IBEHS3I06: A Comprehensive Report on the Development and Evaluation of a Hearing Test App

Zifeng An
400114057

Table of Contents

Introduction

Hearing loss is a widespread condition that affects millions of people worldwide. Timely detection and intervention are crucial in preventing further deterioration and improving the quality of life for those affected. Traditionally, hearing tests have been conducted in person by healthcare professionals, leading to long waiting times and limited accessibility. The development of a hearing test app seeks to address these challenges by leveraging technology to streamline the process and make it more convenient for users [1].

The primary motivation behind this report is to explore the potential of integrating technology and computer systems to assist in acquiring medical data, specifically in the domain of audiology. The hearing test app described herein aims to reduce waiting times for hearing tests, eliminate the need for in-person appointments, and provide users with accurate and reliable results. By enabling individuals to assess their hearing abilities remotely, the app empowers them to take control of their auditory health and seek professional help if necessary [2].

In this report, a comprehensive analysis of the development and evaluation of the hearing test app is presented. The app incorporates three hearing tests: pure tone audiometry, marked noise test, and temporal processing test. We discuss the design of the app, the tests implemented, the user study outcome, limitations, and possible future extensions. Our findings demonstrate the potential of such digital solutions in revolutionizing healthcare and expanding access to vital services.

App Design

Source code: https://github.com/AllenAnZifeng/audioapp
Course content and rubrics: https://github.com/AllenAnZifeng/Audiometry

