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Development of a smartphone-based Turkish digits in noise test

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Abstract

Background Pure-tone audiometry is the traditional gold standard for assessment and screening of hearing impairment, but it requires the use of calibrated devices and soundproof booth. Mobile apps can offer a good alternative to traditional methods in limited circumstances and in some emergency situations, especially when traditional methods are not available. The aim of the study was to develop an easily accessible mobile-based Turkish Digit in Noise Test screening test for the assessment of hearing.

Methods The digits were read by a male speaker whose native language is Turkish. A mobile application was developed in accordance with the Android operating system. Twenty-five individuals with normal hearing, 25 individuals with bilateral mild sensorineural hearing loss, 25 with bilateral mild mixed hearing loss, and 25 with bilateral mild conductive hearing loss total of 100 participated in the study. All participants were between the ages of 18–60. The Turkish Digit in Noise Test mobile application was applied to the participants and the test scores were compared among the types of hearing loss.

Results The Turkish Digit in Noise Test scores of participants with bilateral mild sensorineural hearing loss (19.4 ± 5.39) and mixed hearing loss (22.96 ± 4.52) were lower than those of participants with normal hearing (39.68 ± 6.82) ($p < .01$). In addition, the results of participants with bilateral mild sensorineural hearing loss (19.4 ± 5.39) and mixed hearing loss (22.96 ± 4.52) were lower than those of participants with conductive hearing loss (36.88 ± 6.31) ($p < .01$).

Conclusion An easy and accessible Turkish Digit in Noise Test mobile application has been developed using which one can assess his/her hearing.

Keywords Hearing screening, Digit in Noise test, Mobile application

Background

Smartphones are indispensable in our daily lives. Because smartphones are portable and easy to reach, mobile apps can be upgraded and results obtained quickly. Therefore, mobile apps can offer a good alternative to traditional methods in limited circumstances and in some emergency situations, especially when traditional methods are not available [1].

The use of mobile apps in the field of audiology is increasing due to their easy access, efficiency, low cost, and high quality [2]. Hearing screening and measurement were one of the first apps in mobile or digital health care. Studies have revealed the positive effects of using mobile apps for participant hearing screening. Davison et al. [3] demonstrated the effectiveness of using a tablet-based hearing screening system compared to traditional audiometric testing for population older than 60 years. Rourke et al. [4] used portable tablets to test the hearing loss of 218 children in northern Canadian communities. Their study provided positive and valuable evidence for using the

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tablet-based audiometer in remote areas. Whitton et al. [5] compared home hearing measurements with standard tests in clinical settings using self-administered audiometric software. The results showed statistical significance between the two approaches. Samelli et al. [6] confirmed Whitton et al.'s results in their study. Thirty participants were evaluated with two methods: tablet-based hearing screening and sweep audiometry. In both methods, 26 participants had normal hearing and 4 had hearing loss.

According to the World Health Organization, more than 466 million (more than 5%) people worldwide, including 34 million children, have hearing loss. It is predicted that the number will reach 630 million in 2030 and 900 million in 2050 [7]. According to the Turkey Health Survey 2016 data, 3.6 million people in Turkey have hearing loss [8].

The common complaint of patients with hearing loss is difficulty understanding speech in background noise. Conventional hearing tests are insufficient to evaluate problems encountered in daily life and speech in background noise, since the relationship between pure-tone thresholds found with audiometers and the ability to understand speech in noise (SIN) is weak [9]. Although the use of speech in noise tests in clinical practice is limited, the SIN test is necessary to determine a patient's speech comprehension performance at work, in the classroom, and in everyday life in general. Several SIN tests are available today, which require the patient to repeat 50% of the words correctly to determine the signal-to-noise ratio (SNR). SIN tests have the advantage of being less sensitive to ambient noise and headphone type [10].

Phone-based digits in noise (DIN) screening tests have been developed in many countries over the last decade, including France, Germany, Poland, South Africa, Australia, and Dutch [10–14]. The first mobile app DIN test was launched in 2016 as hearZA [13, 15], the national hearing test of South Africa. However, since the numbers used in the test are in English, they cannot be commonly used in our country.

The aim of our study was to develop a Turkish Digit in Noise Test (T-DIN) mobile app. Its secondary purpose was to compare the test results between participants with normal hearing and participants with conductive, sensorineural, and mixed hearing loss.

Methods

This study was conducted in the clinical laboratory of the Audiology Department of Istanbul Aydin University. It was approved by the Istanbul Aydin University Non-Interventional Clinical Research Ethics Committee (registration number 2019/148) on July 18th, 2019.

