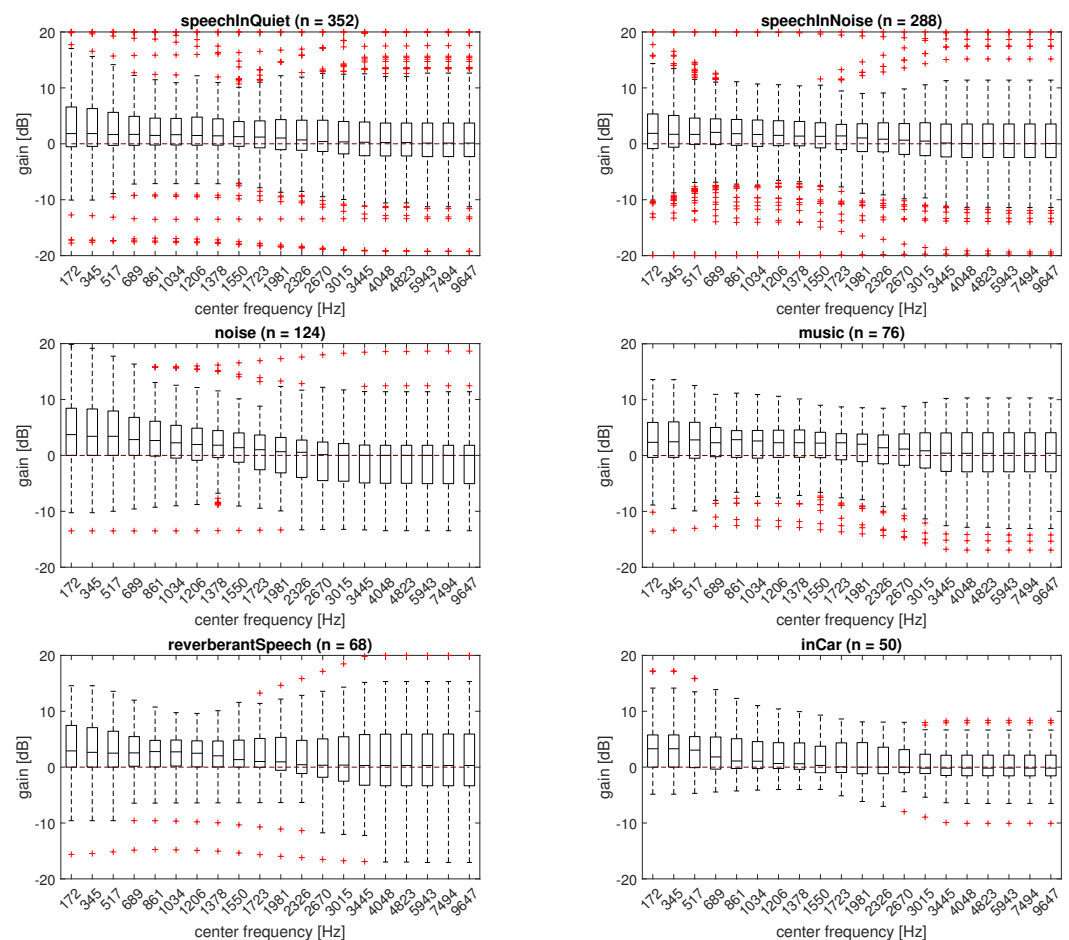


Figure 12. The resulting gains for each filter band depending on the prevailing acoustic environment during self-adjustment. The settings of the left and right sides of each program were taken into account. Outliers were indicated by “+”. The total number of settings n was therefore twice as high as the underlying number of programs.

3.2.3. Side-Dependent Adjustment

Figure 13 shows that in 79.5% of all self-adjustments, different settings were created for the two sides. Among the bimodal-aided participants, 85.8% exhibited a higher proportion of programs with differing settings between the sides compared to bilateral participants, at 71.1%.

