The South African English Smartphone Digits-in-noise Hearing Test: Effect of Age, Hearing Loss and Speaking Competence

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The University of Pretoria has assigned the IP of the hearZA digits-in-noise smartphone test for commercialization. The second and third authors are involved in the commercialization process.

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ABSTRACT

Objective: This study determined the effect of hearing loss and English speaking competency on the South African English digits-in-noise hearing test to evaluate its suitability for use across native (N) and non-native (NN) speakers.

Design: A prospective cross-sectional cohort study of N and NN English adults with and without sensorineural hearing loss compared pure-tone air conduction thresholds to the speech reception threshold (SRT) recorded with the smartphone digits-in-noise hearing test. A rating scale was used for NN English listeners' self-reported competence in speaking English. This study consisted of 454 adult listeners (164 male, 290 female; range 16 – 90 years), of which 337 listeners had a best ear 4 frequency pure-tone average (4FPTA; 0.5, 1, 2 and 4 kHz) of ≤25 dB HL.

Results: A linear regression model identified three predictors of the digits-in-noise SRT namely 4FPTA, age and self-reported English speaking competence. The NN group with poor self-reported English speaking competence (≤5/10) performed significantly ($p<0.01$) poorer than the N & NN (≥6/10) group on the digits-in-noise test. Screening characteristics of the test improved with separate cut-off values depending on English speaking competence for the N & NN (≥6/10) group and NN (≤5/10) group. Logistic regression models, that include age in the analysis, showed a further improvement in sensitivity and specificity for both groups (AUROC .962 and .903 respectively).

Conclusions: Self-reported English speaking competence had a significant influence on the SRT obtained with the smartphone digits-in-noise test. A logistic regression approach considering SRT, self-reported English speaking competence and age as predictors of best ear 4FPTA >25 dB HL showed that the test can be used as an accurate hearing screening tool for N and NN English speakers. The smartphone digits-in-noise test therefore allows testing in a multilingual population familiar with English digits using dynamic cut-off values that can be chosen according to self-reported English speaking competence and age.

INTRODUCTION

An important part of maintaining health and wellbeing for older adults is to screen for and treat hearing loss (Bushman et al. 2012). Nevertheless adult hearing screening programs are very scarce. Hearing screening tests will become increasingly important as the adult population is continuously growing and life expectancy escalates. It is expected that the world's adult population aged 60 years and older will almost double from 12% to 22% by 2050 (World Health Organization [WHO] 2015). The incidence of hearing loss increases as the adult population ages with approximately one-third of adults aged 65 years and older affected by a disabling hearing loss (WHO 2013). The latest Global Burden of Disease study (GBD 2016) indicates that 1.33 billion people suffer from hearing loss making it the 2nd most common impairment evaluated. Unfortunately, only about 20% of adults with hearing loss seek help (Smits et al. 2006; Davis et al. 2007).

An untreated hearing loss negatively impacts communication abilities and cognitive, physical and psychological functioning and general quality-of-life (Nachtegaal et al. 2009; Lin 2011; Davis et al. 2016). Communication difficulties related to hearing loss can lead to poor social engagement resulting in restricted socialization, impaired relationships with friends and family with loneliness as a consequence, especially in the elderly (Davis et al. 2016). Persons with hearing loss demonstrate greater cognitive decline that may be associated with an increased risk of dementia (Lin 2011, Lin & Ferrucci 2012; Davis et al. 2016). Hearing loss is also related to physical impairment in older adults with an increased likelihood to fall due to impaired auditory and vestibular cues that limit environmental awareness, attention and postural control (Lin & Ferrucci 2012). The communication, physical and cognitive effects of hearing loss have also been linked to psychological impairments and feelings of depression, anxiety, frustration and fatigue resulting in poor quality-of-life (Davis et al. 2007). The physical impairments associated with a hearing loss can furthermore cause an added financial burden on the elderly due to increased health care costs (Simpson et al. 2016).

Early hearing loss intervention and counseling are important services that may prevent or forestall cognitive decline, dementia, the negative psychological and physical effects associated with hearing loss and save future health related costs (Simpson et al. 2016). Hearing screening programs are important for early detection of hearing loss to maximize hearing rehabilitation and quality-of-life outcomes. Various hearing screening tests exist of which standard hearing screening options usually include self-administered questionnaires and pure-tone audiometry. Self-administered questionnaires are an affordable method to detect hearing loss and could be utilized by any health care professional (Swanepoel et al. 2013). In recent years more accessible hearing screening methods have been developed that individuals can access directly without a health care professional. Many countries which include the Netherlands, United States of America, Australia, Germany, Poland, Switzerland and France now offer landline telephone hearing screening tests based on the recognition of digits in noise. These self-administered tests measure the signal-to-noise ratio (SNR) where a listener recognizes 50% of the digit triplets correctly (i.e., the speech reception threshold, SRT) (Jansen et al. 2010; Smits et al. 2004; Zokoll et al. 2012; Watson et al. 2012). These digits-in-noise hearing screening tests are fully automated which makes the tests appealing because they can be self-administered. The tests are also quick to administer and can be completed in only a few minutes. Furthermore, the digits-in-noise hearing screening tests mimic everyday speech-in-noise environments and are sensitive to detect hearing loss (Jansen et al. 2010; Smits et al. 2004; Zokoll et al. 2012; Smits et al. 2013, Williams-Sanchez et al. 2014).

