The Journal of International Advanced Otology

J Int Adv Otol 2016; 12(1): 61-6 • DOI: 10.5152/iao.2016.1421

Original Article

# Smartphone Based Audiometric Test for Confirming the Level of Hearing; Is It Useable in Underserved Areas?

**Levent Renda, Ömer Tarık Selçuk, Hülya Eyigör, Üstün Osma, Mustafa Deniz Yılmaz**

Department of Ear Nose and Throat, Antalya Training and Research Hospital, Antalya, Turkey

**OBJECTIVE:** To determine the hearing levels of participants of a randomized group using a smartphone hearing application and to compare these results with the results from a pure-tone audiogram.

**MATERIALS and METHODS:** A heterogenous group consisting of both normal-hearing and hearing-impaired participants were included in this study. Pure-tone audiogram thresholds were measured from 250 Hz to 8000 Hz, while smartphone measurements were obtained with a Samsung Galaxy GT-19500 S4 with a bundled headphone running the Hearing Test™ software (e-audiologia.pl), which was downloaded from the Google Play Store as a free application. We compared these results with those obtained from pure-tone audiograms performed by an audiologist as a reference.

**RESULTS:** Validity analysis indicated that the results for each ear and each frequency were excellent (>0.75). We assessed the mean difference between the pure-tone audiogram and the smartphone hearing test results and found the absolute difference to be less than 8.8 dB.

**CONCLUSION:** Smartphone hearing test applications are providing alternative tests that present low-cost solutions. Using the hearing application test may decrease the demand for audiological services in underserved areas. The study suggests that smartphone hearing test results are comparable to pure-tone audiometry results.

**KEYWORDS:** Smartphone, audiometry, hearing

## INTRODUCTION

According to the World Health Organization (WHO), 360 million people have disabling hearing loss throughout the world. Hearing loss is a global health care problem. It is estimated that the majority of this population lives in low- and middle-income countries [1]. There are several impacts of hearing loss on an individual's life. Hearing loss affects the individual's ability to communicate with other people, which results in depression, social isolation, feeling of uncertainty or anger, and a lack of self-confidence [2, 3]. Hearing loss also affects social and emotional functioning, academic achievement, and economic impact. The most important aspect of this type of deficit is to detect hearing loss as soon as possible. Audiological services can provide early detection and solutions. Unfortunately, the majority of the world's population is unable to access such services because of the shortage of trained professionals and limited resources [4]. Therefore, there is a huge difference between the demand for audiological services by the number of individuals in need and the capacity to meet that demand with the number of audiological services available.

During the last decade, mobile phones have been converted from simple phones to pocket-sized computers. With large-bandwidth mobile networks such as 3G and 4G, consumers can easily access the World Wide Web via their smartphones. Furthermore, the utilization of health-related applications has gained acceptance [5]. Health-related applications are useful time savers and increase efficiency by speeding diagnoses and reducing unnecessary visits to hospitals. Some applications are designed for doctors, and some applications are recommended for patients by their doctors. There are a number of smartphone hearing applications that are already in use. These programs utilize the same principles of automated audiology in a smartphone-sized device. These smartphone-based hearing applications are available for free and are accessible. The individual can perform a self-test anytime. In addition, no skill or expertise is required to perform the test, which takes approximately 5 minutes. The results are saved on the mobile device and can be sent to any expert if necessary. Such applications can be useful where no other audiology services are available and thus provide a solution that will narrow the difference between the demand of the individual and the capacity of the audiology services.

The purpose of our study was to monitor the hearing levels for frequencies ranging from 250 Hz to 8000 Hz of a randomized, heterogenous group consisting of both normal-hearing and hearing-impaired participants using a self-administered smartphone hearing application and to compare these results with those observed from pure-tone audiograms performed by an audiologist as a reference.

**Corresponding Address:** Levent Renda E-mail: rendalevent@yahoo.com

**Submitted:** 13.10.2015 **Revision received:** 18.02.2016 **Accepted:** 22.02.2016

**MATERIALS and METHODS**

This is a within-subject study design to screen participants across different situations. The study was approved by the Research Ethics Committee of the Antalya Education and Research Hospital hospital. The participants were recruited at our outpatient clinic between October 2014 and November 2014 from among patients who had been sent to the audiology service for a tympanogram and conventional audiometry. A total of 100 participants (41 female and 59 male; 200 ears) with a mean age of 34.6±12.8 years (range, 18-66 years) were included in this study. Twenty-six had a high-frequency hearing loss, 6 had sudden sensorineural hearing loss, while 68 of the participants had normal hearing.