Participants

This study was carried out in different audiological units. From all randomly selected a total of 100 individuals from different clinics who were willing to participate, could communicate verbally and use smartphones in the study were included. Participants with normal hearing (NH) and bilateral mild (26–40 dB) conductive hearing loss (CHL), sensorineural hearing loss (SNHL), and mixed hearing loss (MHL) were included in the study. NH was defined as 15 dB HL on PTA in both ears. Bilateral mild CHL was determined normal bone conduction (0–15 dB HL) and abnormal air conduction threshold levels (26–40 dB HL). Bilateral mild SNHL was defined 26 to 40 dB HL in both ears, with air-bone conduction gaps $\leq$ 10 dB. Bilateral MHL was determined abnormal air and bone conduction hearing levels with air-bone conduction gaps > 10 dB.

A total of 100 individuals between the ages of 18–60 were included in the study, including 25 individuals with NH, 25 individuals with bilateral mild CHL, 25 individuals with bilateral mild SNHL and 25 individuals with bilateral mild MHL.

Procedure

The purpose of the study was explained in detail to all the participants. After otoscopic examination, a tympanometry test and a pure-tone audiometry test were performed on all the participants.

T-DIN was explained in detail to all the participants before earphones were placed in their ears. They then performed the test by following the steps on the app. All the participants performed the T-DIN on two smartphones and earphones (Samsung Galaxy EO-EG920BW) from the same brand that used the Android operating system.

Voice recording for T-DIN

The Turkish numbers were recorded in 24-bit in the sound recording studio of Istanbul Aydin University's Faculty of Communication applied TV studio using Pro Tools 12.7.1 and a Rode NT-5 microphone. A male speaker whose native language is Turkish and read the numbers. Before recording, the Rode NT-5 microphone and amplifier were calibrated. Recording took place in a double-walled quiet room with acoustic foam on the wall and floor. The reader was given pre-registration instructions to read the numbers as naturally and clearly as possible. Each number was recorded six times to select the numbers that were the most fluent and understandable. The most fluent and understandable numbers were chosen by the researchers. The duration of each number was equalized by subtracting the silent intervals at the beginning and end of each number. All numbers in the Turkish language are used in the test (0–9).

In Fig. 1, the time–amplitude graph of the recorded and edited numbers is given. Figure 2 shows the frequency spectrograms of the numbers.

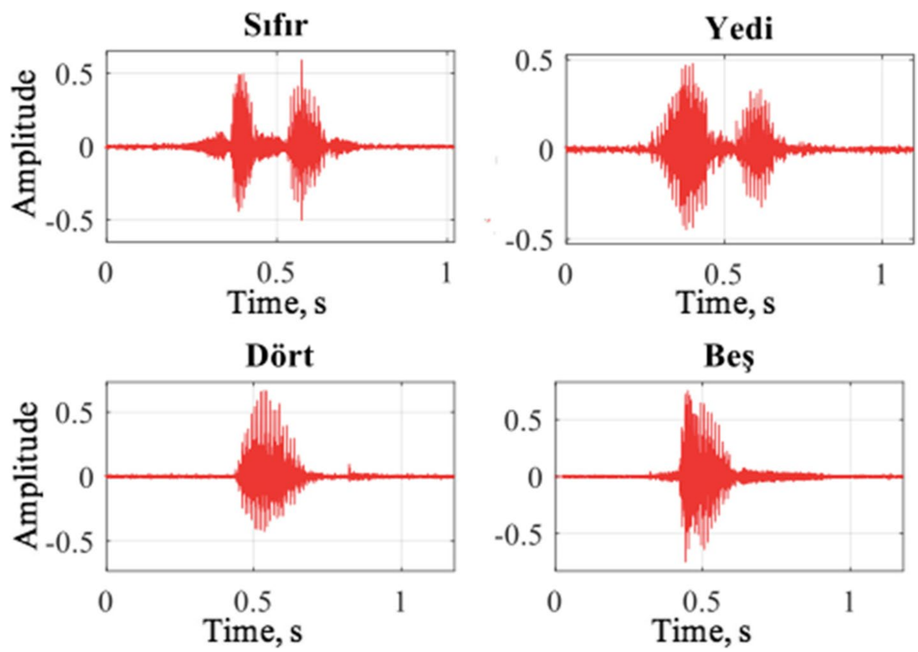

Fig. 1 Amplitude-time graphs of recorded digits (0,7,4,5)