Architecture

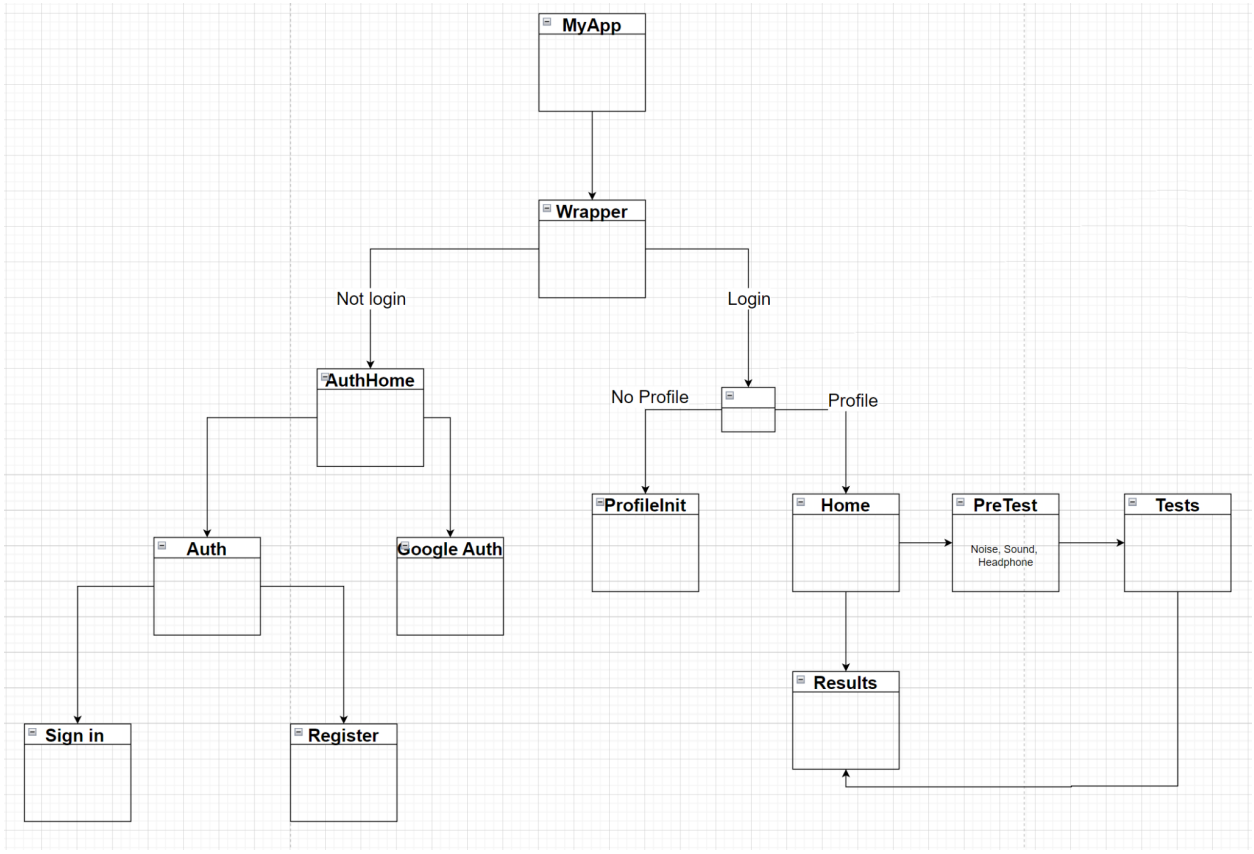

Figure 1: the overall architectural design of the Flutter widgets tree.

Figma Design

Figma URL:
https://www.figma.com/proto/esWcmIBPSXO6ShWqrsdn6g/Audiometry-App?node-id=16%3A30&scaling=scale-down&page-id=0%3A1&starting-point-node-id=16%3A30

Flutter and Firebase

The hearing test app is developed using the Flutter framework for the frontend and Firebase for the backend. Both technologies offer a host of advantages, making them ideal choices for the app.

Flutter is an open-source UI software development kit created by Google. It allows developers to create natively compiled applications for mobile, web, and desktop platforms from a single codebase. Firebase, on the other hand, is a Backend-as-a-Service (BaaS) platform offered by Google. It provides various services such as real-time databases, authentication, storage, and analytics, among others. In summary, the combination of Flutter and Firebase offers a powerful and efficient solution for developing the hearing test app. Their advantages in cross-platform development, performance, scalability, and ease of integration allow for the creation of a high-quality, user-friendly, and reliable application.

