Performance and reliability of a smartphone digits-in-noise test in the sound field

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ABSTRACT

Purpose: This study compared the speech reception thresholds (SRTs) and test-retest reliability of the smartphone digits-in-noise (DIN) test coupled to various sound field transducers.

Method: Fifty normal hearing participants (bilateral pure tone thresholds 0.5 – 8kHz ≤ 15dB HL) between the ages of 18 to 25 years (mean 20; SD ±1.93) were recruited. The study used a- repeated measure counterbalanced Latin square design to compare the SRTs of the smartphone DIN test recorded with earphones, two smartphone speakers and two external loudspeakers in a sound booth. Test-retest reliability across sound field conditions was also determined.

Results: Mean SRTs across earphone and different sound field transducers ranged from -11.3 (0.8 SD) to -11.7 (1.2 SD). SRTs across the four different loudspeaker transducers and earphones were not significant ($p > 0.05$) for both the initial test and retest.

Conclusion: The smartphone DIN test is reliable and can be conducted using various sound field transducers. This could allow home-based testing without earphones, with special application to aided performance for speech-in-noise testing.

INTRODUCTION

Hearing impairment is the fourth leading cause of disabling conditions globally (WHO, 2018). Approximately 466 million individuals live with disabling hearing loss where the majority of these individuals reside in low and middle-income countries (WHO, 2018). It is expected that the number of people with disabling hearing loss will increase with annual population-growth due to increasing life expectancy and dropping mortality rates (WHO, 2018). This increasing incidence has raised global awareness to reduce disabilities and handicaps such as hearing impairments.

Approximately 50% of hearing impairments could be prevented, and the remainder treated effectively (WHO, 2014; WHO, 2018). However, the prevention and treatment of permanent disabling hearing loss in low and middle-income countries are not prioritized in public health systems (WHO 2014). Typically, other health problems are favoured above hearing loss due to a lack of resources, such as trained health personnel and educational facilities (WHO, 2014; Wilson, Tucci, Merson & O'Donoghue, 2017). The inability to prevent or treat a hearing loss gives rise to societal and psychological consequences (Davis et al., 2016), due to communication exclusion resulting in increased feelings of loneliness, isolation and frustration (WHO, 2018; Davis et al., 2016). This may lead to depression and anxiety which all contributes to a reduced quality of life (Davis et al., 2016).

One of the most significant consequences and greatest handicap associated with a permanent disabling hearing loss is difficulty understanding speech-in-noise (Kramer, Kapteyn & Festen, 1998; Smits, Kapteyn & Houtgast, 2004). Tests to assess speech-in-noise recognition are valuable indicators of real-life communication difficulties as opposed to pure tone and speech audiometry in quiet (Taylor, 2003). A rapidly conducted speech-in-noise test using a closed response set of randomised digit triplets was developed by Smits et al. (2004). It measures an individual's ability to understand speech in the presence of background noise by varying the ratio between speech and noise levels (i.e. signal to noise ratio; SNR) (Smits et al., 2004; Smits et al., 2006; Rashid, Leense, de Laat & Dreschler, 2017). This self-administered screening test was developed to improve detection rates of underdiagnosed and untreated hearing loss globally (Smits et al., 2006; Potgieter, Swanepoel, Myburgh, Hopper & Smits, 2016). A telephone-based DIN screening test was successfully implemented in many high-income countries and access to such a test could provide an affordable option in low- and middle-income countries (LMICs) (Jansen, Luts, Wagener, Frachet & Wouters, 2010; Watson, Kidd, Miller, Smits & Humes, 2012; Potgieter, Swanepoel, Myburgh & Smits, 2017).