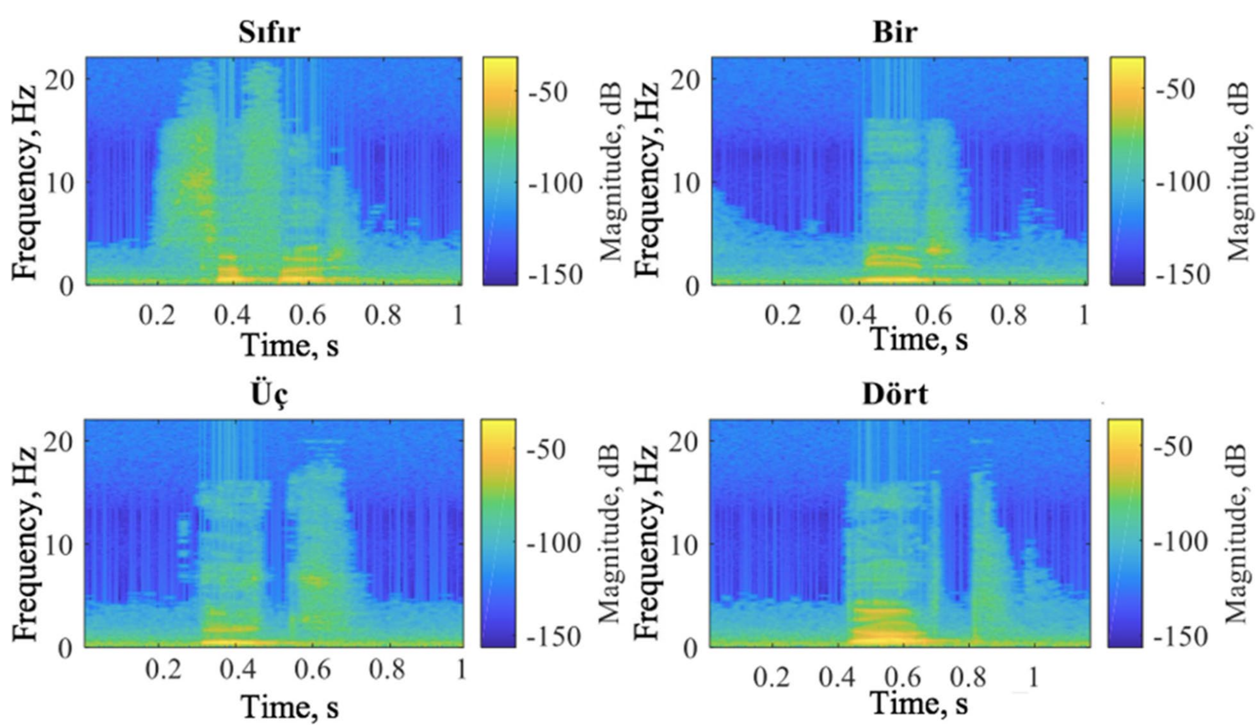

Fig. 2 Frequency-time graphs of recorded digits (0,1,3,4)

Development of mobile application

Within the scope of the research, a mobile application for the Android operating system was developed, and it can run on any Android smartphone. The application interface was developed to be simple and convenient.

The test starts with the screen where the participant enters the demographic information and continues with the screen with the necessary instructions for the test. Before starting the test, the participant could adjust the most comfortable sound level. The test was performed by playing an audio recording of a random sequence of three numbers. After the recording ended, a keyboard appeared on the screen so that the participants could choose the numbers they hear. In the DIN test, digits that individuals are familiar, closed-set pattern with are used as a speech material. This requires a lower linguistic demand and allows the test to be applied to wider age groups [16]. In cases where the participant was not sure of the digits he/she heard, he/she was asked to guess the numbers. The test progressed adaptively to the participant. When the participant recorded at least two of the three numbers correctly, the SNR decreased by 2 dB, and when the participant recorded one or none of the numbers correctly, the SNR increased by 2 dB. Scoring was done separately for each trial of numbers, and participants had to correctly identify at least two of the three numbers to score points from each trial. The first 3 triplets were not included in the scoring to allow the participant to get used to the test. A total of 23 triplets were presented to each participant. The maximum score is 60. White noise was used as the noise type because it includes all frequencies. The test takes less than 5 min.

