MPHA: A Personal Hearing Doctor Based on Mobile Devices

Yuhao Wu
Research Group of Human Computer Speech Interaction
Tsinghua University, Beijing, China, 100084
yh-wu14@mails.tsinghua.edu.cn

Jia Jia
Research Group of Human Computer Speech Interaction
Tsinghua University, Beijing, China, 100084
jjia@mail.tsinghua.edu.cn

WaiKim Leung
Research Group of Human Computer Speech Interaction
Tsinghua University, Beijing, China, 100084
william.tsinghua2014@gmail.com

Yejun Liu
Research Group of Human Computer Speech Interaction
Tsinghua University, Beijing, China, 100084
onlyeye@live.cn

Lianhong Cai
Research Group of Human Computer Speech Interaction
Tsinghua University, Beijing, China, 100084
clh-dcs@mail.tsinghua.edu.cn

ABSTRACT

As more and more people inquire to know their hearing level condition, audiometry is becoming increasingly important. However, traditional audiometric method requires the involvement of audiometers, which are very expensive and time consuming. In this paper, we present mobile personal hearing assessment (MPHA), a novel interactive mode for testing hearing level based on mobile devices. MPHA, 1) provides a general method to calibrate sound intensity for mobile devices to guarantee the reliability and validity of the audiometry system; 2) designs an audiometric correction algorithm for the real noisy audiometric environment. The experimental results show that MPHA is reliable and valid compared with conventional audiometric assessment.

Categories and Subject Descriptors

H.5.2. [**Information Interfaces and Presentation**]: User Interfaces - Graphical user interfaces

Keywords

Multimodal interaction; Mobile device; Assessment; Audiometry; Hearing level; Health care.

1. INTRODUCTION

Hearing plays an important role in our daily life. Auditory sense influences not only the ability of listening, but also the ability of speaking and reading [21]. There is no doubt that hearing health has a strong relationship with our daily communication. So it is quite necessary to pay more attention to our hearing health condition.

Traditional hearing level assessment must be proceeded in hospital department of ear-nose-throat (E.N.T.), or hearing rehabilitation centers [10, 11]. The equipment (audiometer and soundproof room) is so expensive that not every E.N.T. holds qualification to evaluate people's hearing condition, resulting in medical resources lack for hearing health. Since it is always overcrowded in those medical institutes, people feel inconvenient to have an audiometry assessment regularly. Usually, we don't realize our hearing health condition until some serious problems on our listening come up, and have missed the best treatment period [21, 1].

To resolve the issues above, we propose a novel interactive mode to assess audiometry on mobile devices called mobile personal hearing assessment (MPHA). During the procedure of audiometric accessment using MPHA, no assistant people is needed. MPHA generates a series of accurate test tones and play them to users directly. Users judge whether they can hear the sound and feed back to MPHA. After the test, MPHA will show the results of hearing level healthy to the users.

Experiments results show that with an available interactive distance(30 ± 5 cm) and angle(30° to 90°), the MPHA can generate accurate sound signals compared with audiometers. Moreover, MPHA is proved to be reliable in both quiet and daily noisy(35dB) environment, and the errors are within the smallest unit(5dB) in audiometry.

The main contributions of the paper are:

- We present an automatic and reliable interactive mode to audiometry based on mobile devices. It is a good alternative for the pre-screening phase of hearing diagnosis, which is cost effective and convenient compared with the doctor-to-patient mode used in conventional hospitals.
- We propose a general method to calibrate sound intensity for mobile devices. It provides accurate test sounds, which guarantees the reliability and validity of the audiometry system.

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- For the real audiometric environment with noises, we design an audiometric correction algorithm. Our implementation enables people to check his hearing level in working environment.

The rest of the paper is organized as follows. We first give an overview of related work in Section 2. Then in Section 3, we present our preliminary survey of 100 people, inquiring about their attitude towards hearing condition evaluation. The design and implementation of MPHA is described in Section 4 and five experimental results are reported in Section 5. We present the application scenarios of MPHA in Section 6 and conclude our work in Section 7.