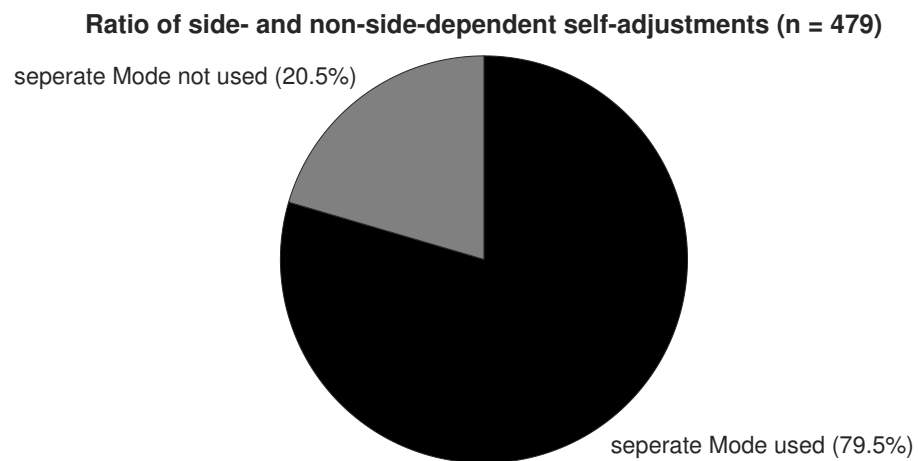


Figure 13. Ratio of side-independent and side-dependent self-adjustments.

Figure 14 illustrates the variations in the settings for each individual parameter between the two ears. The calculation formula of δ is provided in Equation (1). The “Volume” parameter encompasses the volume settings of both the EQ and 2D-Surface UIs. The parameters “Bass”, “Mids”, and “Treble” reflect the settings adjusted within the EQ UI. The “Tone” parameter represents the slider position along the y -axis within the 2D-Surface UI, indicating the chosen frequency curve. The three remaining parameter sets “BeamFomerStrength”, “NoiseCancellerStrength”, and “WindNoiseCancellerStrength” represent the settings for the pr-processing steps in both the EQ and the 2D-Surface UIs.

$$\delta = |value_{par_left} - value_{par_right}| \quad (1)$$

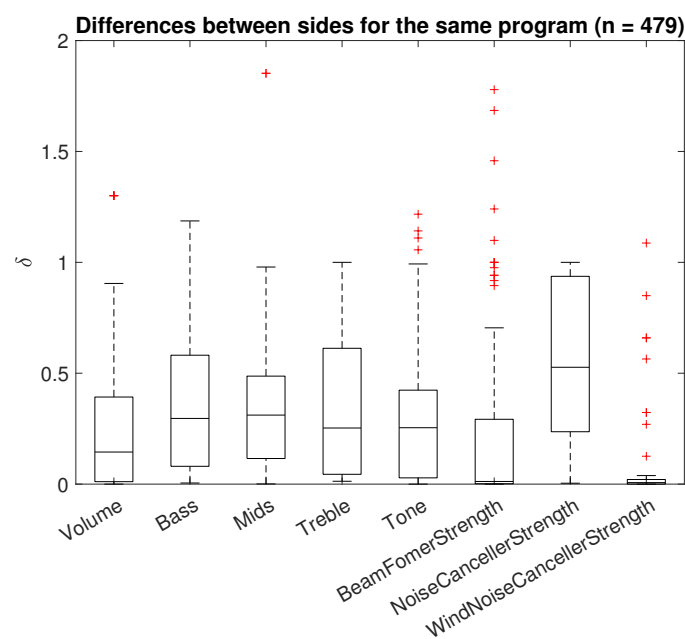


Figure 14. Differences for each parameter between sides for the same program. Outliers were indicated by “+”.

3.2.4. Iteration Loops for One Program

Figure 15 illustrates how frequently a program was modified by the users, indicating the number of iteration loops each program underwent. It can be observed that 43% of all created programs were modified at least once after their initial creation. This also implies that 57% of all created programs did not require further modifications. As shown in Figure 15, the likelihood of a program being modified decreased with each additional iteration loop.