**Audiometric Procedures**

An otoscopic examination was conducted on each participant before testing. This was followed by tympanometry. Tympanometry was performed to gain information regarding the middle ear using an impedance audiometer (AZ26, Precision Acoustics; New York, USA) and an 85-dB sound pressure level tone set at 226 Hz to measure the middle ear function. Participants with normal peak compliance, peak pressure, gradient, and ear canal volume, according to American Speech-Language-Hearing Association criteria, were included in the study [6]. After assessing the middle ear, a pure-tone audiogram (PTA) was performed by the same audiologist using the same audiometer (AC-40 Clinical Audiometer, Interacoustics; Denmark) because PTA is the gold standard for describing hearing sensitivity. The audiometer was calibrated in decibels hearing level (dB HL), according to the International Organization for Standardization [7] and American National Standard Institute standards [8]. TDH 39 and HDA 200 headphones are the only available devices for obtaining audiometric calibration standards [9]. All the participants used a Telephonics TDH-39P (headphone) during the test. Pure-tone audiometric thresholds were measured in a soundproof booth from 250 Hz to 8000 Hz using the modified Hughson-Westlake procedure of bracketing (250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, 8000 Hz); this procedure is detailed in ANSI S3.21-1978 (R-1992) [10].

All the smartphone measurements were obtained with a bundled headphone, which was connected using a 3.5 mm stereo plug to a Samsung Galaxy GT-19500 S4 running the Hearing Test™ software (e-audiologia.pl). This was downloaded from the Google Play Store as a free application. It generates pure-tone signals with a calibration function to the required RETSPL (reference equivalent threshold sound pressure level). In addition, ambient noise levels were measured using the SoundMeter™ application; if the noise levels were appropriate to ensure the reliability of the hearing application test results, the smartphone hearing test was then performed in a quiet room [11]. The SoundMeter™ application was also downloaded from the Google PlayStore.

**Participants**

One hundred individuals voluntarily participated in this study. All the participants signed the informed consent form. An otoscopic examination was performed on each participant before the tympanometry and audiometry testing. The participation exclusion criteria were the following: less then age 18 years of age, the presence of a conductive or mixed hearing loss, and having the inability to perform the test. Participants were first recruited from our outpatient clinic and were then sent for tympanometry and conventional audiometry examinations. After undergoing the tests, which were performed by a trained audiologist using the same device, the participants were sent to a quiet room, and the smartphone hearing application test was performed using the same procedure as for the typical audiometer when the ambient sound levels measured approximately 35-40-dB sound pressure level (Figure1). These levels allow valid testing by modern standards (EN ISO 8253-2010) [12].

**Performing the Application Test**

Applications to evaluate hearing levels using smartphones are available at no charge. The applications emit pure tones at different frequencies and also test both ears individually and sequentially. There are some additional features, such as writing notes to the test results, printing the results, or sending the test results to a clinician. Headphones are required to perform the test and these should be provided with the mobile device. For performing the hearing application test, we first had to select headphones that were either bundled or not. We chose the bundled headphones, because calibration was not required. If other headphones had been chosen, calibration by a normal-hearing person would have been required prior to the test. Each individual completed the test in less than 8 minutes. The ears were sequentially tested. When performing the test, if there was more than a 40 dB (HL) hearing loss, suppression with the masking noise was begun. Masking noise was conducted using the narrowband filter. Sounds of intensity below 40 dB HL were not masked, while for the sounds of intensity between 40 dB HL and 60 dB HL, the application used the contralateral masker at 40 dB; while the sounds above 60 dB HL were masked with 60 dB contralateral noise. Once the test was completed, we noted the patient's details on the phone and saved the data. In addition, the smartphone hearing test does not measure hearing loss levels above 100 dB due to the software program.