Unfortunately, in LMICs, landline telephones are usually unavailable. For example, in South Africa, less than 10% of households have access to landline telephones compared to an estimated 80% of households with access to smartphones (Statistics South Africa, 2013; Ericsson, 2015). The mobile revolution, in contrast, has seen cellular phones become part of everyday life in LMICs but the poorer audio call quality makes this inappropriate for a telephone test (Smits et al., 2004). Therefore, an alternative set-up is to use a smartphone application. Health surveillance utilizing smartphones has taken a significant foothold with estimates of 1.7 billion downloads by 2017 and global revenues of $21.5 billion in 2018 (Economist, 2016). As a result, a smartphone-based application that allows for widespread access to hearing screening in rural and urban areas and across different socio-economic strata was recently developed and validated (Potgieter et al., 2016; Potgieter et al., 2017). This test was released and marketed as South Africa’s national hearing test allowing for an accessible hearing screening solution (De Sousa, Swanepoel, Moore & Smits, In Press).

Since smartphones can be coupled with different headphones, the influence of several types and quality of headphones was investigated (Potgieter et al., 2016). The test was found to be reliable across devices and different earphone and headphones without significant differences in results (Potgieter et al., 2016). The recommended procedure for a DIN test is coupling with earphones or headphones since an earlier study indicated that the SRTs recorded with headphones were better compared to loudspeakers (Smits et al., 2006). This difference was assumed to arise from poor listening conditions when using loudspeakers and the attentiveness of the listener when using headphones (Smits et al., 2006).

Listening to an auditory signal through the sound field differs from listening through earphones where a subject is more isolated from the surroundings, with more control on the distance to the acoustic signal (Kallinen & Ravaja, 2007). In sound field conditions, the interaction between the test stimuli, room acoustics and psychoacoustic perception in the listener becomes critical (Rochlin, 1993). Sound field testing is often used to evaluate the need and the degree of the benefit of hearing aids and to assess speech discrimination testing in noise (Rochlin, 1993).

Accurate and reliable DIN testing in the sound field using a smartphone may be important for national screening programmes and home-based test applications. For example, in LMICs, earphones or headphones may not be readily available to all those who own a smartphone as these countries are characterised with high unemployment rates and poor economic circumstances (Agarwal, 2017). Therefore, the alternative method of performing the smartphone DIN test would be the smartphone speaker itself. Also, although mobile phones are responsible for over half of the web traffic globally (52.2%); it is also largely accessed through laptops and tablets (Statista, 2018). Furthermore, most electronic equipment, such as smartphones, laptops, and tablets, have built-in speakers or can easily be coupled wired or wireless to external speakers (Leesen & Drechsler, 2013). Therefore, the speakers of these devices are another avenue through which the test could be performed.

Individuals such as children, who have tactile sensitivity issues or those with structural abnormalities such as atresia, barring placement of earphones, would also benefit from access to sound field test paradigms. Speech-in-noise tests are essential objective measures to maximise the validity and reliability of a listener’s speech understanding with hearing aids or cochlear implants (Mendel, 2009). In clinical monitoring, newly implanted cochlear implant users require appointments to a centre between eight to ten visits a year with assessment of their speech recognition abilities nearly six times in the first three to six months post-implantation (Hughes, Goehring, Buadhuin, Diaz, Sanford, Harpster & Valente, 2012; de Graaff, Huysmans, Merkus, Goverts & Smits, 2018). Transportation to these centres can be financially and resource intensive, especially in LMICs, keeping patients from these visits. The DIN test in the sound field would, therefore, be convenient as a home-based clinical measure for hearing device performance over time. Furthermore, performing the smartphone DIN test through the sound field in tele-audiology models for screening and rehabilitation purposes would be beneficial to access underserved populations where hearing health care services are lacking in availability (Swanepoel et al., 2010).

The smartphone application of the DIN test has not been assessed in sound field conditions for accuracy and reliability. The aim of this study, therefore, was to evaluate the performance and reliability of the smartphone DIN application across various sound field transducers.

MATERIALS AND METHOD

Institutional review board approval was obtained prior to data collection which took place across two test sessions, ranging five to ten days apart. The first test session compared the smartphone DIN across a variety of loudspeakers compared to the coupling with the earphone condition. The second test session assessed the test-retest reliability of the earphone condition and the various sound field transducers.