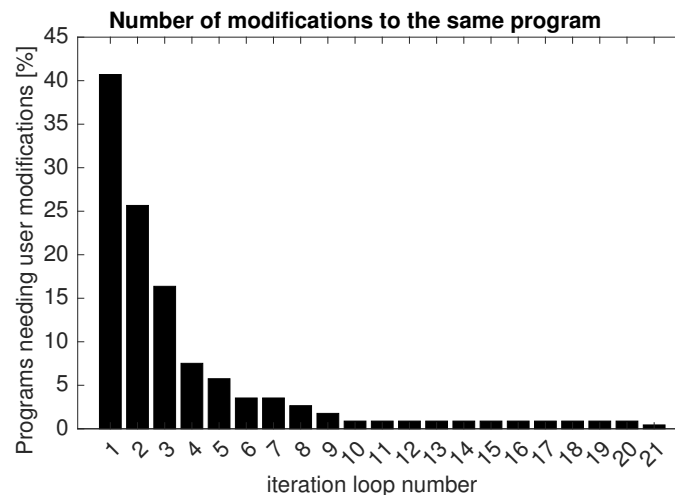


Figure 15. Number of iteration loops that the same program went through.

3.2.5. User Rating

The spontaneous evaluation of the self-adjustments is shown in Figure 16. It presents the distribution of the awarded stars (1–5) in response to the question: “Please rate your updated adjustments on a scale from 1 (far worse than before) to 5 (much better than before), where 3 is neutral”. The results indicate that approximately 40% of all self-adjustments resulted in a subjectively improved sound quality. For 33%, neither improvement nor deterioration was noted, while about 25% led to a poorer sound quality, indicating that the majority of self-adjustments (75%) did not negatively impact sound quality.

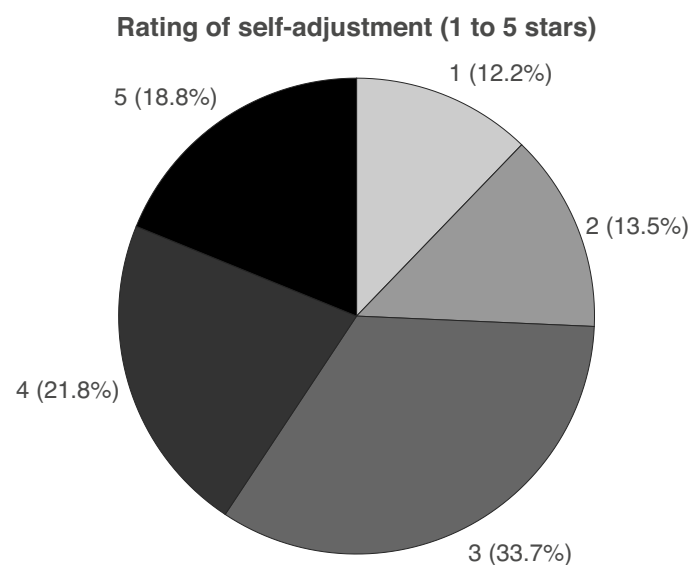


Figure 16. Overview of the user rating of the self-adjustments.

4. Discussion

The findings of this study provide valuable insights into the usage patterns and effectiveness of a self-adjustment app for cochlear implants and hearing aids in real-life scenarios. Generally, the app was very well accepted by the participants and was used consistently across the study duration of six months. Our findings highlight the potential for such tools to empower users in managing their auditory experiences, while also identifying areas for improvement and further investigation.