In countries like South Africa, where landline telephone penetration is less than 13% of households (Statistics South Africa [STATSSA] 2013) a digits-in-noise hearing test over the landline telephone is inadequate to reach the general population. To provide access to ear and hearing health care services an alternative platform was considered. A smartphone-based digits-in-noise hearing test for end-users was developed and validated in South African English (Potgieter et al. 2016). The test can be downloaded in South Africa (www.hearZA.co.za) as an application and on a smartphone or other iOS or Android device. Low-cost smartphone penetration is approaching 80% of households, making widespread access to the test possible for people living in rural and urban areas (Potgieter et al. 2016; Ericsson Mobility Report 2015). The test enables users to conduct a self-test in the comfort of a home setting using the application downloaded to a smartphone. The smartphone-based digits-in-noise hearing test provided equivalent results across earphones and headphone types. Contrary to landline telephone hearing tests that are limited to the bandwidth of the telephone network (approximately 300 - 3400 Hz), the App-based smartphone test uses broadband digital quality signals (30 – 20,000 Hz) (Potgieter et al. 2016).

Employing an English-based smartphone digits-in-noise hearing test in South Africa presents its own challenge considering the multilingual population, with 11 official languages. Estimates indicate that only 9.6% of the population is native English speaking (STATSSA 2011). Non-native language listeners typically perform worse on standard speech-in-noise tests compared to native listeners (van Wijngaarden et al. 2002; Zokoll et al. 2013). The speech material may contain unfamiliar vocabulary and complex grammatical structures which influence non-native language listeners' performance on speech recognition tasks (van Wijngaarden et al. 2002; Zokoll et al. 2013). In addition to age of non-native language acquisition, amount of non-native language use and linguistic background, age itself may also influence speech recognition (Rogers et al. 2006; Rimikis et al. 2013).

An English-based digits-in-noise test has several advantages compared to speech-in-noise tests that are based on open set sentence or word recognition that makes this test more amenable for use in a multilingual setting. Firstly, digits-in-noise tests employ simple speech material with low linguistic demands. Secondly, the speech material is presented as a closed set (i.e., digits between 0 and 9). Thirdly, English digits are mostly familiar and often used by speakers of other languages (Branford & Claughton 2002). Finally, Kaandorp et al. (2016) have shown that normal-hearing non-native listeners only needed a 0.8 dB higher SNR than native listeners to recognize 50% of digit triplets correctly. These advantages provide the potential for an English-based smartphone digits-in-noise hearing screening test to be used as a national screening test in a multilingual country like South Africa.

The aim of this study was to evaluate the South African digits-in-noise hearing test's suitability for use as a hearing screening test. The study hypothesis posited that the digits-in-noise SRT would be poorer in non-native listeners with poor English speaking competence than in native listeners or non-native listener with good English speaking competence, but would be sufficiently accurate for screening purposes.

MATERIALS AND METHODS

Listeners

Three private hearing health care practices, three public hospital audiology units and the University clinic at the Department of Speech Language Pathology and Audiology, University of Pretoria were involved in data collection. A convenience non-probability sampling procedure was followed with participants at clinical data collection sites who were available and willing to participate in the research study. All listeners provided written informed consent to participate. The group of listeners comprised of participants who represented all 11 official languages in South Africa (Table 1). The 11 official languages in South Africa are English, Afrikaans, Northern

Sotho, Zulu, Sotho, Tswana, Xhosa, Tsonga, Swazi, Ndebele and Venda (STATSSA 2011). A total of 458 listeners (166 male, 292 female) participated in this study. Four listeners with a mixed hearing loss were excluded from all analyses, resulting in 454 adult listeners (164 male, 290 female). Eleven of the 454 listeners did not have an English speaking competence score. The 11 listeners were excluded in analyses where the English speaking competence scores were used. The mean age was 36 years (±22 years) with a range of 16 – 90 years (Table 1).

TABLE 1. Characteristics of subjects according to their native language, gender and age.

Native Language	Subjects (n)	Male (n)	Female (n)	Age Range (years)	Mean Age (years)	Standard Deviation
English	134	43	91	16 – 89	35	24
Afrikaans	109	40	69	16 - 90	49	24
Northern Sotho	60	23	37	16 - 79	34	19
Zulu	32	9	23	16 - 63	34	18
Sotho	25	15	10	16 - 67	33	17
Tswana	22	6	16	16 - 46	19	8
Xhosa	20	13	7	16 - 83	24	16
Tsonga	18	7	11	16 - 64	30	18
Swazi	10	5	5	16 - 25	18	3
Ndebele	9	1	8	19 - 59	29	16
Other	15	2	13	16 - 65	27	13

Material and Apparatus

Test procedures included otoscopy, diagnostic pure-tone air and bone conduction audiometry, the South African English smartphone-based digits-in-noise test and a self-administered English language competence questionnaire. An otoscopic evaluation was performed for observation of any obstruction in the external auditory meatus. Excessive cerumen was removed by a qualified audiologist or medical practitioner before testing commenced.