Participants

A convenience sample of fifty participants (both male and female) aged 18 to 25 years were recruited for this study. Participants had pure tone thresholds <15 dB HL across 250 Hz to 8000Hz bilaterally and were otologically normal as assessed by the ISO 389-1 checklist for otologically normal hearing. Furthermore, participants were English home-language speakers, or, had good English proficiency. Participants rated their English competence on a scale of 1 to 10 (Potgieter et al., 2017). Only those with a rating of 7 or higher were considered to have good proficiency and were included in the study sample.

Equipment

Hearing screening equipment

Test equipment included the ISO 389-1 checklist for otologically normal hearing, otoscopy, tympanometry, hearing screening, and the smartphone DIN test. A Welch Allyn PocketScope Otoscope 22891 was used to examine the external auditory meatus bilaterally to detect any abnormalities in the ear canal. A GSI Tympstar, Grasen-Stadler using a 226Hz probe tone was used for tympanometry. The Tympstar was calibrated according to the SANS 10154-1/2 10182.

Hearing screening was conducted using the Grason-Stadler GSI 61 clinical audiometer calibrated according to the SANS 10154-1/2 10182 standards utilizing the Telephonics TDH-50P audiometric earphones.

Smartphone DIN test

The smartphone DIN research application (Android OS) using South African English digits (Potgieter et al., 2016; Potgieter et al., 2017) was performed with a binaural diotic (in-phase) stimulus paradigm. The application contains 120 unique digit triplets (e.g., 4-7-2) consisting of English mono- and bi-syllabic digits from 0-9 (Potgieter et al., 2016). This test involves listening and identifying digit-triplets randomly presented from the list of 120 triplets in the presence of broadband speech-shaped noise (Potgieter et al., 2016; Potgieter et al., 2017). The smartphone DIN test measures the signal-to-noise (SNR) ratio at which an individual identifies 50% of the digits correctly in the presence of changing levels of masking noise (Potgieter et al., 2016; Potgieter et al., 2017). The test used an up and down adaptive procedure, going down in 4 dB steps for the first three responses when triplets were entered correctly, thereafter, continuing in 2 dB steps. Each test uses 23-digit triplets and averages the last 19 responses to determine the SRT in dB SNR.

The smartphone DIN test was presented in five different conditions, varying between high- and low-end smartphones and loudspeakers. These included the 1) Samsung Fame Lite smartphone earphones coupled to the Samsung S4 smartphone and the smartphone speakers of the 2) Samsung J2 and, 3) Samsung S4 smartphones. The loudspeakers comprised of the 4) Philips Docking Entertainment System BTM630 and 5) Jam Classic wireless Bluetooth speaker.

Procedure

Data was collected at the Department of Speech-Language Pathology and Audiology, University of Pretoria, in a sound booth. All participants underwent hearing screening to establish normal hearing thresholds (<15 dB HL). Thereafter, participants completed the ISO 389-1 checklist to determine otologically normal criteria. After all inclusionary criteria were met, participants completed the DIN test in five test setups. Participants performed the smartphone DIN with earphones, two smartphone speakers and two external loudspeakers after which the SNRs of the DIN tests were compared across test conditions. Participants were seated one meter away from the external loudspeakers in the booth facing the loudspeaker. The participant held the smartphone speakers at eye and ear level in front of them (Figure 1). The tests were

Figure 1. Position of participant and smartphone during testing with smartphone speaker

counterbalanced using a Latin square to control the variation of the five listening conditions and avoid first-order carryover effects.

The second test session took place between five to ten days after the first test session. It involved retesting the smartphone DIN test through the sound field with three of the five conditions to avoid fatigue of the participant. The Samsung Fame Lite earphones were retested on all participants whereas only one of the smartphone speakers and one of the external loudspeakers were retested per participant.