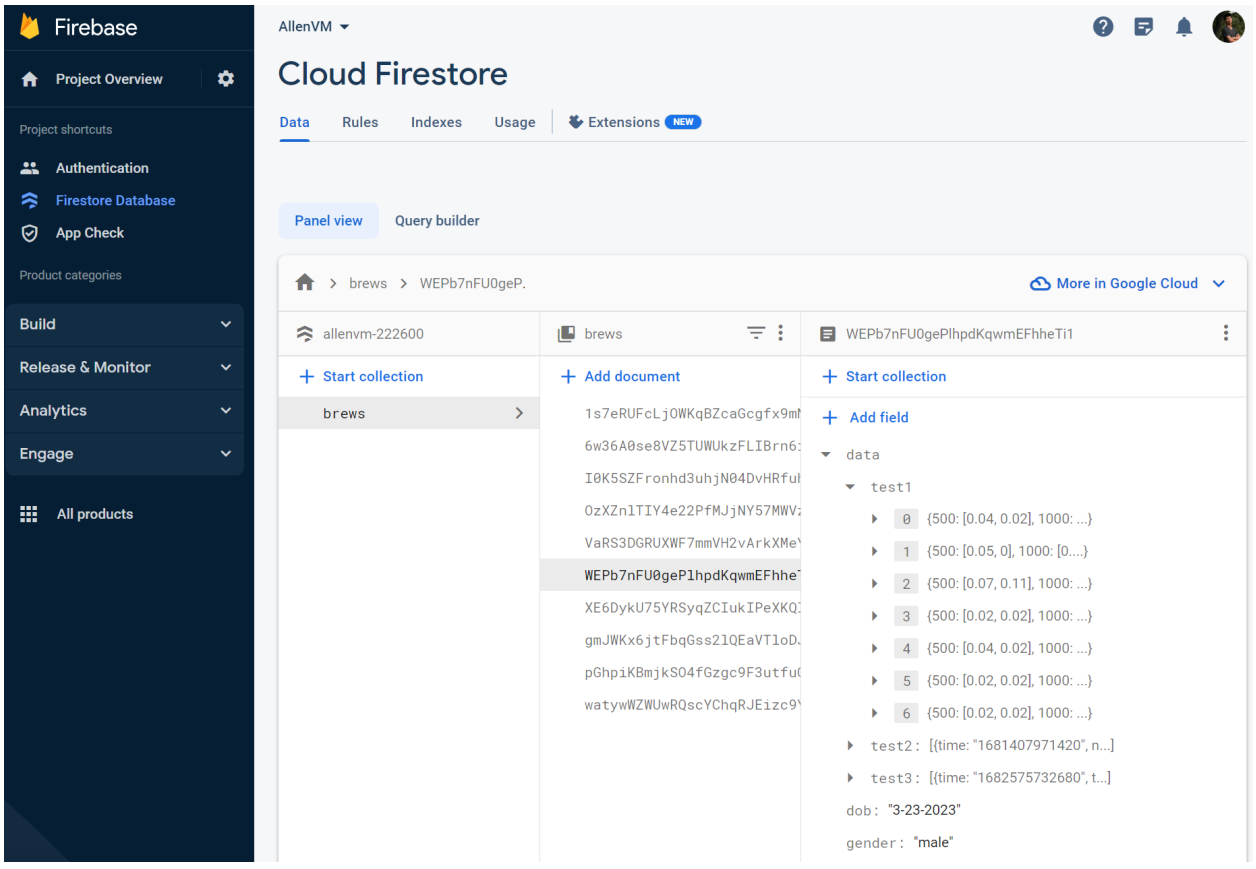

Figure 2: firestore backend as a service

Login: Google OAuth and Email Password

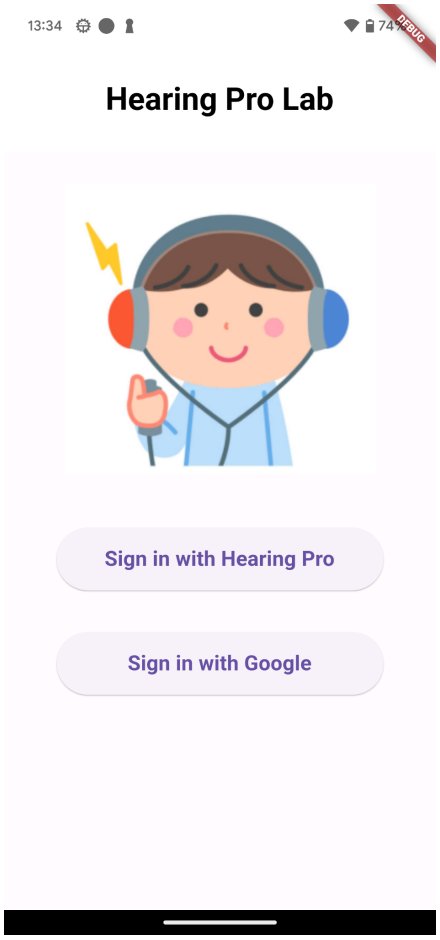

Figure 3: the two login methods -- email and password, Google OAuth.

The hearing test app employs two authentication methods for user login: Google OAuth and email/password. These options cater to different user preferences while providing a secure and convenient way to access the app. Google OAuth is an open standard for access delegation, allowing users to sign in with their existing Google account without the need to create a new account specifically for the hearing test app. Implementing Google OAuth provides convenience, security and simplified user data management. The email/password authentication method allows users to create an account using their email address and a unique password. This option provides an alternative for users who may not have a Google account or prefer not to use it for third-party applications.

In conclusion, the hearing test app offers two secure and user-friendly authentication methods, Google OAuth and email/password, ensuring a seamless and accessible login experience for users. By leveraging Firebase Authentication, the app benefits from a robust, secure, and scalable solution for user account management.

Hearing Tests

The app features three hearing tests: pure tone audiometry, marked noise test (digit in noise test), and temporal processing test (FM detection). Each test comes with a practice test beforehand. Each test serves a specific purpose in assessing different aspects of an individual's hearing abilities.