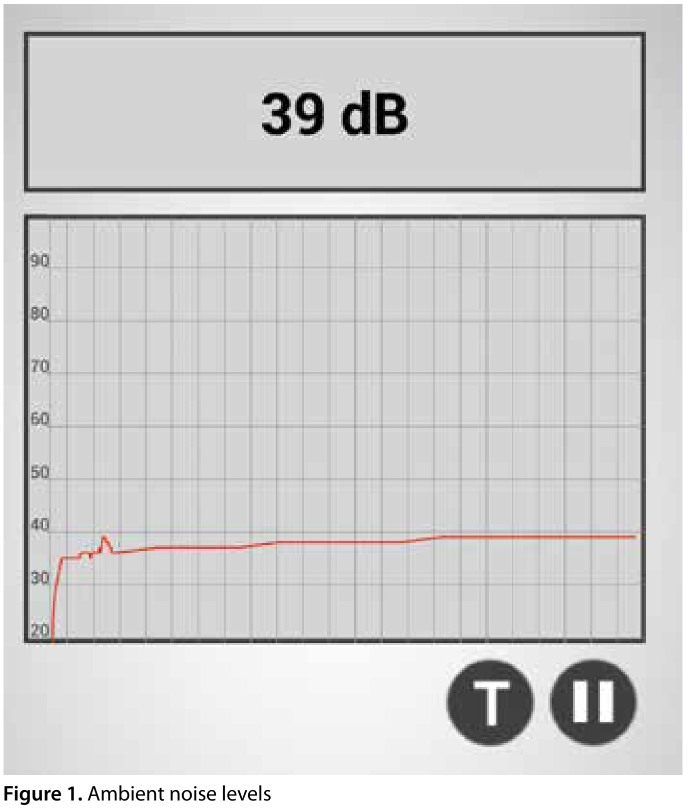


**Figure 1.** Ambient noise levels

### Statistical Analysis

Data analysis was performed using Statistical Package for the Social Sciences v.18.0 for Windows (SPSS Inc.; Chicago, IL, USA). The results of the smartphone hearing test, which was performed in a quiet room, were compared with the pure-tone audiogram results. The continuous data were expressed as the means and standard deviations, and categorical data as the frequency and percentage. Normality testing was performed using the Kolmogorov-Smirnov test. For the comparison of repeated measures, the Wilcoxon signed-rank test was used. To test the validity, the degree of agreement between the smartphone audiogram and conventional audiogram was calculated in terms of the interclass correlation coefficient (ICC) with a 95% confidence interval. Interpretation of the data was performed according to Cicchetti et al. [13]. An agreement was graded as poor for ICC values less than 0.40, fair for values between 0.41 and 0.59, good for values between 0.60 and 0.74, and excellent for values between 0.75 and 1.0. The difference between the pure-tone audiogram and smartphone audiogram was calculated for each frequency (ΔdB=|audiogram−smartphone audiogram|). A 2-sided p value of <0.05 was considered statistically significant.

## RESULTS

A total of 100 patients with a mean age of 34.6±12.8 years (range, 18-66) were included in this study. There were 39 (39%) female and 61 (61%) male participants. Among the participants, 26 patients had high-frequency sensorineural hearing loss. We included 6 patients who had sudden sensorineural hearing loss (3 patients had hearing loss in the left ear and 3 patients had hearing loss in the right ear). Findings of validity analysis of the results for each ear and each frequency are presented in Table 1 (all frequencies>0.75). The ICC values were measured between 0.878 and 0.933. When we assessed the mean difference between the pure-tone audiogram and the smartphone hearing test results, we found an absolute difference (ΔdB) of less than 8.9 dB for each frequency (Table 1). With regard to the comparison of the measurements at 500 Hz, 1000 Hz, 2000 Hz, and 6000 Hz with both the left and right ears, we found a statistically significant difference (p<0.05) (Table 2). The audiometric results at 500 Hz, 1000 Hz, and 2000 Hz and the smartphone hearing test results at 6000 Hz had better outcomes. At these frequencies, the mean difference was lower than 4.60 dB. When assessing the 250 Hz, 3000 Hz, 4000 Hz, and 8000 Hz frequencies in both the right and left ears, we found that the results were not significantly different (p>0.05) (Table 3). The smartphone hearing test results at 250 Hz, 4000 Hz, and 8000 Hz (only at right ear) had better outcomes than the pure-tone audiogram results. The mean difference between these 2 methods across these frequencies was lower than 1.43 dB. Therefore, these insignificant differences between the pure-tone audiogram and smartphone hearing test results in high-frequency measurements indicate that both tests are similar for these frequencies.

