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Toward Accessible Hearing Care: The Development of a Versatile Arabic Word-in-Noise Screening Tool: A Pilot Study

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Abstract: Speech-in-noise tests are used to assess the ability of the human auditory system to perceive speech in a noisy environment. Early diagnosis of hearing deficits helps health professionals to plan for the most appropriate management. However, hospitals and auditory clinics have a shortage of reliable Arabic versions of speech-in-noise tests. Additionally, access to specialized healthcare facilities is associated with socioeconomic status. Hence, individuals with compromised socioeconomic status do not have proper access to healthcare. Thus, In the current study, a mobile and cost-effective Arabic speech-in-noise test was developed and tested on 30 normal-hearing subjects, and their ability to perceive words-in-noise was evaluated. Moreover, a comparison between two different background noises was explored (multi-talker babble noise and white noise). The results revealed a significant difference in the thresholds between the two types of background noises. The percent-correct scores ranged from 100% to 54.17% for the white background noise and 91.57% to 50% for the multi-talker babble background noise. The proposed Arabic word-in-noise screening tool has the potential to be used effectively to screen for deteriorated speech perception abilities, particularly in low-resource settings.

Keywords: word in noise; speech in noise; hearing; healthcare accessibility; rural; out of clinic; hearing impairment; diagnostic tool; cost-effective; Arabic

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1. Introduction

With over 430 million cases worldwide, hearing loss is one of the most critical global health issues that must be addressed [1]. In addition, approximately 344 million sufferers of hearing loss (80% of total cases) reside in low- and middle-income countries, as reported by the World Health Organization [1]. Societies with low socioeconomic status and poor education often do not have the same access to specialized healthcare services as those with quality education and higher incomes [2], which in turn could significantly delay the diagnosis and treatment of hearing impairment. Moreover, hearing impairments have an indirect impact on the individual's social, occupational, educational, and psychological well-being [3–5]. For instance, people with hearing problems are highly susceptible to depression compared to people with normal hearing [6]. Despite the high prevalence of hearing impairments, deployment of diagnostic and therapeutic hearing healthcare is sparse [3]. It has been reported that the time gap between the initial onset of hearing impairment and the actual seeking for rehabilitation interventions for people with hearing problems is long, typically 10 years [7]. Thus, there is an emerging need to develop and validate accurate and highly sensitive hearing screening instruments and tests that are accessible with high fidelity, to help ensure the detection of hearing impairment at early stages to facilitate timely intervention.

Numerous hearing tests are currently deployed in hearing clinics to evaluate the integrity of the auditory system, assess hearing ability, and detect the degree of existing hearing loss. The pure-tone test, for example, is the most commonly used test in auditory clinics that determines the person's hearing ability by listening to tones at different frequencies. Another common clinical hearing test is the auditory brainstem responses test, in which the integrity of the neural pathway is investigated by measuring the electrophysiological responses to an acoustic stimulus delivered either monaurally or binaurally [8,9]. However, administering the most widely available hearing tests often requires costly audiometric booths to reduce the background noise [10]. Additionally, both of the aforementioned hearing tests lack important diagnostic features, such as the capability to identify the person's ability to comprehend complex stimuli as speech perception, which is a critical aspect of the patient's everyday life situations [11].

Perceiving speech with background noise can be challenging, even for people with normal hearing. Speech perception is not only the recognition of sound segments but also the ability of the listener to detect and interpret signals. Therefore, speech perception is defined as the act of labeling acoustic signals with appropriate linguistic symbols [12].

Several conditions are associated with speech perception difficulties, such as central auditory processing disorder (CAPD) [13]. Patients with CAPD face difficulties in comprehending spoken language in an environment with competing background noise. Children with CAPD frequently ask for repetitions, frequently saying "what?" or "huh?" [13]. Moreover, individuals with dyslexia may encounter difficulties in perceiving speech in noisy environments [14]. Furthermore, autism spectrum disorder is associated with speech perception difficulties and auditory processing deficits [15].

Speech perception tests are commonly used to screen for such disorders in various languages. Compared to standard hearing tests, speech-in-noise tests have advantages such as an inexpensive setup and the ability to efficiently administer the test outside the sound booth [16]. Clinically validated speech-in-noise tests vary based on the linguistics of the stimulus of interest, the specific type of background noise in which the speech is embedded, scoring methods, and the signal-to-noise ratio (SNR) presentation level [17].

One of the most common tests is the quick-speech-in-noise test (QuickSIN) [18]. The QuickSIN test estimates speech-in-noise performance by presenting short sentences with the presence of four-talker babbling in the background [18]. The test contains 12 lists that have six sentences in each list. The babble level increases in 5 dB increments while the sentences are presented at a fixed level. Another standard test is the Bamford Kowal-Bench speech-in-noise test (BKB-SIN). It contains 18 lists of sentences in the presence of a four-talker babbling noise in the background [19].

The Hearing in Noise Test for Children (HINT-C) is also used to diagnose speech perception conditions in children [20,21]. Finally, one of the most widely used tests in audiology clinics is the word-in-noise (WIN) test. The WIN test has the advantage of being relatively easier to administer and requires less working memory and linguistic context during the performance compared to the speech-in-noise test [22].

One of the few Arabic versions of the speech-in-noise tests is the Arabic matrix test. The Arabic matrix test generates sentences randomly from a matrix that are presented with and without background noise [23]. The Speech Perception of Words in Noise test is an Arabic WIN test in which words are presented at zero SNR in a cafeteria background noise [24]. Another example of an Arabic WIN test is the Pediatric Arabic Auditory Speech Test (PAAST), which was developed to investigate speech perception in children [25]. The main difference between the PAAST and the aforementioned Speech Perception of Words in Noise test is how the responses are collected. In the PAAST, children are asked to choose an image that corresponds to a presented word they heard [25].