Procedures

At all test sites calibrated audiometers with supra-aural headphones or insert earphones were used to conduct standard audiometry. Bone conduction audiometry was additionally conducted on participants with average thresholds at 500, 1000, 2000 and 4000 Hz (4FPTA) of more than 25 dB HL. The modified Hughson-Westlake method was used to seek pure-tone air and bone conduction thresholds (Hughson & Westlake 1944). The hearing loss was categorised as conductive or mixed when the difference between the air and bone conduction 4FPTA was >15 dB in the best ear (Margolis & Saly 2007).

The digits-in-noise test was administered binaurally on Vodafone Kicka smartphones or a Samsung Trend smartphone. Intraconchal Vodafone earphones were used to present the stimuli from the Vodafone Kicka smartphones and a HD202II Sennheiser supra-aural headphone was used with the Samsung Trend smartphone. A study conducted by Potgieter et al. (2016) observed no difference between the digits-in-noise SRTs for these headphone types. The digits-in-noise hearing test consisted of 5 screens. The first screen opened to a quick tutorial screen which instructed the listener on how to use the application. The second screen allowed the listener to select his/her gender. The third screen asked the listener to select his/her date of birth. The fourth screen instructed the listener to place either earphones into the ears or supra-aural headphones on the ears. The listener was presented with digits being repeated. A scroll bar allowed the listener to adjust the volume to a comfortable level. On the final screen the listener entered his/her initials and surname. A “start test” button commenced the test.

The test material is selected from a list of 120 unique digit triplets stored in the application (Potgieter et al. 2016). In the application the sound files for the digits 0 to 9 were stored separately in OGG format (Potgieter et al. 2016). The bi-syllabic digits 0 and 7 were also used as speech tokens to minimize a possible learning effect (Smits et al. 2013; Smits 2016). When the test started, the digit triplets were assembled by concatenating the appropriate digits with silent intervals of 500ms at the beginning and end of each triplet. Subsequent digits were followed by 200ms silences with 100ms of uniform jitter between each digit to add some uncertainty in the listening task for when the next digit will be presented. The digit triplet files were mixed with broadband speech-shaped noise at the required SNR to form a stimulus. When triplets with negative SNRs were presented the test operated with a fixed noise level and a varying speech level. The speech level became fixed and the noise level varied when triplets with positive SNRs were presented. By following this test procedure, a nearly constant overall level of the stimuli was ensured (i.e., digit triplet mixed with the noise). The digits were pronounced by a female native speaker of South African English. When the test started, the first stimulus set was presented at the listener's self-chosen comfortable listening level. A pop-up keypad allowed the listener to enter the response. If the digit triplet was entered 100% correctly the next stimulus was presented at a 2 dB lower SNR than the previous digit triplet. When the digit triplet was entered incorrectly the next stimulus was presented at a 2 dB higher SNR than the previous digit triplet. Each test used 24 digit triplets to estimate the SNR corresponding to the 50% correct recognition probability (i.e., the speech reception threshold, SRT). All stimuli were presented binaurally. See Potgieter et al. (2016) for further details.

A non-standardized self-reported rating scale for English language competence was completed by each listener. A facilitator/translator was present to assist illiterate listeners or listeners with poor English language competence to complete the questionnaire. The questionnaire consisted of one simple question. The question asked the listeners to rate their English speaking competence in everyday communication. A simple scoring method was used in the form of a scale between 1 (not competent at all) and 10 (perfectly competent).

RESULTS

The sample of 454 listeners represented a range of self-reported English speaking competences across language groups and ages (Figure 1). For illustrative purposes, the listeners were categorized into three groups with approximately the same amount of listeners in each group (30% native English, 24% Afrikaans and 46% other languages). Figure 2 illustrates the effect of age on hearing loss for these three groups of listeners.