2. BACKGROUND AND MOTIVATION

In clinical audiology, pure tone audiometry is a widely adopted method to test people's hearing sensitivity [21, 10, 1]. Pure tone audiometry is used to find out people's auditory threshold (i.e. the lowest sound people can hear) at different frequencies, and check hearing condition at each frequency level. The results of pure tone audiometry are basis of diagnosis and follow-up treatment [21, 10] and our work of hearing level assessment is based on the pure tone audiology.

Up to now, audiometry is proceeded in soundproof room, and it involves the participation of an audiometer, a subject, and a doctor each time. The subject and the hearing doctor both sit in the soundproof room. The doctor operates the audiometer to play a sound signal to the subject, then the subject feeds back hearing information to the doctor. The doctor decides what to do next according to subject's feedback [11, 9]. For traditional audiology assessment, there are some problems to overcome. First, the equipment and human resources are very expensive, and therefore small hospitals such as infirmary and community hospitals are not able to provide hearing health care. Second, the process is inconvenient and time-consuming, so people usually are not willing to check hearing conditioin regularly. Inspired by these findings, MPHA is designed to facilitate hearing health condition assessment.

3. PRELIMINARY STUDY

Before our research, we conducted a survey about people's attitude towards hearing assessment [20]. We invited 100 participants to answer a questionnaire (60 males and 40 females) involving teachers, managers, IT developers, and university students majoring in computer science, chemistry, physics, art and mathematics. [20, 18].

Questions in the questionnaire were divided into three parts [16]. The first part was about their knowledge of audiometry diseases and diseases potentially lead to hearing impairment. The second part inquired their habits of using ears and self-evaluation of hearing condition. The last part gathered information about whether they needed a convenient method, with which they can have self-assessment regularly, or take a test before going to hospital.

In part 1 of our study, only 3 of 20 kinds of audiometry diseases were known by participants (tinnitus 90%; otitis media 79%; and congenital deafness 71%). Only 29% of the participants had never been attacked by diseases could bring about hearing impair, while the others had got a number of problems such as hypertension (32%), chicken pox (29%) and diabetes (21%).

In part 2, only 12% of our participants never wear headset, while the others all wore headset as shown in Figure 1(a), 46% of them wore headset 2 or 3 days every week. And more than three quarters (76%) had to work in the noisy environment, as depicted in Figure 1(b).

Half of the participants had felt their hearing level decreased (51%), and a quarter of them paid no attention to their hearing condition at all as shown in Figure 1(c). On the other hand, only 17% of all the participants had ever checked their hearing health. For the reason why they didn't go to hospital, 68% of them chose the inconvenience.

In the final part, we asked them whether they needed an application for a private hearing condition assessment. The results illustrated in Figure 1(d) show that 81% of the participants chose yes, and no one opposed this accesssment.

From the results in our preliminary study, we can get conclusion as follow:

- People know little about audiometry.
- Many people don't have a good habit of using ears or silent enough working environment.
- Nearly half of them don't have a good hearing heath condition while many of them don't even realize.
- The majority need an application with which they can take a self-check for their hearing condition.

4. MOBILE PERSONAL HEARING ASSESSMENT (MPHA)

MPHA provides a convenient and reliable audiometry [12, 5]. Moreover, it provides a novel interacting mode based on mobile devices . In order for the validity, international standard [10, 11, 9] is fully taken into consideration during the design of MPHA, as detailed belows. For the convenience of users, we implement the MPHA on the iPad [14].

4.1 Application Design

According to the ISO 8253-2 [11], the MPHA we design is composed of three parts: the test signals generation, the assessment procedure and the hearing condition release[22].