Based on this finding, we determined that the smartphone hearing application test results on both normal-hearing and hearing-impaired participants corresponded with the pure-tone audiogram results (Figure 2, 3).

**Table 1.** Reliability analysis of a conventional audiogram versus a smartphone audiogram for each frequency and ear and the mean difference between each assessment (ΔdB ± SD) ΔdB is defined as the absolute difference between the measurements: ΔdB=|dB Audiogram−dB Smartphone|.

| Left | | | Right | | |
|---|---|---|---|---|---|
| Frequency (Hz) | ICC (95% CI) | ΔdB±SD | Frequency | ICC (95% CI) | ΔdB±SD |
| 250 Hz | 0.914 (0.875-0.941) | 7.1±5.5 | 250 | 0.888 (0.838-0.923) | 7.5±6.5 |
| 500 Hz | 0.898 (0.852-0.930) | 7.5±7.1 | 500 | 0.884 (0.832-0.920) | 7.8±7.3 |
| 1000 Hz | 0.907 (0.865-0.936) | 8.7±6.5 | 1000 | 0.878 (0.823-0.916) | 8.6±7.3 |
| 2000 Hz | 0.899 (0.854-0.931) | 8.7±6.8 | 2000 | 0.932 (0.900-0.954) | 7.0±5.7 |
| 3000 Hz | 0.911 (0.871-0.939) | 7.5±7.0 | 3000 | 0.927 (0.893-0.950) | 6.8±6.3 |
| 4000 Hz | 0.897 (0.851-0.930) | 7.7±6.9 | 4000 | 0.914 (0.874-0.941) | 7.8±7.6 |
| 6000 Hz | 0.907 (0.865-0.936) | 8.8±8.7 | 6000 | 0.917 (0.879-0.944) | 8.2±8.2 |
| 8000 Hz | 0.915 (0.876-0.942) | 8.5±7.9 | 8000 | 0.933 (0.903-0.955) | 6.7±7.6 |

ICC: interclass correlation coefficient; CI: confidence interval

**Table 2.** Mean±SD values for all the measurements (hearing thresholds) and their comparison

| Frequency(Hz) | Side | Audiogram | Smartphone | p |
|---|---|---|---|---|
| 250 Hz | L | 20.88±22.95 | 19.50±20.23 | 0.311 |
| | R | 19.63±22.39 | 18.40±19.49 | 0.142 |
| 500 Hz | L | 21.76±24.29 | 24.60±19.83 | 0.001 |
| | R | 18.88±22.94 | 22.10±19.26 | 0.002 |
| 1000 Hz | L | 21.11±25.02 | 25.70±21.04 | 0.0001 |
| | R | 19.28±24.05 | 22.65±19.77 | 0.0001 |
| 2000 Hz | L | 21.72±25.50 | 24.75±21.98 | 0.012 |
| | R | 20.50±24.37 | 22.85±23.34 | 0.004 |
| 3000 Hz | L | 24.78±26.08 | 25.93±22.37 | 0.164 |
| | R | 23.54±24.53 | 24.96±24.01 | 0.158 |
| 4000 Hz | L | 27.73±27.55 | 27.30±24.49 | 0.485 |
| | R | 27.24±26.85 | 26.50±25.86 | 0.648 |
| 6000 Hz | L | 31.30±29.46 | 28.40±26.76 | 0.001 |
| | R | 30.33±27.68 | 26.70±27.10 | 0.010 |
| 8000 Hz | L | 30.85±29.67 | 31.00±27.31 | 0.359 |
| | R | 30.35±27.78 | 29.47±28.04 | 0.879 |

## DISCUSSION

The accuracy of hearing application test is important for identifying a hearing loss. It does not suggest an alternative scenario to fully replacing audiometry. The hearing application test outcomes should be similar to the results from a pure-tone audiogram to be considered accurate. We aimed to test the validity of smartphone-based audiometry for hearing level testing in a heterogeneous group who were randomly selected. In this study, the agreement between the smartphone audiogram and pure-tone audiogram results was excellent (0.878-0.933). At 500 Hz, 1000 Hz, 2000 Hz, and 6000 Hz, we