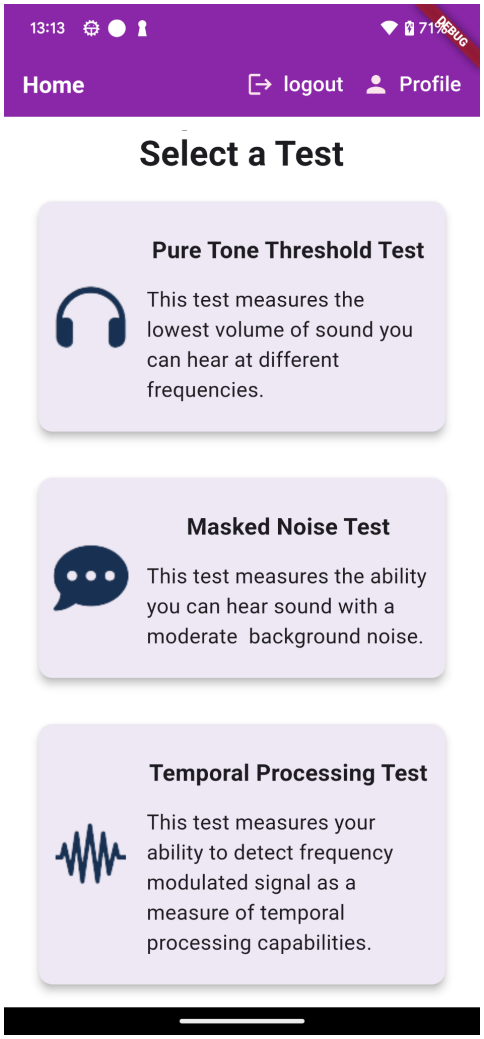

Figure 4: the figure shows 3 audio tests

Pure Tone Threshold Test

Pure tone audiometry is the most common hearing test, used to determine the softest sounds a person can hear at different frequencies. The test measures an individual's hearing sensitivity and helps identify the type and degree of hearing loss [3].

Procedure:
During the pure tone audiometry test, the user is presented with a series of tones at varying frequencies and intensities through headphones. The user is asked to indicate when they can hear the tone. The test is conducted separately for each ear, and the results are plotted on an audiogram, which displays the hearing thresholds at each frequency tested. The user is able to choose the test data from previous days and compare the audiograms. Note that the latest chosen date would show at the forefront of the plot.

Significance:
Pure tone audiometry is crucial in diagnosing hearing loss, determining its severity, and identifying potential causes. The results of the test can help healthcare professionals recommend appropriate interventions, such as hearing aids or cochlear implants, and monitor the effectiveness of these treatments over time.

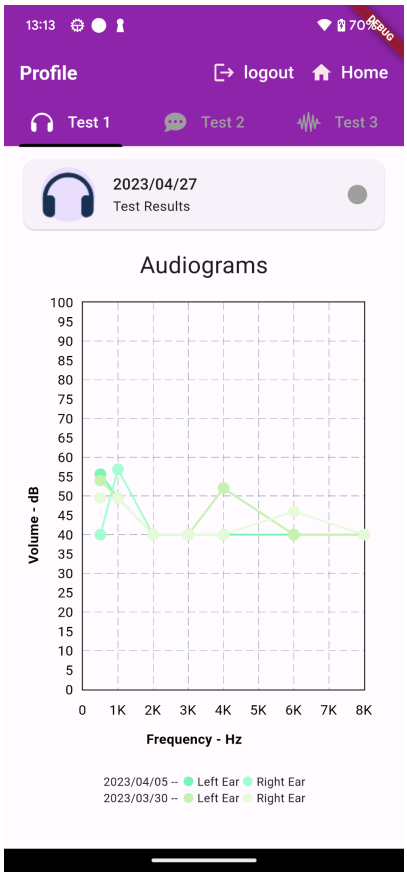

Figure 5: audiograms showing hearing thresholds for both ears

Digits in Noise Test

The marked noise test, also known as the digits in noise test, evaluates an individual's ability to understand speech in the presence of background noise. This test can help identify difficulties in speech perception that may not be apparent in quiet environments [4].

Procedure:
In the masked noise test, the user is asked to listen to a series of digits presented in background noise. The user's task is to identify the digit they hear and respond accordingly. The random numbers are generated and pronounced through google word to Sound API. The signal-to-noise ratio(SNR) is adjusted throughout the test to determine the user's speech recognition threshold in noise. There are only 2 SNR levels in this test. Here is a table to explain the test results:

	Low SNR signal	High SNR signal	Results
Correct Choice?	❌	❌	Severe Loss
	✔	❌	Mild Loss
	✔	✔	Normal