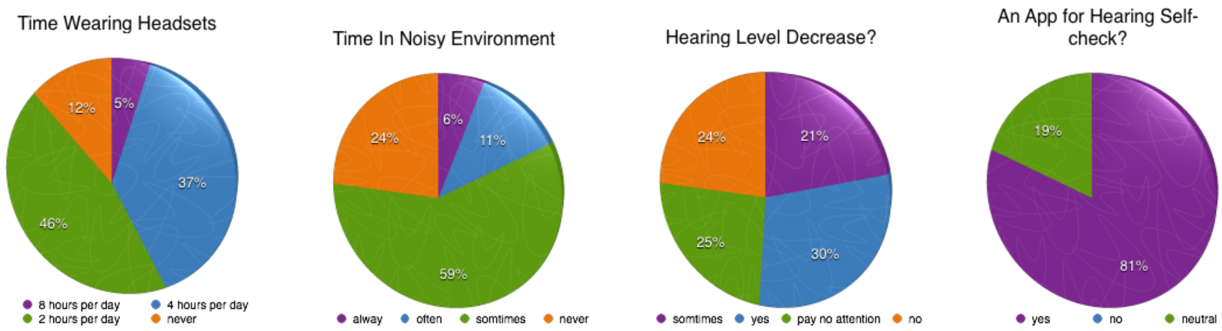
In part 1, MPHA generates accurate test sound signals chosen by the users themselves and the parameter model [11, 22]. In part 2, MPHA plays one signal to subject, and collects user's feedback. Then, MPHA chooses the signal of the next round according to its algorithm [10, 22, 6]. The next frequency and sound intensity should be based on information collected from the users, as the requirements of ISO 6189 [9]. During the interactive process, the MPHA computes the user's hearing level according to [9].

4.2 Target Devices

MPHA requires a stable sound card of the mobile devices. The sound card of iPad has a wide range of frequency response, covering from 30Hz to 9kHz [14]. The frequency response range required by the MPHA is 250Hz to 8kHz [10, 11, 9]. In this work, we choose the iPad as our experimental devices.

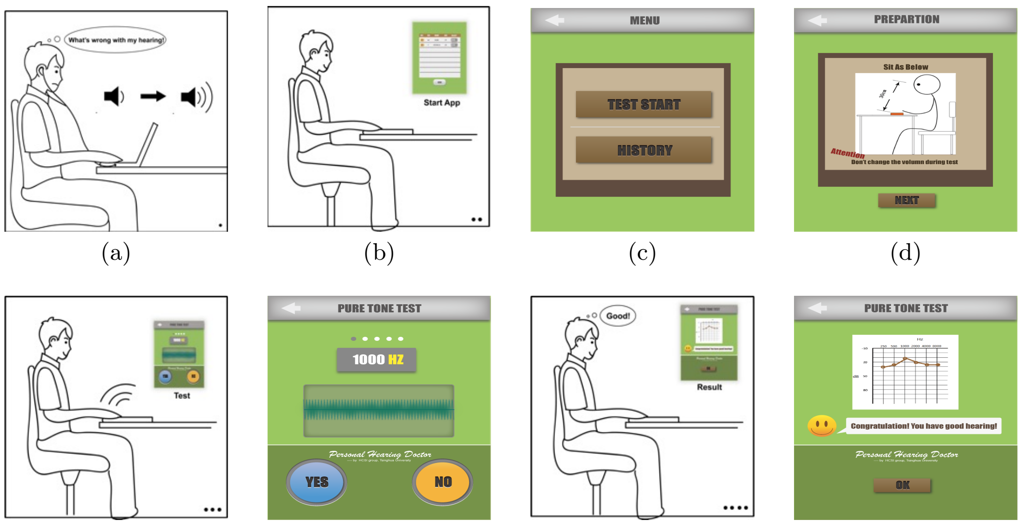
4.3 The interactive mode of MPHA

MPHA is implemented on iPad. Sound signals are pure tone signals of 6 frequencies (250Hz, 500Hz, 1000Hz, 2000Hz,



(a) (b) (c) (d)

Figure 1: Results of preliminary study.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 2: The interface of mobile personal hearing assessment (MPHA).