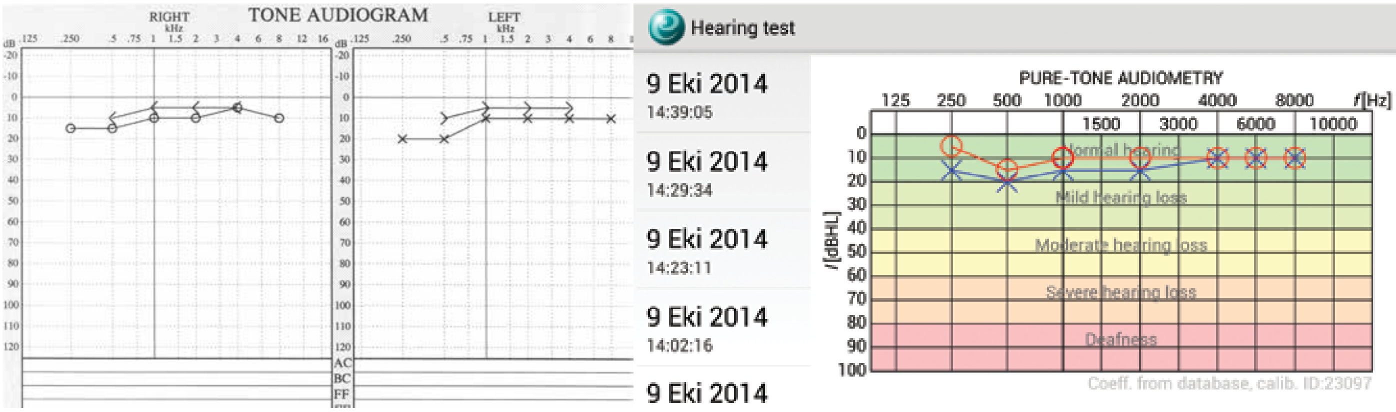


**Figure 2.** Hearing thresholds of a normal-hearing person

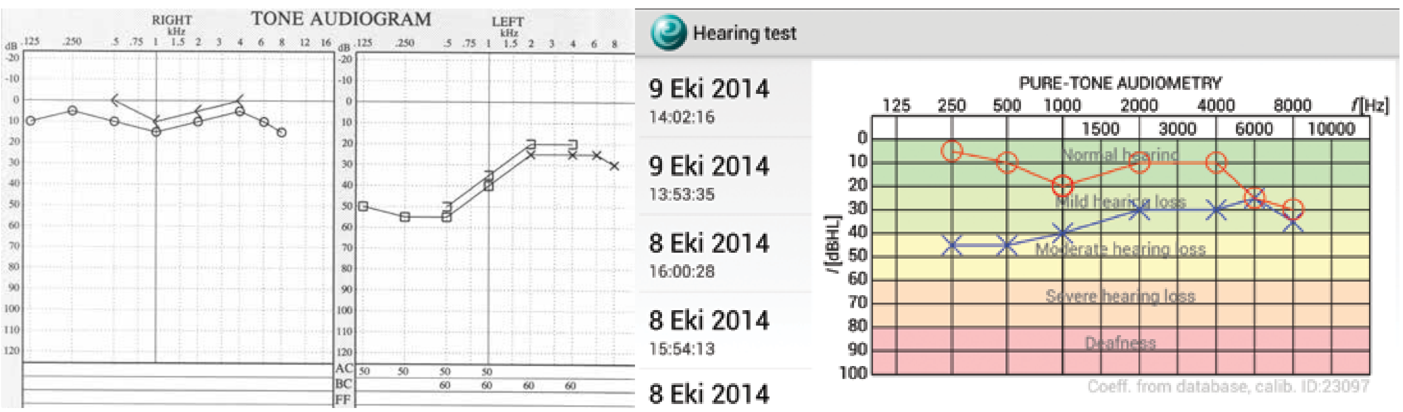


**Figure 3.** Hearing thresholds of left-sided sudden sensorineural hearing loss

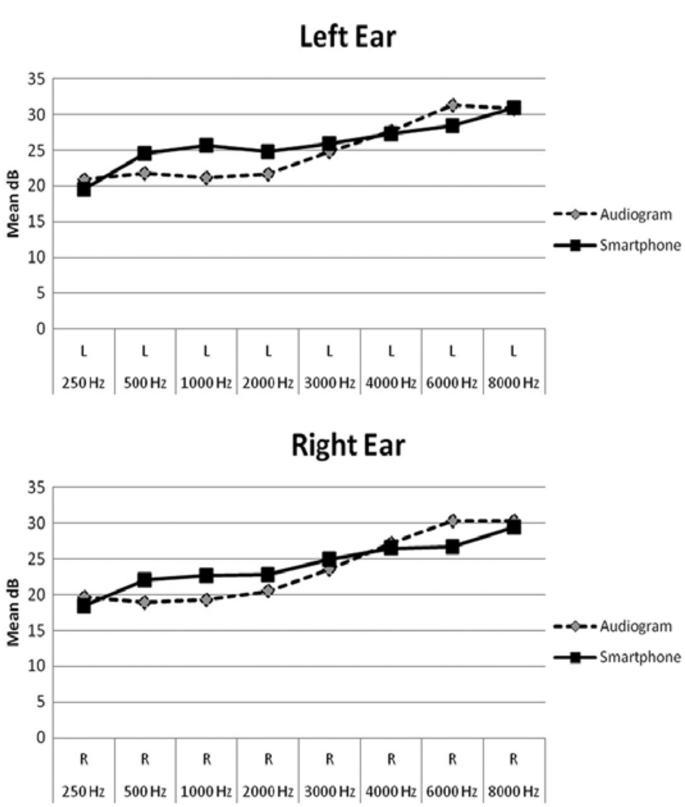


**Figure 4.** Comparison of hearing thresholds of conventional audiometry and smartphone application test

found a statistically significant difference between these 2 methods. This was an expected result, particularly for the 500 Hz and 1000 Hz frequencies, because of the ambient noise. At 250 Hz, 3000 Hz, 4000 Hz, and 8000 Hz frequencies, the results were not significantly different. The better results observed with the smartphone hearing test at 250 Hz, 4000 Hz, 6000 Hz, and 8000 Hz (for right ear) were unexpected (Figure 4). This may be due to the self-administered test that gives the user full control of the result. Additionally, the quiet room where the smartphone hearing tests were performed could be contaminated by ambient noise, which could cause the participant be confused during the smartphone test. Nonetheless, there was no significant difference when comparing high frequencies with low frequencies.

Over 5% of the world's population has hearing loss, comprising 90% adults and 10% children. One-third of the individuals over 65 years of age have hearing impairment [1]. If people are aware of their hearing loss, the progression of the hearing loss can be prevented. Therefore, early hearing screening and initial treatment could significantly improve an individual's quality of life.

The use of mobile phones is increasing rapidly worldwide. Smartphones mimic a personal computer. Health apps are becoming key tools. With the development of mobile phone technologies, there is also increasing interest in using smartphone applications for health and wellness. Individuals are empowered to monitor themselves to assess such parameters as their amount of sleep, heart rate, and blood pressure [14]. These data can thus improve an individual's ability to assess his/her health.

There are many articles regarding the use of smartphone health-related applications. Some of these articles are concerned with tracking the heart rate, blood pressure, caloric intake, or weight, collecting data on alcohol use [15] and cocaine cravings [16] among the homeless or sending short message service (SMS) messages to users about the disease and adherence to treatment. Some of the applications are useful in the clinic, such as orthopedic applications [17] for radiographic evaluation, and some of the applications have a combination of a mobile phone-blood glucose monitor that is monitored by the patient and the clinician [14]. In the otology area, there is a rapidly increasing interest in developing applications, such as the detection of noise levels [18], and monitoring hearing thresholds, as well as using a smartphone-enabled digital otoscope. These applications are used to collect, save, transmit, or share the data.