Data analysis

Data was retrieved from the research Android OS application and was coded into MS Excel 2013 and analysed using Statistical Package of the Social Science (SPSS v25.0; Armonk, New York). Descriptive statistical measures were used to analyse the average SRT and standard deviations of all conditions in the test and retest phase of the study. The different values were normally distributed as assessed by Shapiro Wilk's normality test ($p > 0.05$). Therefore, a parametric analysis was used to analyse data. Repeated measures analysis of variances (ANOVA) was conducted to compare the effect of loudspeakers on the SRT. All pairwise comparisons run reported 95% confidence intervals, and p-values were Bonferroni-adjusted. A paired sample t-test was used to determine whether there was a statistically significant mean difference between the SNR's in the initial test compared to the retest ($p < 0.05$).

RESULTS

A total of 50 adults were included in the study with a mean age of 20 years (±1.93 SD; Range 18 to 24 years). English first-language distribution was 58% and 42% Afrikaans first-language with good English-speaking competence.

Mean SRTs across the earphone, and four different loudspeaker transducers (Table 1), ranged from -11.3 dB SNR (0.8 SD) to -11.7 dB SNR (1.2 SD). A repeated measures ANOVA comparing the SRTs across the earphone and four-different loudspeakers demonstrated no significant difference between conditions (F [4, 196] = 1.902, $p > 0.05$).

SRTs were not statistically significant ($p > 0.05$) across all test retest transducer conditions. Mean test-retest differences ranged from -0.1 (1.0 SD) to 0.2 (1.4 SD) (Table 2).

Table 1. Speech Reception Thresholds across transducer types for the initial test and retest conditions.

Condition	**n**	**Mean**	**SD**	**Minimum**	**Maximum**
Initial test					
Earphones	50	-11.4	0.8	-13.2	-9.8
Smartphone Speaker (HE)	50	-11.3	1.2	-14.0	-8.2
Smartphone Speaker (LE)	50	-11.7	1.0	-14.0	-10
Loudspeaker (HE)	50	-11.3	1.0	-14.2	-9.4
Loudspeaker (LE)	50	-11.5	0.8	-13.4	-9.8
Retest					
Earphones	50	-11.3	1.0	-13.6	-9.0
Smartphone Speaker (HE)	24	-11.3	1.3	-13.4	-8.6
Smartphone Speaker (LE)	26	-11.5	1.4	-15.6	-9.6
Loudspeaker (HE)	25	-11.2	0.7	-13.0	-10.4
Loudspeaker (LE)	25	-11.5	0.8	-13.0	-10.0

HE = Higher end device; LE = Lower end device; Earphones = Samsung Fame Lite earphones; Smartphone speaker (HE) = Samsung S4; Smartphone Speaker (LE) = Samsung J2; Loudspeaker (HE) = Philips Docking Entertainment System BTM630 Bluetooth USB and SD card slots; Loudspeaker (LE) = Jam Classic wireless Bluetooth speaker; n = Number of participants; SD = Standard Deviation

Table 2. Test-retest difference between the SNR means, SD, minimum, and maximum of the earphone and four speaker types.

Conditions	n	Mean	SD	Min	Max
Earphones	50	-0.1	1.2	0.1	0.8
Smartphone Speaker (HE)	24	0.2	1.2	0.6	0.4
Smartphone Speaker (LE)	26	-0.1	1.4	1.2	0.4
Loudspeaker (HE)	25	0.2	1.0	1.2	1.0
Loudspeaker (LE)	25	0.1	1.0	0.4	0.2

Earphones = Samsung Fame Lite earphones; Smartphone speaker (HE) = Samsung S4 speaker; Smartphone speaker (LE) = Samsung J2 speaker; Loudspeaker (HE) = Philips Docking Entertainment System BTM630 Bluetooth USB and SD card slots; Loudspeaker (LE) = Jam Classic wireless Bluetooth speaker; SD = Standard deviation; n = Number of participants