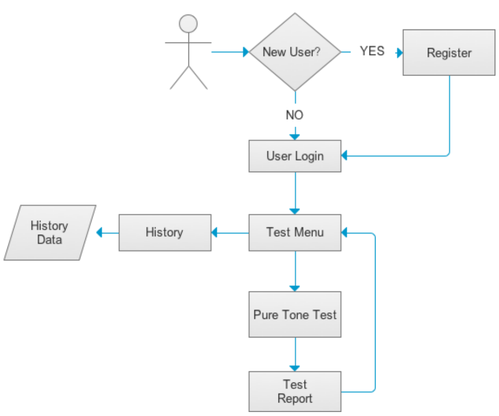


Figure 3: The entrance of MPHA.

4000Hz, 8000Hz) [10, 11, 3]. Sound intensity covers from -10dB SPL to 75dB SPL. The flow path and interactive interface of MPHA is shown in Figure 2, Figure 3, and Figure 4, described as followed.

Step 1, when user wants to have a self-check about his hearing level, user should be seated as shown in Figure 2(a). In this step, the user will see a login page. The user needs to register and login for his/her first access to use MPHA. After login, he/she can choose taking a new test or looking up the test history. The flow is shown in Figure 3 and interface is illustrated in Figure 2(c). If the user chooses to look up the history data, he can track the condition of his hearing health, as shown in Figure 2(h).

Step 2, if the user chooses to have a new self-check, MPHA will do the following two things before assessment. First, it tells the right sitting posture like Figure 2(d). Second, it tests the environment noise. If the background is too noisy, MPHA will suggest not testing right now. The MPHA records the background noise and then comes to the hearing level assessment, with the interface shown in Figure 2(f). In this step, MPHA generates a sound signal and plays it to the user. There are two buttons (Yes and No) on this page. User should click Yes when has heard the sound, or No otherwise. The logic flow of this step is shown in Figure 4.

Step 3, MPHA releases hearing level report when completing pure tone test[7, 8], as Figure 2(h). In the report, the

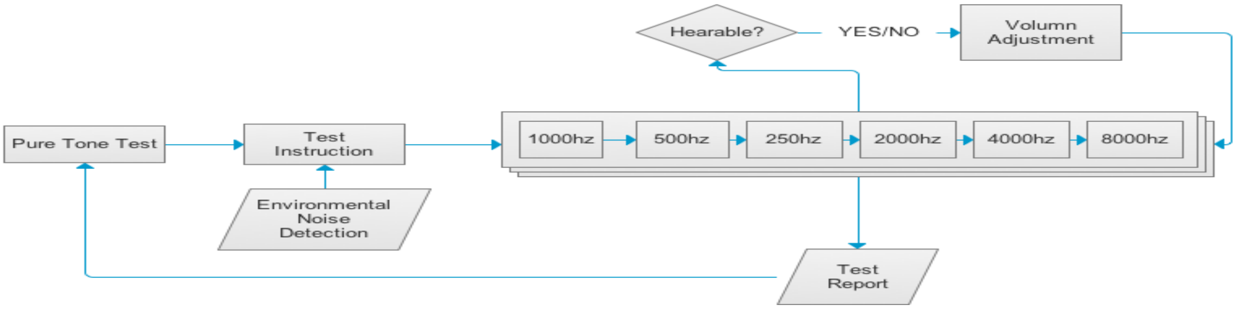
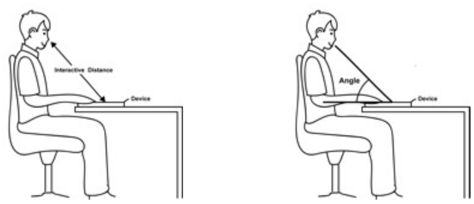


Figure 4: The flow chart of pure tone test.

interactive



(a) (b)

Figure 5: Interactive distance and angle of MPHA.

user can find his/her hearing threshold at the six frequencies, and whether his/her hearing status healthy or impaired.