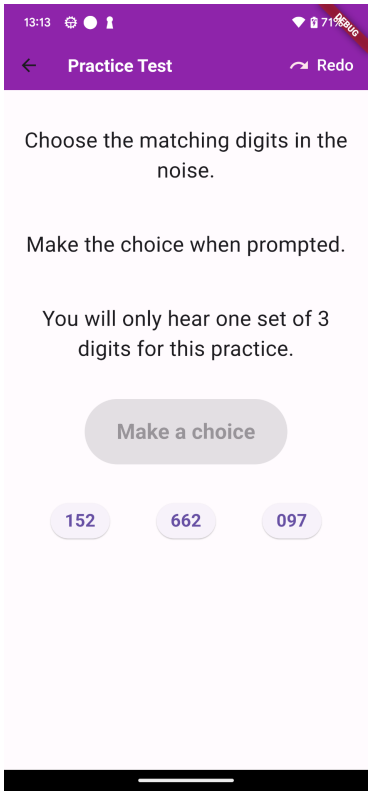

Figure 6: digits in noise test showing random numbers

Importance:
The marked noise test is essential for assessing an individual's real-world hearing abilities, as background noise is a common challenge in daily life. The test can help identify specific difficulties in speech perception and guide recommendations for communication strategies or hearing devices with noise-reduction features.

Temporal Processing Test

The temporal processing test, also known as FM detection, measures an individual's ability to detect frequency modulations (changes in frequency over time) and assesses their temporal processing skills. This test can provide insights into the neural processing of auditory information [5].

Procedure:
In the temporal processing test, the user is presented with a pure tone in one ear and a frequency-modulated (FM) signal in the other ear. The user is asked to decide whether the tones are the same or different. The test determines the user's sensitivity to frequency modulations by varying the modulation depth and rate.

Relevance:
Temporal processing is an essential aspect of auditory perception, particularly for understanding complex sounds such as speech and music. The temporal processing test can help identify deficits in auditory processing that may contribute to difficulties in speech perception, learning, or overall auditory performance. By assessing these skills, healthcare professionals can tailor interventions and rehabilitation strategies to address specific auditory processing challenges.

Software Testing

To ensure the reliability and accuracy of the hearing test app, rigorous software testing was conducted, focusing on two main aspects: audio content verification and Flutter app testing.

Audio Content Verification

Audio content verification is crucial to ensure that the app produces accurate and consistent sound stimuli for the hearing tests. Two tools were employed for this purpose: MATLAB and GoldWave.