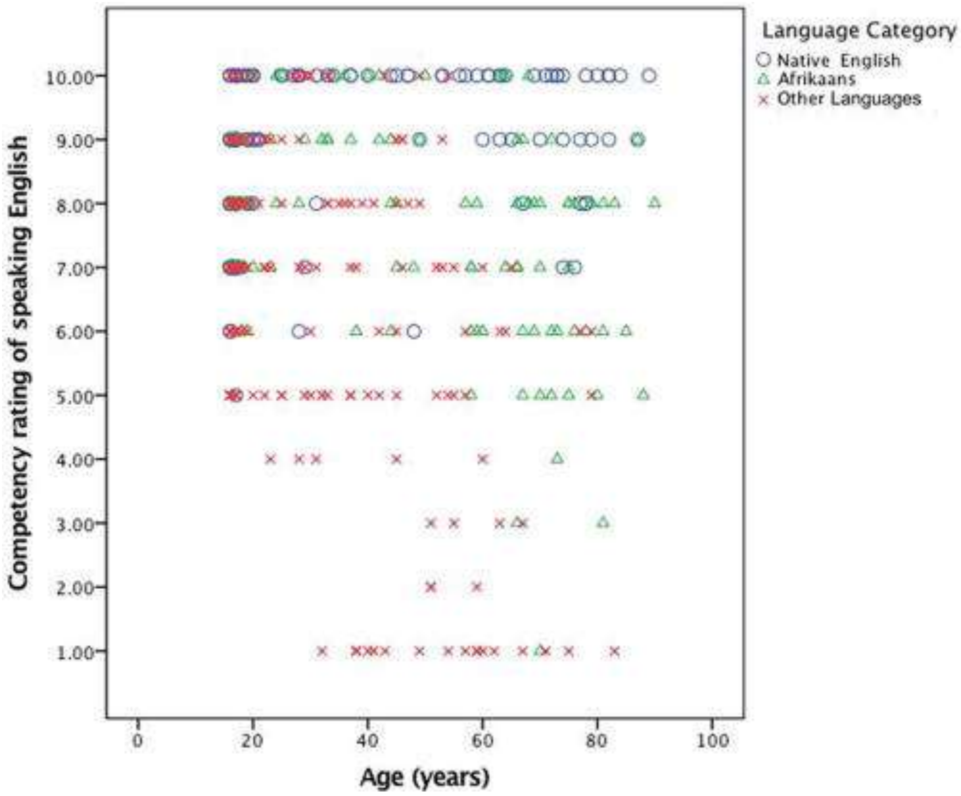

Figure 1. English speaking competence across age and language categories (native English, Afrikaans and all other languages).

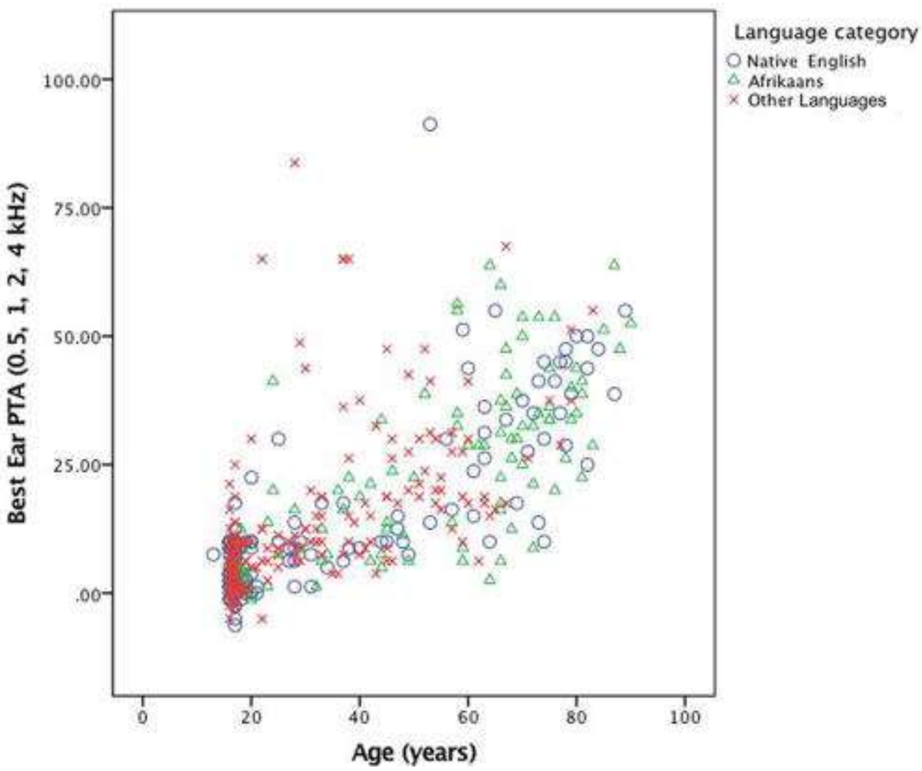

Figure 2. Best ear four-frequency pure-tone average (0.5, 1, 2, and 4 kHz) across age and language categories (native English, Afrikaans, and all other languages).