5. EVALUATION

This section consists of five experiments to evaluate both accuracy and adaptability of MPHA [15]. All the experiments are running on an iPad2 with iOS 8.

Experiment 5.1 shows the available interactive distance of the MPHA. Experiment 5.2 shows the available angle of the MPHA. Experiment 5.3 compares the audiometry results of the MPHA with the traditional audiometer. Experiment 5.4 compares the results of two testing environment: the soundproof room and the regular working office. Experiment 5.5 further compares the hearing level condition of one person on different times of one day.

5.1 Interactive Distance

The interactive distance is defined as the distance between the center of the iPad and ears, shown in Figure 5(a). We measure the difference of sound signals intensity and analyze the variation with the distance increases.

5.1.1 *Platform*

The experiment is set up in a soundproof room, excluding interference from other acoustic sources. Sound sources are pure tone signals, of which the frequencies are covered from 250Hz to 8kHz, and the amplitude are covered from 10 to 20000. We use a sound level meter with the model of Bruel Kjaer 2250 to collect the sound signals and analyze the intensity, as simulation of subjects-ears.

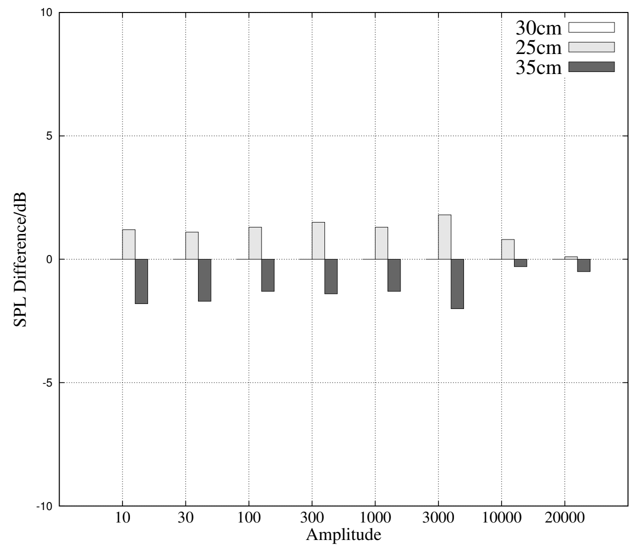


Figure 6: Comparison of sound signal intensity at different interactive distances.

5.1.2 *Content*

During this experiment, the iPad device is placed on a table with a fixed position. For each pure tone signal, we put the sound level meter with its fixed position above the iPad device. The dB SPL value is recorded according to the sound level meter, after the signal is played. Three different distances (i.e. 25cm, 30cm, 35cm) are tested, imitating the interactive distance between users and the iPad device. Each record is repeated three times for accuracy.

5.1.3 *Quantitative Results*

The comparison of sound signal intensity with different interactive distances is depicted in Figure 6. The results shows that average signal intensity of 25cm is higher than that of 30cm by 1.2dB SPL, and average signal intensity of 35cm is lower than that of 30cm by 1.3dB SPL.

In audiometry, the smallest unit of measurement is 5dB SPL [21, 10]. As a result, there is no substantial variation of sound signal intensity beyond the range of 25cm $\sim$ 35cm. Meanwhile, we have designed and implemented the compensation algorithm in our previous work for this difference caused by interactive distance [22, 7, 8]. To summarize, available interactive distance of MPHA is 30 $\pm 5cm$.