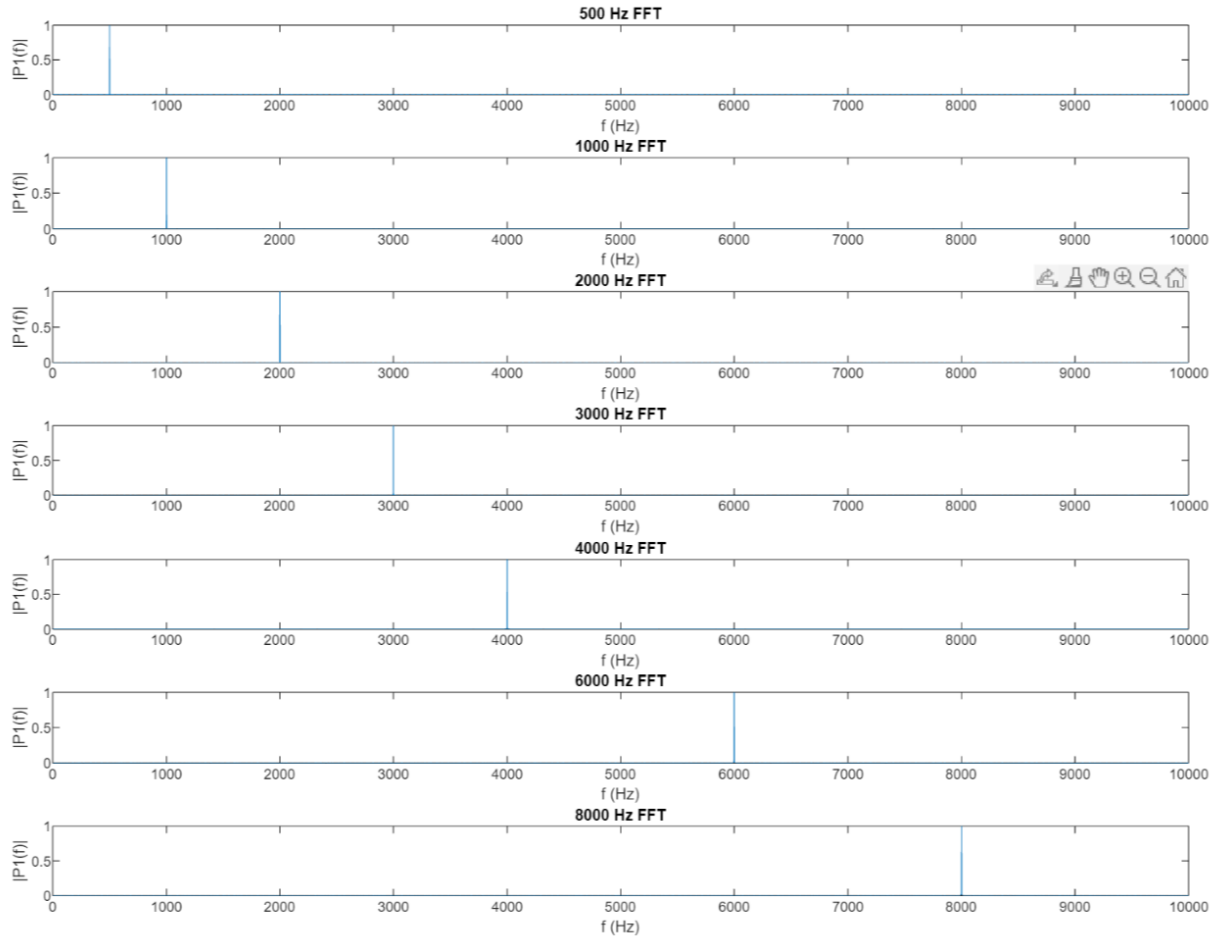

Figure 7: MatLab running FFT on input audio signals

MATLAB:
Using the Fast Fourier Transform (FFT) function in MATLAB, the signal amplitude and frequency of the generated audio stimuli were analyzed. This allowed for the verification of the accuracy of the app's output in terms of frequencies and intensities, ensuring that the stimuli used in the tests correspond to the desired values.

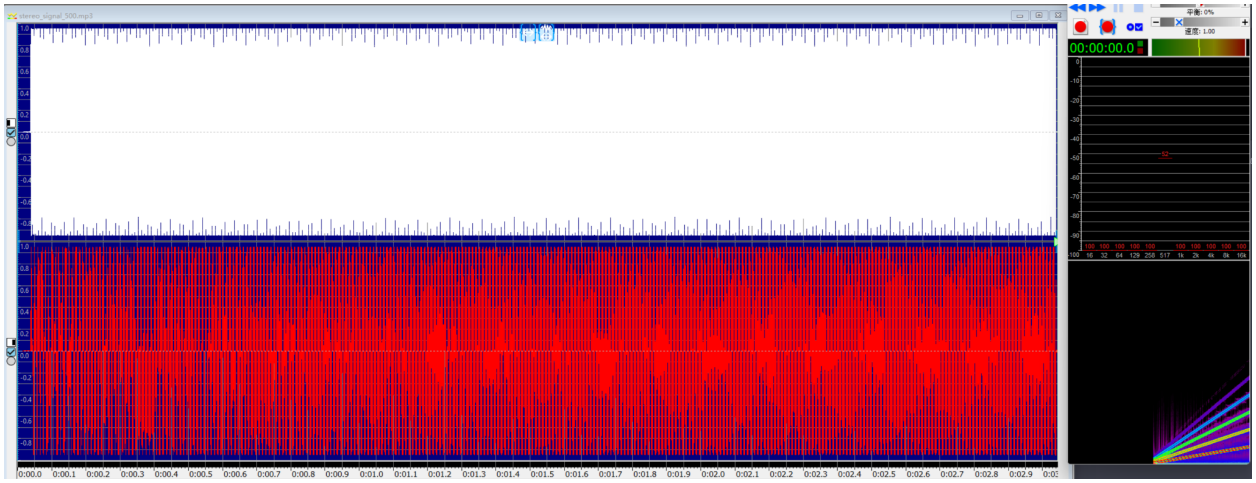

Figure 8: Goldwave showing different signals coming from left and right channels, the bottom right corner shows the linearly modulated frequency change

GoldWave:
GoldWave, a digital audio editing software, was utilized to visualize the sound produced by the app, particularly in the case of the temporal processing test, which presents different sounds to each ear. By examining the sound from different channels, it was possible to verify that the app correctly generates and delivers the required stimuli to the user's headphones.