Predictive variables of the digits-in-noise SRT

Linear regression models were constructed for continuous variables (age and best ear 4FPTA) and categorical variables (gender, English speaking competence) to test whether these variables significantly predicted the digits-in-noise SRT. Final model selection was based on backward elimination of non-significant variables ($p>0.05$). The relative quality of the models was measured by the Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC). The AIC and BIC are measures used to assess model fit. These measures are based upon the likelihood function of the model, and can be used to compare the fit of non-tested models for the same dataset (Hox 2002). A linear regression model for normal-hearing listeners with best ear 4FPTA ≤25 dB HL indicated that English speaking competence (beta -0.210; 95%CI -0.287 to -0.134; $p<0.001$) and age (beta 0.042; 95%CI 0.033 to 0.051; $p<0.001$) were significant predictors of the digits-in-noise SRT for normal-hearing listeners. The linear regression model for listeners with best ear 4FPTA >25 dB HL indicated that English speaking competence (beta -0.294; 95%CI -0.553 to -0.036; $p<0.001$) was a significant predictor of the digits-in-noise SRT. Age (beta 0.018; 95%CI -0.028 to 0.064; $p=0.44$) (however) was not a significant predictor of the digits-in-noise SRT. Gender was not a significant predictor of the digits-in-noise SRT in both linear regression models.

English competence groups

Listeners were grouped based on the self-reported English speaking competence score to allow an even distribution of listeners in each group to determine comparisons in the analysis. The average SRT for normal-hearing (best ear 4FPTA ≤25 dB HL) N listeners was compared to the average SRT of normal-hearing NN listeners within each group of self-reported English speaking competence (scores 1 to 10) using t-tests (no multiple comparison corrections). Significant differences in SRTs were observed between N listeners and the 5 groups of NN listeners with English speaking competence scores ≤5 (all p-values <0.01). No significant differences in SRTs were observed between N listeners and the 5 groups of NN listeners with English speaking competence scores ≥6 (p-values between 0.116 and 0.589). As such NN listener groups were categorised into NN with English speaking competence scores of ≤5 and ≥6.

Next, a two-way ANCOVA was used to evaluate differences in the digits-in-noise SRT for groups of listeners with best ear 4FPTA ≤25 dB HL based on their English speaking competence rating. Age and best ear 4FPTA were selected as covariates. A significant difference was observed ($p<0.01$; $F(4)=154.91$; $R^2=0.579$) between the digits-in-noise SRT (corrected for age and best ear 4FPTA) for N listeners (adjusted mean -9.5 dB; SE: 0.17; 95%CI -9.8 to -9.2 dB), NN ≥6 (adjusted mean: -9.3 dB; SE: 0.13; 95% CI: -9.5 to -9.0 dB) and NN ≤5 (adjusted mean: -7.9 dB; SE: 0.24; 95% CI: -8.4 to -7.4 dB). Pairwise comparisons only demonstrated a significant difference (p<0.01; Bonferroni corrected) between the NN ≤5 and the two other groups. There was no significant difference between the N and NN ≥6 groups. Thus N and NN ≥6 were grouped (N & NN ≥6) and the NN ≤5 were kept as a separate group for further analyses.

The digits-in-noise SRT and best ear 4FPTA correlation was significant (p<0.01) for the N & NN ≥6 listeners group (0.763; Pearson correlation) and for the NN ≤5 listeners group (0.690; Pearson correlation), see Figure 3.