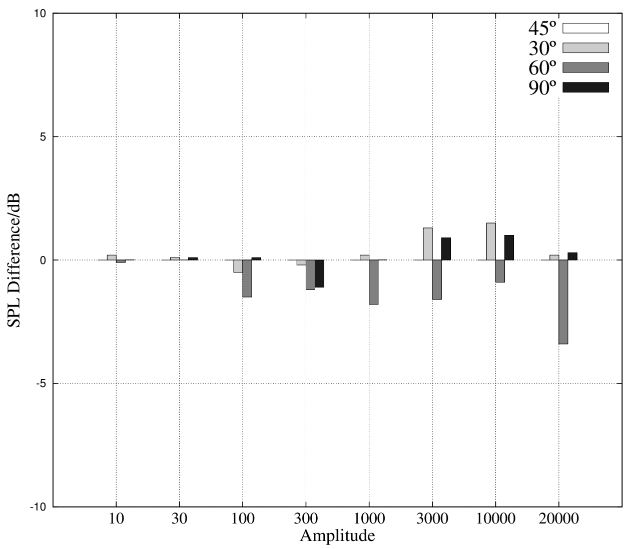


Figure 7: Comparison of sound signal intensity at different interactive angles.

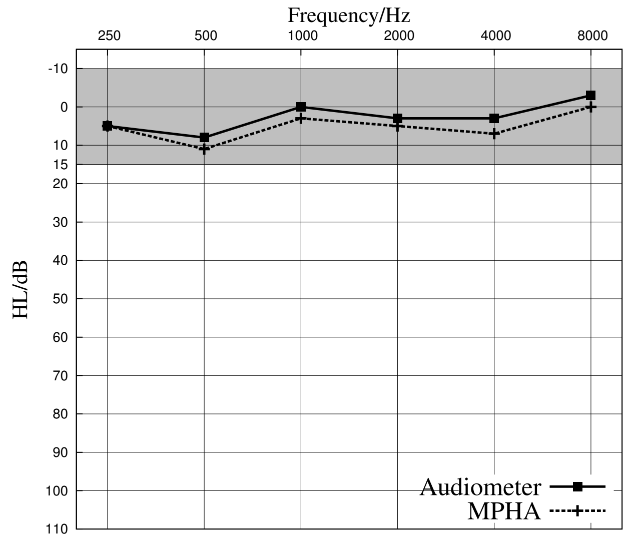


Figure 8: The auditory curve of MPHA and audiometer in a soundproof room.

5.2 Interactive Angle

The interactive angle is defined as the angle of subjects-ears to the iPad device as shown in Figure 5(b). With different angles testes, we analyzed its impact on sound signal intensity. The platform of this experiment is the same with that of Section 5.1.

5.2.1 Content

Similar to the test in Section 5.1, for each pure tone signal, we put the sound level meter with its fixed position above the iPad device. Then we vary the angel between 30° to 90° , imitating the interactive angel of users. The dB SPL value is recorded after the number remains unchanged on the sound level meter display.

5.2.2 Quantitative Results

The comparison of sound signal intensity with different interactive angles is shown in Figure 7. The results shows that average signal intensity at 30°, 60° and 90° is higher than that at 45° by 0.6dB SPL, 1.4dB SPL and 0.2dB SPL respectively. In our previous work, we have also designed and implemented a compensation algorithm for this difference caused by interactive angel [22, 7, 8]. As a result, the avaliable range of interactive angle for MPHA is between 30° and 90°.

5.3 Comparison with Audiometer

In clinical audiology, audiometer is the standard tool to measure hearing level. To prove the reliability of the MPHA, we make a comparison with the traditional audiometer.

5.3.1 Platform & Participants

This experiment is conducted in a soundproof room with an area of 10 square meters. The iPad device and the audiometer is the same with that in Section 5.1. Thirty university students majoring in computer science, art, mathematics, and physics (20 males and 10 females; 20 - 25 years old) have participated in this experiment.

5.3.2 Content

The participants are asked to take a hearing level test with the MPHA first, and then take a traditional test involving the audiometer and a doctor. With the MPHA, participants can freely complete the procedure by themselves. However, they have to feed back relevant information constantly to the audiometry doctor in the second test. Both methods are repeated three times for each participant.

5.3.3 Quantitative Results

Figure 8 shows that the difference between the two methods is 0dB, 1dB, 3dB, 2dB, 3dB, 3dB at the six frequencies respectively. None of these values is higher than 5dB, which is the smallest unit in audiometry. Moreover, the trend of these two curves is nearly the same. It proves the accuracy and validity of the MPHA.