Flutter App Testing

To ensure the functionality, performance, and reliability of the app, various testing methodologies were implemented for the Flutter-based frontend.

Unit tests:
Unit tests were conducted to verify the functionality of individual components of the app, such as the hearing test algorithms, user authentication, and data visualization. These tests helped identify and resolve any issues or inconsistencies within each component. This is achieved by developing testing widgets in Flutter, which ensures every Flutter build must pass the requirements from those testing widgets.

Integration tests:
Integration tests were performed to evaluate the app's overall functionality and ensure seamless interaction between various components, such as the user interface, audio playback, and database management. These tests helped identify any issues that might arise from the integration of different modules.

User interface tests:
User interface tests focused on assessing the app's visual elements and user interactions, such as navigation, button functionality, and responsiveness. These tests also involved clicking all possible buttons in different orders to ensure the app's robustness and prevent users from entering unknown states. A fallback plan was implemented to handle unexpected user actions and maintain a smooth user experience.

Routing tests:
Routing tests were conducted to verify that all navigation paths within the app were functional, ensuring users could seamlessly transition between different screens and features. These tests helped identify any broken links or routing issues that might hinder the user experience.

End-to-end tests:
End-to-end tests were carried out to evaluate the app's performance under real-world conditions, simulating user interactions and verifying the app's ability to produce accurate test results and provide a seamless user experience.

By implementing comprehensive software testing, including Flutter app testing that covers button interactions, routing, and fallback plans, the hearing test app's functionality, accuracy, and reliability can be ensured. This thorough testing process helps provide users with a dependable tool for assessing their hearing abilities and contributes to the app's overall success.

User Survey

The user survey was conducted to gather feedback on the hearing test app from a sample of 20 participants. The survey aimed to assess the users' prior experience with hearing tests, their experience using the app, the user interface, the clarity of instructions, the time taken to complete each test, the informativeness of the app, and the sound volume level. An open-ended question was also included to gather suggestions for improvement.

Survey URL:
https://docs.google.com/forms/d/e/1FAIpQLScj2CnNixvAALIIg2DNV30_v4NbfmTuotQyVSeX-gXmsl1Z1A/viewform

User Study Outcome

Based on the survey responses from the 20 participants, the following analytical summary was derived:

Prior experience with hearing tests: Out of the 20 respondents, 4 reported being very experienced, 8 had tried hearing tests a few times, 7 had never taken a hearing test before, and 1 chose the "Other" option.
Experience with the app: 12 users found the app easy to use, 6 considered it moderate, and 2 found it difficult.
User interface: 14 users found the interface clear, while 5 found it confusing, and 1 chose the "Other" option.
Audio testing instructions: 15 users reported that the instructions were clear, 4 found them confusing, and 1 chose the "Other" option.
Time taken to complete each test: For Test 1, the majority (11 users) completed it in 5 minutes, while the others took between 3 to 7 minutes. Test 2 was completed within 1 minutes by most users, and Test 3 took within 1 minutes for the majority of the respondents.
Informativeness of the app: 9 users found the app pretty informative, 3 considered it very boring, 7 thought it was okay, and 1 chose the "Other" option.
Audio sound volume level: 3 users found the volume very annoying, 14 deemed it comfortable, 2 thought it was okay, and 1 chose the "Other" option.
Suggestions for improvement: Some common suggestions from respondents included providing additional instructions and examples for the tests, improving the layout and design of the user interface, and adjusting the audio sound volume.

Overall, the user study outcome indicates that the majority of participants found the hearing test app easy to use, with a clear interface and audio testing instructions. The time taken to complete the tests was generally within the acceptable range. Most users deemed the app informative and the audio sound volume comfortable. However, the survey results also highlighted areas for improvement, such as refining the user interface and providing additional guidance.

Limitations and Possible Future Extensions

While the hearing test app offers a convenient and accessible way for users to assess their hearing abilities, there are certain limitations that should be addressed for future improvements.