4.1. Acoustic Environments and Self-Adjustments

The analysis of acoustic environments experienced by the participants aligns with that in previous research, such as that of Schinkel et al. [17], who documented similar everyday acoustic scenarios in their study of hearing aid users. The most common environment observed in our study was “Speech in Quiet”, followed by “Speech in Noise” and “Noise”, which mirrors the order reported by Schinkel. However, individual variability was evident, as the specific acoustic situations encountered by the participants differed significantly. While, for example, the average data in Figure 4 well reflect the experiences of participants MHH01 and MHH02, participants such as MHH04 or MHH08 show different distributions for their experienced everyday situations. This variability underscores the importance of tailoring self-adjustment tools to accommodate the diverse environments that users experience daily. Furthermore, it is important to note the significantly different number of data points indicated by “n” in the headings of Figure 5. The occasionally low number of measurement points may have been due to participants only connecting via Bluetooth to their smartphones to make self-adjustments and otherwise using the Bluetooth connection for other purposes. This was often observed in participants who were specifically provided with an iPhone for this study and did not connect with their own smartphone. In addition to the alternative use of the Bluetooth connection, everyday circumstances can also have an impact. As Schinkel [17] showed in her study, participants may turn off their smartphones in situations such as meetings, in the cinema, or in church. Additionally, there is often no Bluetooth connection during physical activities or if the smartphone is simply forgotten at home. It should therefore be noted that although, on average, the distribution of acoustic situations presented in this study and by Schinkel can be assumed, individual deviations from this generally valid distribution always occur and their needs must also be met.

Significant deviations were observed in the frequency of self-adjustments across different acoustic environments. Notably, self-adjustments were more frequent in the “Speech in Noise” condition, a challenging environment for CI users [4–6], and less frequent in the “Noise” condition, which typically provides less auditory content. This pattern suggests that participants were more likely to engage in self-adjustment in environments where they struggled to understand speech, aligning with the findings of Gablenz et al. [18] that emphasized the importance of hearing well in communication-focused situations. However, we also observed that the participants were less likely to make adjustments in certain acoustic environments, such as “noise”. We interpreted this as an indication that the participants did not perceive the need for adjustments when speech comprehension was not the primary concern. In such contexts, participants may have relied on the automatic settings or simply chose not to engage with the app, as the priority shifted away from speech understanding to environmental awareness. This highlights the importance of considering the context in which users are interacting with the app, as it could influence their decision to adjust the settings.

4.2. Situation-Dependent Frequency Adjustments

Interestingly, the frequency adjustments made by the participants did not show a strong correlation with the prevailing acoustic environment, which contrasts the results observed in controlled laboratory settings by Kliesch [9]. In the aforementioned study, adjustments were closely tied to the simulated listening environment. The lack of a similar pattern in our study may have been due to the greater variability in real-life acoustic

environments, which are assigned to broad classification categories that might mask more specific contextual differences. In real-world settings, these environments likely vary significantly, potentially requiring more substantial deviations in settings than those observed under standardized lab conditions. Moreover, the participants in our study had the opportunity to experiment with a wider range of settings to approximate the best possible adjustments. This exploratory behavior contrasts that found by Kliesch [9], where only one self-adjustment per acoustic condition was considered per participant, potentially limiting the ability to replicate those findings in a more dynamic, real-world context.

4.3. Interface Preferences and Usage Patterns

The preference for the 2D-Surface UI over the EQ UI, chosen by 68.5% of participants, reflects a general inclination toward a more intuitive interface. This preference is consistent with the findings of Kliesch et al. [9] and Rennie et al. [14], who noted that self-adjustment using the 2D-Surface UI can be faster and more suited to situations where users have limited time. Our study confirmed that in quieter, less hectic environments, the EQ UI was preferred, likely due to its ability to provide more detailed adjustments across three distinct frequency ranges. Conversely, the 2D-Surface UI was favored in noisier, busier environments where quick adjustments were necessary. This differentiation highlights the need for flexible interface options supporting the varying demands of real-life situations.

4.4. Side-Dependent Adjustments

A commonly observed behavior was the separate adjustment of parameters for the left and right sides, consistent with the findings of Kliesch [9]. Although 79.5% of all created programs exhibited different settings for each side, this proportion was lower than the 94% observed in Kliesch's study, which exclusively included bimodal users. In our study, participants with bilateral implants showed a lower need for side-dependent adjustments, with only 71.1% of programs featuring distinct settings between sides. The magnitude of these differences was generally moderate, with frequency-dependent parameters differing by less than 5 dB, although larger deviations were noted in the preprocessing steps (see Figure 14).