Statistical analysis

The Statistical Program for Social Sciences version 22.0 was used for the data analysis. The normality of the data distribution was examined using the Kolmogorov–Smirnov and Shapiro–Wilk tests. One-way ANOVA was used to compare more than two independent groups of quantitative data with normal distribution. The t test with Bonferroni correction, which is one of the post hoc tests, was used for pairwise comparison of the data with statistically significant differences. The Kruskal–Wallis H test was used to compare quantitative data with more than two independent groups that did not have a normal distribution. In statistical analyses, the significance value was $p < 0.05$ and the significance level was 95%.

Results

Table 1 shows the demographic information of the participants.

Table 1 Participant demographics

Groups	Female (*n*)	Male (*n*)	Total (*n*)	Age (Mean ± SD)
NH	12	13	25	35.36 ± 11.47
CHL	9	16	25	30.40 ± 10.63
SNHL	11	14	25	46.32 ± 11.30
MHL	13	12	25	45.48 ± 10.86

T-DIN scores

The mean T-DIN score of participants with normal hearing included in the study was 39.68 ± 6.82 (range 24–50). The mean of participants with bilateral mild conductive hearing loss was 36.88 ± 6.31 (range 24–50). Participants with bilateral mild sensorineural type hearing loss had a mean of 19.4 ± 5.39 (range 10–29), and those with bilateral mild mixed hearing loss had a mean of 22.96 ± 4.52 (range 15–32).

The summary results of T-DIN in the participant groups are shown in Fig. 3.

The T-DIN scores of participants with normal hearing and those with conductive hearing loss were compared, no statistically significant difference was found between them ($p = 0.556$).

The T-DIN scores of participants in the normal hearing group were significantly higher than those in sensorineural hearing loss ($p < 0.001$).

The T-DIN scores of participants in the normal hearing group was significantly higher than those in mixed hearing loss ($p < 0.001$).

Table 2 shows the comparison of the participants according to the type of hearing loss.

Discussion

This study aimed to develop an easily accessible and applicable national mobile screening test, and developed the T-DIN mobile application. The test was applied to participants with normal hearing, conductive hearing loss, sensorineural hearing loss, and mixed hearing loss; the results of the participant patient tests were compared.

Koole et al. [17] stated that auditory amplification can be done more effectively by evaluating the DIN test results in the selection of hearing aids for the elderly. The authors stated that the DIN test can be used in the screening of moderate-to-severe hearing loss in the elderly population; however, they further mention that the test is insufficient in screening participants with mild hearing loss. All participants in our study had bilateral mild hearing loss. A statistically significant difference was obtained when the scores of the T-DIN of participants with normal hearing and those with mixed hearing loss and sensorineural hearing loss were compared.

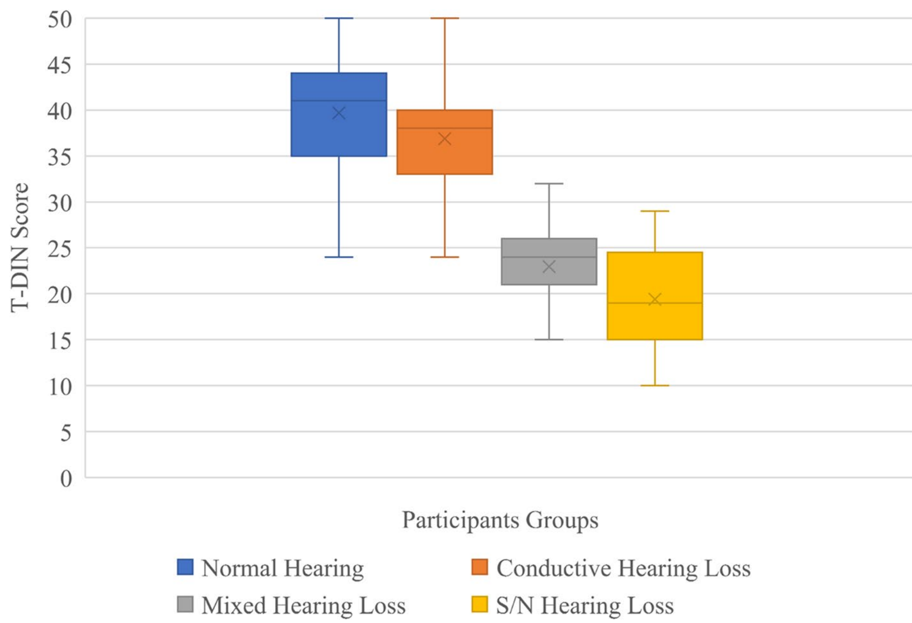

Fig. 3 Boxplot depicting summary results of T-DIN in the participant groups. Median is given as horizontal lines in the middle of the box. Boxes give 25 and 75% quartiles. Whiskers denote minimum and maximum values