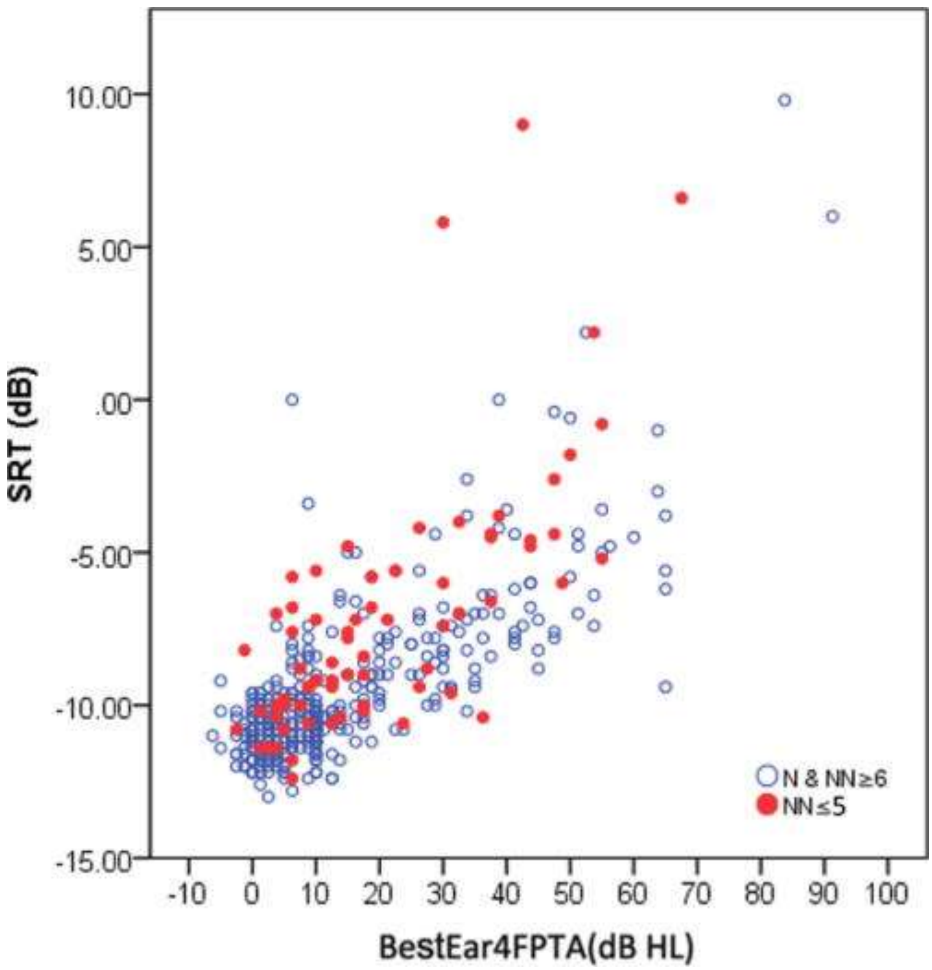

Figure 3. Smartphone digits-in-noise speech reception threshold correlation with best ear four-frequency pure-tone average (0.5, 1, 2, and 4 kHz) for N and NN >=6 group (r = 0.763) and NN <=5 group (r = 0.690). N, Native speakers; NN, non-native speakers.

Reference scores

Reference scores were determined from normal-hearing listeners (best ear 4FPTAs ≤25 dB HL). Table 2 shows the mean, range and standard deviation of the SRT for the whole group of listeners and for the N & NN ≥6 group and NN ≤5 group separately. The average normal-hearing SRT in the N & NN ≥6 group is approximately 1.7 dB better (lower) than in the NN ≤5 group.

TABLE 2. Demographics and performance summary for normal-hearing according to self-reported English speaking competence (best ear 4FPTA ≤25 dB HL) *N – Native speakers; NN – non-native speakers*

Description	All Lang	N&NN≥6*	NN≤5*
Subjects (n)	337	291	46
Mean Age (yrs)	27	26	36
Age Range(yrs)	16 to 81	16 to 81	16 to 67
StDev Age(yrs)	16	14	17
SRT Range (dB)	0.0 to -13.0	0.0 to -13.0	-4.8 to -12.4
Mean SRT(dB)	-10.2	-10.4	-8.7
StDev SRT(dB)	1.6	1.5	1.9

** "How competent are you in speaking English?" Rating scale (1 = no competence; 10 = perfect competence)*

Screening characteristics

To determine the screening characteristics of the test, logistic regression models were used to determine equations to discriminate between listeners with best ear 4FPTA ≤25 dB HL and best ear 4FPTA>25 dB HL. Logistic regression models were constructed for all listeners grouped together and for the subgroups N & NN ≥6 and NN ≤5 separately. The SRT was used as predictor and the additional value of using age as a predictor was determined (Table 3). Highest test accuracy was obtained by including age and SRT for both groups. In both groups, the addition of age as predictor increased the specificity of the test.

TABLE 3. Logistic regression models for N & NN ≥6 and NN ≤5 listeners.

	Predictors	Equation	AUROC	Cut-off value	Sensitivity	Specificity
All subjects	SRT	-	.925	SRT=-9.55 dB	.94	.77
N&NN≥6	SRT	-	.943	SRT=-9.55 dB	.95	.83
	SRT, age	p=1/[1+exp(-0.562 ·SRT-0.080·age)]	.962	p=0.149	.95	.87
NN≤5	SRT	-	.873	SRT=-7.50 dB	.84	.74
	SRT, age	p=1/[1+exp(-0.478 ·SRT-0.054·age)]	.903	p=0.263	.84	.77

Receiver operator characteristic curves (ROC) were determined from the results of the logistic regression analyses for N & NN ≥6 and NN ≤5 separately. The first set of ROC curves were based on the SRT of the listeners; the second set of ROC curves were based on the SRT and age of the listeners. The ROC curves were used to determine the area under the ROC curve (AUROC), the cut-off values and the sensitivity (proportion correctly identified listeners with a hearing loss among the listeners with a hearing loss) and specificity (proportion correctly identified listeners with normal-hearing among the listeners with normal-hearing) of the digits-in-noise test. Figure 4 shows the ROC curve based on all listeners as one group and Figure 5 shows the ROC curves for the subgroups with SRT as predictor and with SRT and age as predictors.