4.5. Program Iteration and User Satisfaction

In this study, the analysis of iteration loops—the number of times a program was modified before reaching a stable configuration—provided new insights into user behavior that had not been extensively explored in previous research involving cochlear implant recipients. Approximately 57% of the programs created by the participants were deemed satisfactory after their initial setup, requiring no further modifications. This suggests that many users were able to quickly identify settings that met their auditory needs, achieving a high level of satisfaction early in the process. For the remaining 43% of the programs, the participants made modifications at a later time, indicating that some users continued to refine their settings to different acoustic environments or as their preferences evolved. The relatively low number of iteration loops observed, combined with the positive spontaneous evaluations (as seen in Figure 16), indicates that the participants generally found the self-adjustment process effective and user-friendly. This early achievement of satisfactory results reflects the app's potential to empower users by providing them with the tools to fine-tune their auditory experience according to their personal needs. However, while the subjective ratings of sound quality improvements are encouraging, they do not necessarily translate to measurable improvements in speech comprehension or other objective auditory outcomes. Therefore, future investigations should incorporate objective measurement methods such as speech intelligibility tests or determination of the hearing threshold.

5. Limitations

This study has several limitations that could influence the interpretation and generalizability of the findings:

1. **Small sample size:** This study included only 15 participants, limiting the statistical power and generalizability of the results. While the sample aimed to represent a diverse population of cochlear implant (CI) users, a larger cohort would provide more robust insights into user behavior and adjustment practices.
2. **Participant criteria:** Only bilateral and bimodal CI users were included, excluding unilateral users. This limitation restricts the findings to specific user groups and leaves the applicability of the self-adjustment app for unilateral CI users unexplored.
3. **Technological proficiency bias:** This study required participants to have prior experience using smartphones, ensuring they could navigate the app. This criterion may have excluded less technologically adept individuals, potentially skewing the results. Future research should examine whether users with limited smartphone experience achieve similar outcomes or face additional challenges.
4. **Range of parameter adjustments:** The objective data showed that the range of possible parameter adjustments was sufficient for meaningful modifications. This finding aligns with Kliesch et al. [9].
5. **Environmental contextual data:** This study collected extensive data on daily hearing situations but did not analyze the specific factors influencing participants' preferences for user interface types or app usage in diverse environments. This gap limits the understanding of context-driven adjustment behaviors.
6. **Participant user ratings:** The user rating data only reflected saved adjustments. Settings discarded by participants were not included, potentially overlooking instances where the app failed to meet user expectations. This omission could introduce bias by emphasizing positive outcomes over neutral or negative experiences.

Addressing these limitations in future studies could enhance the understanding of self-adjustment practices and broaden the applicability of the findings. Future work might involve larger and more diverse participant groups, longitudinal studies with technologically inexperienced users, and detailed investigations into situational factors affecting app usage.

6. Conclusions

This study demonstrates the feasibility and benefits of using a smartphone app for the self-adjustment of hearing aids and cochlear implants in daily life. All participants were able to use the app effectively and integrate it into their routine. A total of 13 out of the 15 participants used the app during the entire study period. The increased creation of new programs at the beginning of this study and their sustained use over time highlight the value of personalized self-adjustments for improving the auditory experience in real-world settings. The positive ratings of the self-created programs and personal feedback from the participants during the second study session further underscore the app's utility. The participants reported that the app frequently supported them in challenging acoustic scenarios, contributing to their overall satisfaction. Notably, 13 out of 15 participants indicated that they would continue to use the app beyond this study, suggesting that the app has significant potential to enhance patient satisfaction in everyday life. However, two participants did not use the app throughout the entire study and withdrew early. These participants were included in this study shortly after their first activation of the cochlear implant. Additionally, they reported using only the AutoSense OS™ program and did not engage with manually switchable programs in general. These findings suggest that factors such as the duration of CI use and the overall acceptance of manually adjustable programs may influence the adoption of the app. Unlike the findings from Kliesch's [9] laboratory-based study, the prevailing acoustic environment did not significantly influence frequency settings during self-adjustments in real-life scenarios. Instead, the choice of user interface (EQ UI or 2D-Surface UI) was significantly impacted by the acoustic environ-