Table 2 The mean, standard deviation, and range of the Digit in Noise Test scores according to the hearing of the participants included in the study

Groups	$\bar{x} \pm SD$	Min–max	*F*	*p*	Bonferroni
NH[1]	39.68 ± 6.82	24–50	74.205	< .001*	1 > 3 1 > 4 2 > 3 2 > 4
CHL[2]	36.88 ± 6.31	24–50			
SNHL[3]	19.40 ± 5.39	10–29			
MHL[4]	22.96 ± 4.52	15–32			

It is important to develop easily accessible hearing screening procedures for the early diagnosis and instrumentation of participants with hearing loss. In the study conducted by Folmer et al. [18], a comparison was made between pure tone audiometry test results and the DIN test results of 20 participants with normal hearing and 20 participants with mild to moderate sensorineural hearing loss. Pearson correlation coefficients (*r*) between 0.74 and 0.76 were obtained, versus the DIN signal-to-noise ratios, which showed pure tone audiometry threshold values for two different participant groups [14]. The results of participants with normal hearing are similar to the Dutch ($r = 0.72$) [14], French ($r = 0.77$) [10], and Australian ($r = 0.77$) [19] versions.

Smith et al. developed a new Dutch speech-in-noise test using digit triplets as the speech material. The test is fully automatic, controlled by a computer, and can be performed over the phone [15]. It has been stated that since the correlation between the DIN test and the Speech Reception Threshold ($r = 0.72$) is high, it can be used as a screening test [14, 20]. The DIN test, developed by Smits et al., was first used as a national hearing test in the Netherlands in 2003 and yielded successful results [14]. Based on this test, similar tests were developed in various countries, such as France, Germany, Poland, South Africa, Australia, and Dutch [10–14]. In a study conducted by Jansen et al. [21], which included 84 participants with high-frequency hearing loss, a strong correlation ($r = 0.86$) was found between pure tone audiometry thresholds (PTA 2 k, 3 k, 4 k, and 6 kHz) and the DIN test. Considering the ease of application of the DIN test, it was thought that it could be used for screening and as a control test for participants at high risk of hearing loss. In our study, the scores of the participants with bilateral mild degree mixed type and sensorineural type hearing losses were lower than those with normal hearing. This app can be used as a quick home hearing screening tool, not to replace traditional audiological assessment.

In order to ensure homogeneity in the Dutch language, it has been suggested that the test should only include monosyllabic numbers [20]. If there is a disproportion between the number of monosyllabic and bisyllabic numbers, the homogeneity of speech material may be reduced, since some numbers are perceptually different from others. If the ratio of numbers with one syllable and two syllables is unbalanced (for example, eight monosyllables, two syllables), those with fewer numbers should be excluded from the test, as it will make a perceptual difference and disrupt homogeneity. For this reason, some numbers have been omitted from the German, English, Dutch, and Swedish versions of the Number in Noise Test. In the Polish version of the Number in Noise Test, developed by Ozimek et al. [12] all numbers were used, since four of the numbers in Polish are monosyllabic and six of them are two-syllable. Moreover, it was stated that the inclusion of three-syllable numbers in the test did not make a significant difference in their study on intelligibility [22]. Monosyllabic and bi-syllable numbers in the Turkish language show homogeneous distribution. It is thought that the use of monosyllable and bisyllable numbers in the Number in Noise test we developed does not create a disadvantag. Therefore, all digits in the Turkish language are used.

Conclusions

T-DIN can distinguish participants with normal hearing from participants with bilateral mild mixed hearing loss and sensorineural hearing loss. An easy and accessible Turkish Digit in Noise mobile application has been developed using which one can assess his/her hearing.

In future studies, it is recommended to apply the application and to expand the findings in different types and degrees of hearing loss, especially in S/N type hearing loss.

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Authors' contributions
UCC made contribution in the data collection and design of the manuscript. OK made contribution in the interpretation of data. UCC and OK made contribution in data analysis. All authors read and gave approval to the final version of the submitted manuscript.

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This study did not receive any funds.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Istanbul Aydin University Non-Interventional Clinical Research Ethics Committee (registration number 2019/148) on July 18th, 2019. Informed written consent to participate in the study was provided by all participants.

Consent for publication
Written consent for publication was obtained from the patients participating in the study after informing them about the purpose of the study.

Competing interests
The authors declare that they have no competing interests.

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