There are a few articles that have reported data on the validity of the smartphone-based applications. These studies mostly used the iPod© device and iPod-based applications, for which there is no standardized calibration procedure as yet. The clinical validity of smartphone-based audiometry was studied by Swanepoel et al. [19], who compared the hearScreen™ application using a smartphone with conventional audiometry on 162 school children. These authors demonstrated that these 2 methods were in agreement in 97.8% of ears. Kam et al. [20] compared the application tests with conventional audiometry and checked the reliability and validity of the application in 325 subjects between 6-10 years of age. Kam et al. [20] found 63% sensitivity and 82% specificity ratios. Foulad et al. [21] determined the feasibility of a smartphone-based application and compared its accuracy with formal audiometry. These authors performed the application test in a quiet room and found 94% of the threshold values were within 10 dB of the threshold values obtained with formal audiometry in 42 subjects. These hearing applications were successful in demonstrating the close correspondence of the threshold values to those obtained via conventional audiometry. A different group of patients with unilateral sudden sensorineural hearing loss were tested with both conventional and smartphone-based audiometry by Handzel et al. [22]. The results showed that the application test had a sensitivity of 76% and specificity of 91%. The correlation coefficient for the comparison of the hearing grade was 83% and the smartphone-based hearing application results were more accurately reflected, particularly at middle and high frequencies. Szudek et al. [23] studied a group of patients with moderate hearing loss, and demonstrated that UHear™ (an iPod-based hearing screening test) was useful and provides accurate results for ruling out hearing loss. The present study has a sensitivity of 98% in correctly diagnosing hearing loss, whereas the application results overestimated by 8 dB the conventional audiometry results in the sound booth. In contrast, Khoza-Shangase et al. [24] carried out a study with 86 participants to compare non-calibrated insert earphones with conventional audiometry. These authors found inaccurate thresholds that were significantly elevated and large deviations at lower frequencies. The mean thresholds that were measured using UHear™ reflected worse hearing results than conventional audiometry in both ears across all frequencies. It was stated that non-calibrated smartphone applications and ambient noise levels may have resulted in the elevated thresholds with the UHear™ test. Recent studies have limitations due to the use of smartphone-based devices that have no standardized calibration procedure. Additionally, there are possible effects of ambient noise influences, which may lead to poor accuracy because current applications do not offer a facility to control for ambient noise influences. A clinical study was carried out by Wong et al. [25] pointing out that ambient noise results in an increased variance in the hearing thresholds at lower frequencies. It was stated that the level of ambient noise would have had an effect at both high and low frequencies.

There are some limitations regarding the performance of the application hearing test. First, the users can drive it to any result they want because of self-administration of the test. The instructions are in English language. In addition, the test must be performed in a quiet room to prevent ambient noise. The application test uses pure tones and not speech audiometry and is thus less reliable than a pure-tone audiogram performed by audiologists. The hearing test does not distinguish between conductive and sensorineural hearing loss critical to populations in underserved areas, and smartphone hearing applications do not deal with this condition. There may be inaccurate results, particularly for low frequencies, because of the ambient noise.

In conclusion, smartphone hearing test applications are providing alternative tests in underserved areas that provide low-cost solutions that can result in early detection. This is particularly important in developing areas where audiology services are unavailable. A smartphone hearing test is easy to perform and can be self-administered at any time. The findings from our study demonstrate that the smartphone hearing test may be an alternative method in underserved areas to screen the hearing levels of patients.

**Ethics Committee Approval:** Ethics committee approval was received for this study from the ethics committee of Antalya Training and Research Hospital.

**Informed Consent:** Written informed consent was obtained from patients who participated in this study.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Design - L.R.; Supervision - Ü.O., M.D.Y.; Resources - H.E.; Data Collection and/or Processing - L.R., H.E., Ü.O.; Analysis and/or Interpretation - Ö.T.S., M.D.Y.; Literature Search - Ö.T.S.; Writing Manuscript - L.R.; Critical Review - L.R.

**Conflict of Interest:** No conflict of interest was declared by the authors.

**Financial Disclosure:** The authors declared that this study has received no financial support.

## REFERENCES

1. World Health Organization. Deafness and Hearing loss. Available from: http://www.who.int/mediacentre/factsheets/fs300/en. Accessed October 30, 2014.
2. Lin FR, Yaffe K, Xia J, Xue QL, Harris TB, Purchase-Helzner E, et al. Hearing loss and cognitive decline in older adults. JAMA Intern Med 2013; 173: 299. [CrossRef]
3. Olusanya BO, Newton VE . Global burden of childhood hearing impairment and disease control priorities for developing countries. Lancet 2007; 369: 1314-7. [CrossRef]
4. Fagan JJ, Jacobs M. Survey of ENT services in Africa: Need for a comprehensive intervention. Global Health Action 2009; 2: e1-e7. [CrossRef]
5. Swanepoel D, Hall JW . A systematic review of telehealth applications in audiology. Telemed J e-Health 2010; 16: 181-200. [CrossRef]
6. Guidelines for screening for hearing impairment and the middle ear disorders. Working group on Acoustic Immitance Measurements and the Committee on Audiologic Evaluation. American Speech-Language-Hearing Association, ASHA Suppl 1990; 2: 17-24.