ment, with participants preferring the intuitive 2D-Surface UI in noisier conditions and the EQ UI in quieter settings, probably due to time constraints in challenging situations. Moreover, this study revealed that approximately 80% of all self-adjustments exhibited different parameter sets between the left and right sides. Bimodal users demonstrated a higher tendency for side-dependent adjustments, with nearly 86% of their programs showing differences between sides, compared to just under 69% for bilateral users. This finding suggests a more pronounced need for individualized adjustments among bimodal users. Overall, the app's ability to enable users to make self-adjustments in their daily lives is a promising development, offering significant benefits for user satisfaction and strong potential for broader adoption. Nevertheless, participant feedback during the study appointments pointed out areas for enhancement, including the demand for more intuitive guidance during the adjustment process and clearer communication of the effects of parameter changes, especially for the 2D-Surface UI. To address these issues, future versions of the app should prioritize improved user support, such as incorporating contextual guidance or interactive tutorials directly within the interface. Design updates should also emphasize accessibility, ensuring the app remains user-friendly for individuals with varying levels of technological expertise. Further studies are necessary to evaluate the app's effectiveness across more diverse user groups, particularly unilateral CI users and those with limited smartphone proficiency. A promising avenue for future development of the app could be the integration of features beyond self-adjustment. For instance, therapeutic modules could be included to provide users with targeted auditory training or rehabilitation exercises. Moreover, the app could play a role in monitoring users' medical health by collecting data on user behavior or acoustic challenges in various environments. Such insights could help identify potential deficits at an early stage, enabling timely intervention. Additionally, the app could facilitate better planning and coordination of follow-up appointments by proactively signaling the need for adjustments or maintenance. These advancements could transform the app into a comprehensive tool that not only enhances users' auditory experience but also contributes significantly to their long-term medical care.

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Conflicts of Interest: Author Josef Chalupper was employed by the company Advanced Bionics GmbH. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The sponsors had no role in the execution, interpretation, or writing of the study.

Appendix A

Table A1. Overview of the number of days the participant was included in this study.

Participant	Days in Study
MHH01	188
MHH02	188
MHH03	183
MHH04	185
MHH05	217
MHH06	183
MHH07	189
MHH08	189
MHH09	182
MHH10	186
MHH11	199
MHH12	200
MHH13	222
MHH14	113
MHH15	50
MEAN:	187

Table A2. Overview of the participant's selected standard user interface.

Participant	Default User Interface
MHH01	2D-Surface
MHH02	2D-Surface
MHH03	2D-Surface
MHH04	2D-Surface
MHH05	2D-Surface
MHH06	EQ
MHH07	2D-Surface
MHH08	2D-Surface
MHH09	EQ
MHH10	2D-Surface
MHH11	2D-Surface
MHH12	EQ
MHH13	2D-Surface
MHH14	2D-Surface
MHH15	2D-Surface

Table A3. Overview of the demographics of all 15 participants given in years (n.a. = not available).

ID	Age at Study Inclusion	Duration of CI Use (First Supplied Side)	Duration of HA Use (First Supplied Side)	Duration of Hearing Impairment (First Supplied Side)	Duration of Profound Hearing Loss (First Supplied Side)
MHH01	74	4.69	34.76	44.52	5.74
MHH02	59	4.63	12.78	13.78	4.63
MHH03	64	4.33	n.a.	15.03	4.33
MHH04	67	6.52	27.37	27.79	6.52
MHH05	64	2.98	32.81	32.81	2.98
MHH06	47	4.44	n.a.	n.a.	34.81
MHH07	52	12.56	37.91	40.92	23.90
MHH08	51	16.43	40.97	45.65	16.43
MHH09	51	2.03	17.88	24.89	7.87
MHH10	41	22.20	38.17	41.20	23.00
MHH11	68	11.01	36.88	47.89	16.86
MHH12	68	0.02	21.08	51.10	13.07
MHH13	68	3.95	17.93	31.94	8.46
MHH14	56	0.11	10.51	25.52	0.11
MHH15	74	13.19	56.81	67.82	67.82

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