It worth to be noted that the MPHA has greatly improved the efficiency of audiometry. The time of the whole precedure is measured and we find that with MPHA, the average time spent on each participant is 120s, while the number is up to 300 for the traditional method.

5.4 MPHA in Office

Since the soundproof room is scarce in daily life and it may potentially limit the wide usage of the MPHA, we compare the results of the hearing condition of these participants in a soundproof room and then in a working office.

5.4.1 Platform & Participants

This experiment is conducted in a regular working office with an area of about 30 square meters. The background noise is 35dB. Participants are the same with that in Section 5.3.

5.4.2 Content

The participants are asked to take a hearing level test with MPHA. To prove its robustness, the same test is repeated in the soundproof room and the working office.

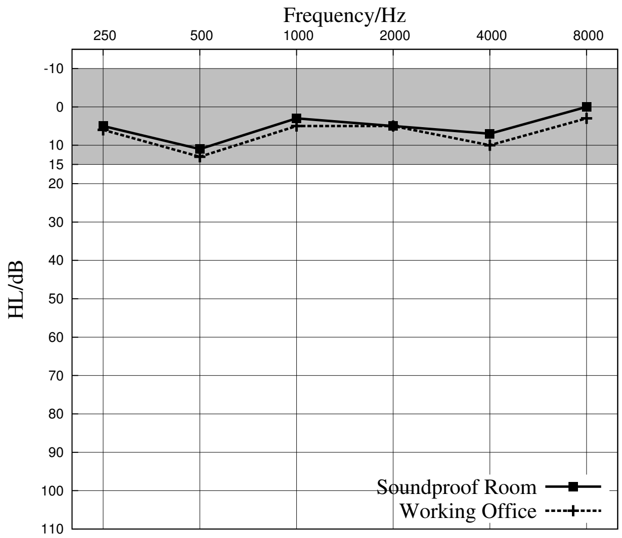


Figure 9: The auditory curve of MPHA in a soundproof room and a working office.

5.4.3 Quantitative Results

We compare the results in this experiment with the data in Section 5.3, as shown in Figure 9. We can see that the difference between the two kinds of environment is 1dB, 2dB, 2dB, 0dB, 3dB, 3dB at the six frequencies respectively. These two auditory curves indicate that MPHA has good reliability even for the noisy environment.

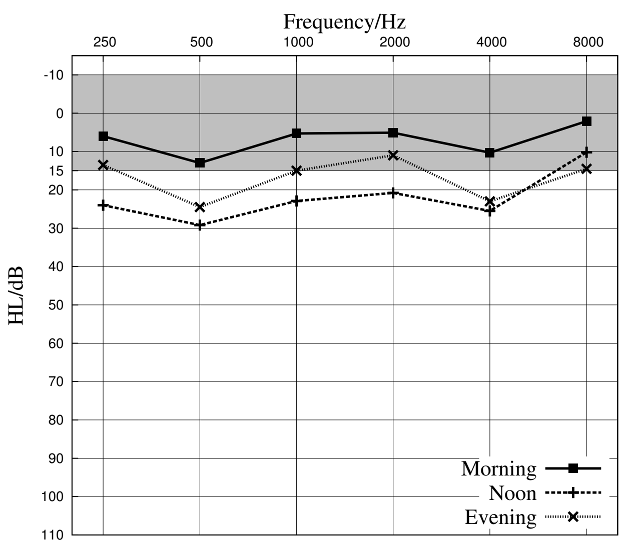


Figure 10: The auditory curve of MPHA in a day.

5.5 Morning, Noon and Evening in a Day

In this experiment, different times of one day is taken into consideration for the hearing test with MPHA. The platform and participants are the same with Section 5.5. The hearing condition at 9:00, 15:00 and 20:00 are recorded and analyzed.