Limitations

Sound volume variability across devices and headphones: Different phones and headphones may produce sounds with varying decibel levels, even when set at the same volume percentage. This inconsistency can affect the accuracy of the pure tone audiometry test.

Calibration for common headphones: The app currently lacks calibration for various headphones, which can impact the precision of the pure tone audiometry test. The marked noise test is less affected by this issue, as the signal-to-noise ratio remains consistent regardless of the volume.

Accessibility features: The app may not cater to users with certain disabilities, such as vision impairment or limited motor skills, which could make it difficult for them to interact with the user interface or complete the hearing tests.

Limited test varieties: The app currently offers three hearing tests, but additional tests could be included to provide a more comprehensive assessment of a user's hearing abilities and potential auditory processing difficulties.

Possible Future Extensions

Device and headphone calibration: Implement a calibration feature that allows users to adjust the app's output based on their specific device and headphone model, improving the accuracy of the pure tone audiometry test.

Expanded test varieties: Incorporate additional hearing tests, such as speech audiometry and otoacoustic emissions testing, to provide a more comprehensive assessment of a user's hearing abilities and potential auditory processing difficulties.

Improved accessibility features: Enhance the app's user interface and functionality to better accommodate users with disabilities, such as providing voice guidance, adjustable font sizes, and alternative input methods.

Integration with teleaudiology services: Connect the app with teleaudiology platforms, allowing users to share their test results with healthcare professionals for further evaluation and recommendations.

Personalized hearing health education: Based on the user's test results, the app could provide personalized information and resources to help users understand their hearing abilities, learn about potential interventions, and maintain good auditory health.

By addressing these limitations and exploring potential future extensions, the hearing test app can further enhance its accuracy, accessibility, and usefulness in assisting users with their hearing health needs.

Conclusion

The hearing test app provides a valuable tool for users to assess their hearing abilities through a series of tests, including pure tone audiometry, marked noise test, and temporal processing test. The app leverages Flutter for frontend development and Firebase for backend services, ensuring a smooth and secure user experience.

The user study involving a 20-person survey provided insights into the app's usability and areas for improvement. Overall, the majority of users found the app easy to use, with a clear interface and informative content. However, some limitations were identified, such as sound volume variability across devices and headphones, lack of calibration for different headphones, and the need for improved accessibility features.

To address these limitations and enhance the app's functionality, future extensions could include device and headphone calibration, integration with teleaudiology services, expanded test battery, improved accessibility features, noise-cancellation integration, and personalized hearing health education.

By addressing the identified limitations and exploring potential future extensions, the hearing test app can better serve users in assessing and maintaining their hearing health, ultimately contributing to the integration of technology and healthcare to provide accessible and convenient medical data acquisition.

Figure 9: AI-generated animated figure using the Hearing Pro Lab mobile application

Appendix

1. Cunningham, L. L., & Tucci, D. L. (2017, December 21). *Hearing loss in adults*. The New England journal of medicine. Retrieved April 28, 2023, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6457651/
2. *Hearing loss prevalence and years lived with disability ... - the lancet*. (n.d.). Retrieved April 28, 2023, from https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)00516-X/fulltext
3. J;, C. A. C. H. M. H. C. (n.d.). *Audiology pure tone evaluation*. National Center for Biotechnology Information. Retrieved April 28, 2023, from https://pubmed.ncbi.nlm.nih.gov/35593838/
4. JM;, S. C. T. G. S. F. (n.d.). *The digits-in-noise test: Assessing auditory speech recognition abilities in noise*. The Journal of the Acoustical Society of America. Retrieved April 28, 2023, from https://pubmed.ncbi.nlm.nih.gov/23464039/
5. Author links open overlay panelJohn H. Grose, AbstractThe detection of low-rate frequency modulation (FM) carried by a low-frequency tone has been employed as a means of assessing the fidelity of temporal fine structure coding. Detection of low-rate FM can be made more acute, Clinard, C. G., Batra, R., Buss, E., Dobreva, M. S., Ernst, S. M., Green, G. G., Grose, J. H., He, N. J., & Hopkins, K. (2012, October 3). *Frequency modulation detection as a measure of temporal processing: Age-related monaural and binaural effects*. Hearing Research. Retrieved April 28, 2023, from https://www.sciencedirect.com/science/article/abs/pii/S0378595512002390