DISCUSSION

To confirm accurate SRTs with the smartphone DIN test, various types of sound field transducers would have to agree across test conditions and have agreement between test and retest (Margolis et al., 2007). Mean SRTs across loudspeakers when compared to earphones was not significantly different and no significant differences across test-retest comparisons were found ($p > 0.05$). Therefore, the smartphone DIN application can be administered using smartphone speakers and external loudspeakers in a low reverberated room with the same accuracy and reliability as in the earphone conditions. These results agree with a study conducted on an online DIN test, namely *Earcheck*, where different transducer types did not show a main effect on the results (Leesen & Dreschler, 2013).

In contrast, Smits et al. (2006) found a significant difference in SRT score of 1.1 dB between headphones compared to loudspeakers using the Dutch National Hearing Test. In the current study, there was no significant improvement in average SRT for the earphone condition (0.1 dB SNR). A probable reason for the Smits et al. (2006) result was that the sound field testing was not conducted in a sound booth but rather in a home environment (Smits et al., 2006). Therefore, possible ambient noise and reverberation in the environment, as well as distractions of the listener could have interfered with the results (Culling et al., 2005; Smits et al., 2006). Furthermore, the smartphone DIN test utilised broadband quality signals which range from 30Hz to 20 000Hz compared to the restricted bandwidth used with the Dutch National Hearing test (Smits et al., 2004; Potgieter et al., 2016; Potgieter et al., 2017). Previous studies on other speech-in-noise tests yielded results that differ in a home environment when compared to a controlled environment ranging on average from 1 dB to 1.45 dB poorer when compared to the SRT's obtained in a controlled environment (Culling et al., 2005; Leesen & Dreschler, 2013).

The average SRT across the loudspeakers in the current study (-11.5 dB SNR) was approximately 0.9 dB SNR better than the average mean of the normative diotic smartphone DIN test (-10.6 dB SNR) using earphones in normal hearing individuals (Potgieter et al., 2016). This difference may result from the adaptive procedure that was utilised in the current study where the first three digit-triplets, if identified correctly, used a 4 dB step size as opposed to a 2 dB step size by Potgieter et al. (2016).

Furthermore, the reliability of the test was derived from the mean differences between the SRTs in the initial test and retest, which ranged from -0.1 dB (1.0 SD) to 0.2 dB (1.4 SD) across all four speakers. The average retest SRT for earphones was small (0.1 dB SNR) compared to the smartphone speakers and external loudspeakers. Furthermore, no significant difference was noted in the test and re-test measures, taken on different days, of the DIN test ($p > 0.05$). This indicates that the DIN test can be performed reliably with various types of sound field transducers.

One limitation of the current study is that it was conducted in a controlled environment in a sound booth. The use of the application for screening and rehabilitation purposes, however, would typically be administered in a home environment which is not controlled. Earlier studies have suggested that the results of speech-in-noise tests presented through the sound field will be affected by the environment (Culling et al., 2005; Smits et al., 2006; Leesen & Dreschler, 2013). Furthermore, poorer speech recognition results were obtained via the sound field in home environments compared to a sound booth for CI users due to the prominent factors of background noise and room reverberation (Goehring et al., 2012; Hughes et al., 2012). In contrary, de Graaff et al. (2018) demonstrated that self-assessed speech recognition in noise tests in a home environment had no significant effect on results, suggesting that self-administered tests at home could be reliable. Thus, for the smartphone DIN test to be a useful home-based clinical tool, it should be tested in various home environments in a future investigation.

The current study indicates that the smartphone DIN test can be used in the sound field for screening and rehabilitation purposes such as monitoring amplification devices in clinics that have access to a sound booth. However, the problem of room noise can be overcome by properly instructing listeners on appropriate test environments. Therefore, based on these results, it is expected that the smartphone DIN test performed in the sound field could be a promising tool for home-based assessments.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest to disclose.

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