5.5.1 Quantitative Results

The results are depicted in Figure 10. We can see that people's hearing level is best in the morning, and then evening but the worst at noon. Our hearing level is actually influenced by a number of things, and we should pay more attention to our hearing health.

5.6 Summary of Experimental Results

Overall, the participants have a nice experience with the MPHA. Through the five experiments, we can come to the following 4 conclusion:

- In the interactive distance and angle tasks (Section 5.1 and 5.2), MPHA showed great accuracy compared with traditional audiometry.
- In the comparison between MPHA and audiometer in soundproof room (Section 5.3), MPHA gets nearly the same results(auditory curve) with the audiometer. But the MPHA takes less time.
- In the noisy environment test(Section 5.4), MPHA generate the acceptable results compared with ideal quiet environment(soundproof room).
- In the one-day task (Section 5.5) for track recording, we find people' hearing level is actually greatly relevant to the time. Additionally, MPHA is able to tell our hearing health status in real time.

Before each experiment started, we asked the participants when they wanted a hearing test as the traditional way [18, 16, 17, 4]. 22 of the 30 participants chose NO. However, after the experiment, the nice experience with the MPHA impressed them, and 26 of them chose YES with the MPHA. As mentioned in the introduction, people are willing to pay more attention to their health condition if the procedure is not that complicated. We believe the MPHA will become popular [13, 2, 19].

6. POTENTIAL APPLICATION SCENARIOS

From the experimental results, we present possible application and extensions for future implementation of MPHA.

- **Hearing Condition Self-Check**
  Self-check of hearing condition is one of the main focus of the MPHA. As shown in the experimental results, MPHA can be used in quiet environment as well as working offices. In particular, hearing condition test in the traditional way with audiometer is very time-consuming. A mobile device with MPHA provides a effective interaction model for hearing condition self-check.
- **Recovery Record for Hearing Impaired Persons**
  For hearing impaired people, they may not able to have access to regular hearing check. After they have weared the hearing aids for a period of time, it is likely that their hearing level condition have changed. It means the hearing aids are not fully suitable for their ears any more, and the follow-up treatment should be adjusted. The MPHA facilitates the access of people's hearing condition, favouring the recovery process.

- **Pre-Screening in Hearing Rehabilitation Center**
  Even though there are many hearing rehabilitation centers, their audiometric equipment is usually expensive and energy-consuming. Additionally, the assessment procedure with traditional audiometric method needs the involvement of professional audiometry doctors. From the description in Section 4.3, MPHA can be used freely by the users themselves, which greatly improves the efficiency. Even for the hearing rehabilitation centers, the MPHA can be applied to alleviate the overcrowded environment.

Our MPHA technique is a sound-signal-based implementation for the current testing scenario, the accuracy of the pure tones generated has not been calibrated strictly for a large numbers of mobile devices. The sound volume generated by different mobile devices is actually different, so the application/interface should be calibrated.

The implementation of MPHA is dependant on sound card of devices to some extent. In this work, the highest sound intensity of the mobile device used(iPad) is 75dB. As a result, our MPHA cannot be correctly used in too noisy environment. For instance, the noise intensity of aircraft cockpit can reach higher than 80dB, currently MPHA can't work in such a environment. Generating high intensity signals on mobile devices is a part of the future work.

Finally, whether non-semantics sound is acceptable is still under investigation, especially for the tests in the working environment. However, we believe that the MPHA has shown the potential of popularity because of the concise access to people's hearing condition.

7. CONCLUSION

We present a novel interactive mode called MPHA, which evaluates people's hearing level on mobile devices. MPHA can generate accurate sound signals for audiometry, interact with users in a convenient way, and figure out users' hearing level reliably. The experimental results show that MPHA has proved its reliability and validity in quiet and noisy environment. Compared with conventional audiometry, MPHA is more efficient and cost effective. The concise audiometric assessment provided by MPHA can be further applied to a number of mobile devices, which helps people better understand their hearing health.

8. ACKNOWLEDGMENTS

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