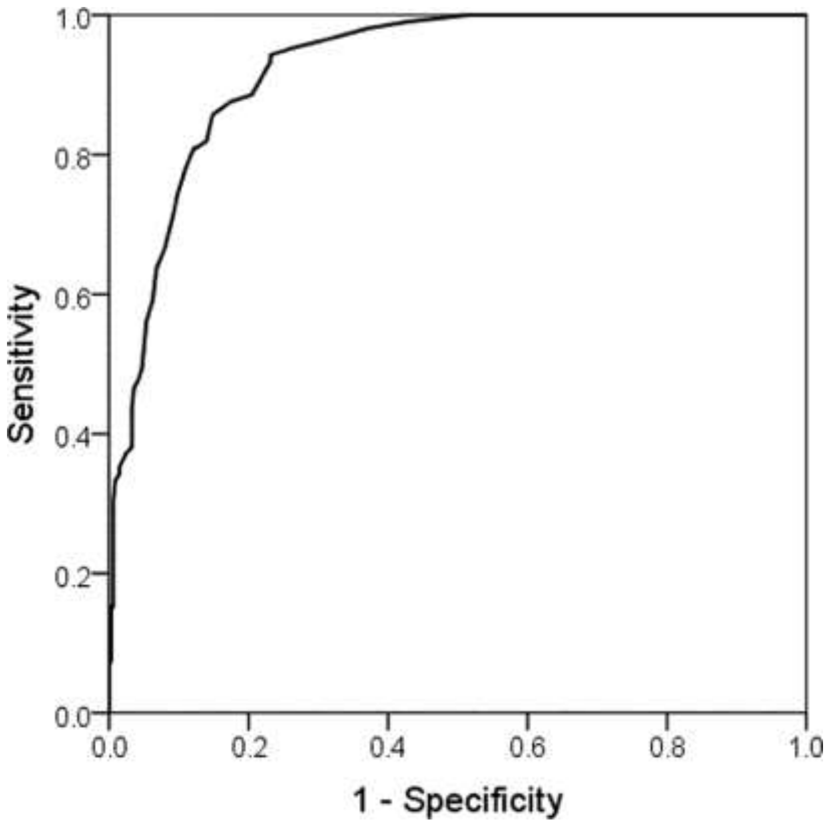

Figure 4. Receiver operating characteristic curve for all listeners with speech reception threshold as predictor.

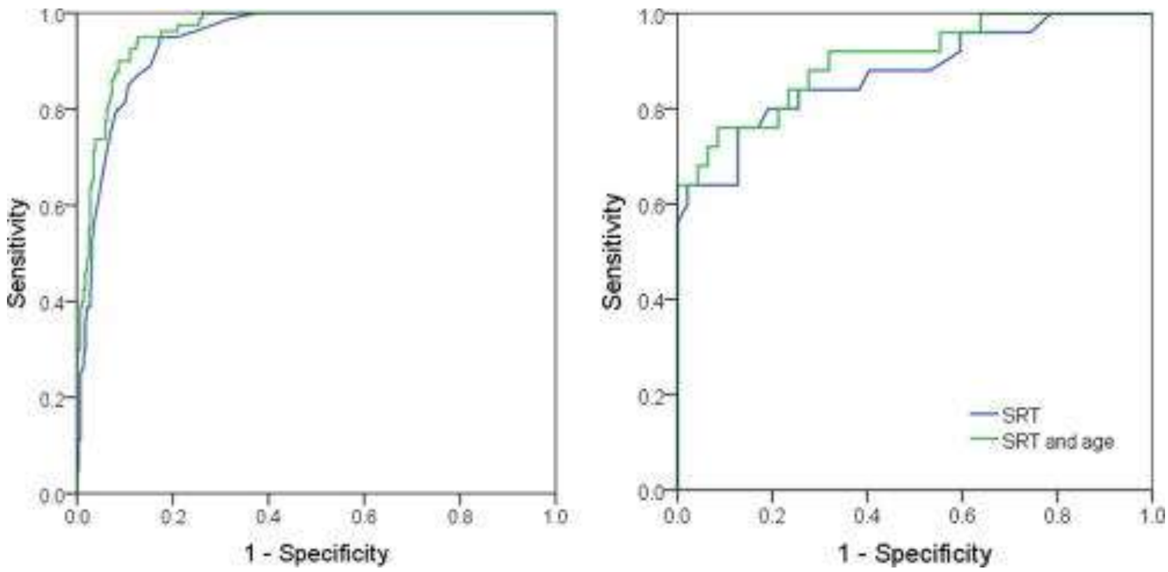

Figure 5. Receiver operating characteristic curves for N and NN >=6 group (left) and NN <=5 group (right). The improvements of test characteristics are illustrated by the shift of the curves to the upper left corner with the inclusion of age as a predictor. N, Native speakers; NN, non-native speakers.

DISCUSSION

The recently developed English smartphone digits-in-noise test (Potgieter et al. 2016) promises widespread access to hearing screening in a country like South Africa where smartphone penetration is approaching 80% of households (Ericsson Mobility Report 2015). Because of the multilingual population in South Africa, it is important to consider the effect of non-native listeners' performance on the digits-in-noise test. This study determined the performance of non-native English listeners on the South African English smartphone digits-in-noise hearing test, compared to native English listeners.

The smartphone digits-in-noise SRTs and the best ear 4FPTA were significantly correlated (r=0.76 for N & NN ≥6; r=0.69 for NN ≤5). The correlation for the N & NN ≥6 group agrees with previous results reported for the Dutch (r=0.72), French (r=0.77) and American-English (r=0.74) landline telephone digits-in-noise hearing screening tests (Smits et al. 2004; Jansen et al. 2010; Watson et al. 2012). The smartphone digits-in-noise test was conducted binaurally whilst the Dutch, French and American-English tests were ear specific. Another difference, compared to previous reports, is the inclusion of 70.4% non-native listeners (n=320) in this study. These findings indicate that comparable correlation between digits-in-noise SRTs and best ear 4FPTAs can be obtained in a sample where the majority of listeners are non-native English listeners with some degree of self-reported English speaking competency.