7. International Organization for Standardization Technical report (1998) Acoustics-Reference zero for the calibration of audiometric equipment. Part 1- Reference equivalent threshold sound pressure levels for pure tones and supra-aural earphones. ISO/TR 389-1.
8. American National Standard Specification for audiometers (2004) NSI S3.6-2004.2204. ANSI, New York.
9. Carhart R, Jerger J . Preferred methods for clinical determination of pure-tone thresholds. J Speech Hear Disorders 1959; 24: 330-45. [CrossRef]
10. American National Standard Methods for Manual Pure-Tone Threshold Audiometry (R-1992) ANSI S3.21-1978.
11. Kardous CA, Shaw PB . Evaluation of smartphone sound measurement applications. J Acoust Soc Am 2014; 135: EL 186-92.
12. EN ISO 8253-2010. Acoustics-Audiometric test methods-Part 1: Pure-tone air and bone conduction audiometry. International Organisation for Standardisation. Available from: http://www.iso.org/iso/catalogue.
13. Cicchetti DV . Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychological Assessment 1994; 6: 284-90. [CrossRef]
14. Logan AG, McIsaac WJ, Tisler A, Irvine MJ, Saunders A, Dunai A, et al . Mobile phone-based remote patient monitoring system for management of hypertension in diabetic patients. Am J Hypertens 2007; 20: 942-8. [CrossRef]
15. Collins RL, Kashdan TB, Gollnisch G. The feasibility of using cellular phones to collect ecological momentary assessment data: application to alcohol consumption. Exp Clin Psychopharmacol 2003; 11: 73-8. [CrossRef]
16. Freedman MJ, Lester KM, McNamara C, Milby JB, Schumacher JE . Cell phones for ecological momentary assessment with cocaine-addicted homeless patients in treatment. J Subst Abuse Treat 2006; 30: 105-11. [CrossRef]
17. Ege T, Kose O, Koca K, Demiralp B, Basbozkurt M . Use of iPhone for radiographic evaluation of hallux valgus. Skeletal Radiol 2013; 42: 269-73. [CrossRef]
18. Na Y, Joo HS, Yang H, Kang S, Hong SH, Woo J. Smartphone-based hearing screening in noisy environments. Sensor (Basel) 2014; 14: 10346-60. [CrossRef]
19. Swanepoel DW, Myburgh HC, Howe DM, Mahomed F, Eikelboom RH . Smartphone hearing screening with integrated quality control and data management. Int J Audiol 2014; 53: 841-9. [CrossRef]
20. Kam AC, Gao H, Li LK, Zhao H, Qiu S, Tong MC. Automated hearing screening for children: A pilot study in China. Int J Audiol 2013; 52: 855-60. [CrossRef]
21. Foulad A, Bui P, Djalilian H . Automated audiometry using Apple iOS-based application technology. Otolaryngol Head Neck Surg 2013; 149: 700-6. [CrossRef]
22. Handzel O, Ben-Ari O, Damian D, Priel MM, Cohen J, Himmelfarb M . Smartphone-based hearing test as an aid in the initial evaluation of unilateral sudden sensorineural hearing loss. Audiol Neurootol 2013; 18: 201-7. [CrossRef]
23. Szudek J, Ostevik A, Dziegielewski P, Robinson-Anaqor J, Gomaa N, Hodqetts B, et al . Can Uhear me now? Validation of an iPod-based hearing loss screening test. Otolaryngol Head Neck Surg 2012; 41: 78-84.
24. Khoza-Shangase K, Kassner L . Automated screening audiometry in the digital age: exploring uhear and its use in a resource-stricken developing country. International Journal of Technology Assessment in Health Care 2013; 29: 42-7. [CrossRef]
25. Wong TW, Yu TS, Chen WQ, Chiu YL, Wong CN, Wong AH. Agreement between hearing thresholds measured in Non-soundproof work environments and a soundproof booth. Occup Environ Med 2003; 60: 667-71. [CrossRef]