The results of the linear regression models indicated that English speaking competence is a significant predictor of the digits-in-noise SRT; age is only a significant predictor for listeners with best ear 4FPTA ≤25 dB HL. A contributing factors could be the difference in distribution of age and hearing loss between listeners with best ear 4FPTA ≤25 dB HL and listeners with a best ear 4FPTA>25 dB HL. Results also support findings by Moore et al. (2014) who indicated that age may possibly have an effect on the digits-in-noise SRT. They showed that a decline in cognitive functioning, associated with age, has an effect on the digits-in-noise SRT. Koole et al. (2016) indicated a low correlation between age and the digits-in-noise SRT after controlling for pure-tone thresholds. In light of the above, it is important to consider age when determining the result of the digits-in-noise test in normal-hearing listeners because it may contribute to the accuracy of the screening test outcome. Accuracy of the smartphone digits-in-noise test was evaluated by determining the AUROC, sensitivity and specificity of the test to discriminate between listeners with best ear 4FPTA >25 dB and those with best ear 4FPTA ≤25 dB, for native and non-native English listeners. Logistic regression models and ROC curve analysis demonstrate that subgroups based on English speaking competence and including age as predictor increases the AUROC, sensitivity and specificity of the test.

Test performance improved in the N & NN ≥6 group (AUROC=0.962) when self-reported English speaking competence and age were considered. The sensitivity (0.95) and specificity (0.87) for N & NN ≥6 English listeners (best ear 4FPTA >25 dB HL) compared well to the Dutch (0.91 and 0.93 respectively) and American-English (0.80 and 0.83 respectively) digits-in-noise tests (Smits et al. 2004; Watson et al. 2012). The sensitivity and specificity was poorer for the NN ≤5 group than for the N &

NN ≥6 group. Possible reasons for this finding might be the fact that the NN ≤5 group was more heterogeneous in English speaking competence; the group included a smaller number of listeners; and varying distributions of hearing loss degrees may have influenced the calculated test characteristics. Self-reported English speaking competence was a significant predictor of the digits-in-noise SRT. Results by Kaandorp et al. (2015) also indicated that non-native listeners did not perform as well as native Dutch listeners on the Dutch digits-in-noise test. Vocabulary size and educational level had a small effect (0.8 dB SNR increase) on the performance of non-native listeners on digits-in-noise recognition (Kaandorp et al. 2015). This small difference in the performance between native listeners and non-native listeners was measured to re-validate that digits-in-noise depend minimally on top-down processing (e.g., linguistic skills) (Smits et al. 2013).

ROC curve analysis was used to determine cut-off SNR values for “pass” (4FPTA ≤25 dB HL) and “refer” (4FPTA >25 dB HL) for hearing loss for native and non-native English listeners. The cut-off SNR value for “pass” or “refer” for hearing loss for N & NN ≥6 English was -9.55 dB and -7.50 dB for NN ≤5 English listeners. The higher cut-off SNR for NN ≤5 English listeners can be expected as the linear regression model demonstrates that English speaking competence has a negative effect on the digits-in-noise SRT, and the mean SRT for normal-hearing listeners is higher for the NN ≤5 group than for the N & NN ≥6 group (Table 2). The mean SRT of the normal-hearing N & NN ≥6 English listeners (-10.4 dB) is similar to the diotically measured average SRT for the Dutch and American-English digits-in-noise test (-10.0 and -11.2 dB SNR respectively) (Smits et al. 2016). This comparison indicates that the digits-in-noise test provides close comparisons across non-native listeners with good language proficiency (Smits et al. 2016).

The current study demonstrates that a smartphone application provides an opportunity to use the English digits-in-noise hearing test as a national test for South Africans. The fact that English digits are often used by speakers of other languages in South Africa (Branford & Claughton 2002) allows for the possibility to accommodate non-native listeners by adjusting reference scores based on a self-reported English speaking competence. More representative data from diverse language groups and English competence levels would be useful to improve the validity of the test as a nationally used screening tool. The smartphone application could be programmed to report the test results in a listener's native language to allow for correct interpretation of test results across non-native listeners. The result of this study also indicates that age could be included when determining the screening test result of the digits-in-noise SRT, thereby increasing the accuracy of the screening test in normal-hearing listeners. Providing these adjustments can ensure adequate test performance across native English and non-native English listeners. It is important to note that this study was limited to a small group (15.9%; 72/454 listeners) of non-native English listeners with poor self-reported English speaking competence (scores ≤5/10). Future studies should aim to expand data on this group of listeners.

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DECLARATION OF INTEREST

The University of Pretoria has assigned the IP of the hearZA digits-in-noise smartphone test for commercialization. The second and third authors are involved in the commercialization process.

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