Although speech-in-noise tests can provide a good assessment of speech perception inside hospitals and clinics, it is difficult to access specialized healthcare facilities for some individuals, communities, and countries, especially during pandemic and quarantine situations or even in rural areas. For that, several investigators have designed, developed, and validated computer-based applications for speech perception assessment outside the clinic to help with the early detection of hearing impairments. Outside clinic tests have the potential to alert individuals of possible hearing problems and a referral to secondary-level healthcare could confirm the level and type of the hearing impairment. For instance, computer-based or smartphone applications for audiological screening have shown reasonable efficiency [25–31].

For example, Hussein et al. [28] investigated the feasibility of implementing an existing mobile health application in a community-based setup to screen the hearing of young children. The study examined a mobile application, hearScreen^{TM}, which can be easily trained to be used by non-professional personnel such as school teachers, social workers, or nurses. The employment of the hearScreen^{TM} solution led to a referral rate of 24.9% in preschool children in a poor community. This study concluded that smartphone-based hearing screening could be a viable tool to detect unidentified hearing impairments with minimal training of non-professional individuals.

In addition, Bauer et al. [32] developed and validated an application named Ouviu that can be used pre-clinically to identify undetected hearing problems outside the clinical sound booth. The application conducts a hearing test that screens for 500, 1000, 2000, 5000, and 8000 Hz at low, medium, and high intensities. Results showed that Ouviu is capable of measuring environmental noise and outperformed the HearCheck screener equipment.

Alhussaini et al. [33] assessed auditory temporal resolution by utilizing an auditory gap-in-noise test. The authors compared the assessment of auditory temporal resolution in a controlled environment (inside a soundproof booth) versus assessing auditory temporal resolution in a normal room with an acceptable surrounding noise level (below 50 dB). The results showed that gap detection thresholds obtained outside the soundproof booth are reliable and comparable to the standard method currently used in a controlled clinical setting (inside a soundproof booth).

Furthermore, Govender and Mars [34] explored the outcomes of implementing asynchronous automated telehealth-based hearing screening and automated audiometric testing to detect or confirm hearing impairment in school-age children in rural South African schools. Their combined model showed a 100% specificity rate and a moderate sensitivity rate of around 65%, which they claim to be affected by randomization error and the susceptibility of children being easily distracted.

Note that hearing screenings, diagnostic examinations, and rehabilitation interventions in speech audiometry (speech-in-noise or word-in-noise) must always be implemented in a language that is native to the listeners [16,35]. Screening an individual's hearing with a language different than their native language often leads to poorer performance when compared to native listeners [22,35]. Hence, to our knowledge, there are currently no versatile Arabic versions of word-in-noise tests that can facilitate and sup-port the deployment of hearing screening programs that can be utilized in hard-to-reach environments.

Therefore, this study aims to develop an Arabic version of a word-in-noise hearing test that is cost-effective and has the potential to support its deployment in a low-resource setting and during community-based outreach programs. Furthermore, having such a hearing screening tool can reduce the burden on millions of people that have hidden hearing problems or do not have easy access to quality healthcare.

The current study presents the development of the proposed Arabic word-in-noise using an easy-to-use custom-made MATLAB (MathWorks, Natick, MA, USA) program. The main features that were considered during the design of the proposed Arabic word-in-noise screening tool are its ease of use with minimal training for generalist healthcare personnel, usability for Arabic-speaking communities, short testing time with reliable screening results, and the use of simple and common monosyllabic Arabic words that can be used to screen school-age children, young adults, and elderly persons. The words in the proposed Arabic hearing screening test in this study are implanted in various types of background noise to incorporate everyday life scenarios. In addition, the words were presented at different SNR levels to enhance the accuracy of identifying possible hearing impairments.

2. Materials and Methods

2.1. Participants

Thirty bilingual male participants with normal hearing volunteered in this study. All participants had acquired the Arabic language from birth and learned the English language during their formal education for at least five years. The screened participants were 18 to 33 years old, with a mean of 22.57 ± 2.42 SD years. All participants reported no history of neurological disorders, hearing loss, or hearing difficulties. Additionally, the screened participants confirmed that they had no history of cochlear and neural injuries or complaints of their cognitive functions. All participants had normal hearing as tested by pure tone audiometry through a smartphone application (uHear), which was validated for audiometry testing [29]. The uHear automated pure tone audiometry test was conducted via the same equipment across all participants (iPhone 11 and AirPods, Apple Inc., Cupertino, CA, USA). Participants were directed to follow the application instruction, and the tones were delivered at 500, 1000, 2000, 4000, and 6000 Octave Hz for the left and right ears. A consent form was required in the study for all the participants. The study was approved by the Institutional Review Board (I.R.B.) at the College of Applied Medical Sciences, King Saud University (K.S.U.) (I.R.B. Approval number: CAMS 029-3940).

2.2. Arabic Word Selection Process

To choose proper words to be used in this test, a total of 220 monosyllabic Arabic words were selected. The monosyllables were chosen based on their familiarity [11]. Seventy-five words of the total words (34%) were provided by the Department of Audiology at King Faisal Specialized Hospital and Research Center (KFSHRC), and the remaining 145 words were identified from school materials. The complete list of the Arabic words was then sent to two faculty members within K.S.U. to evaluate the words' complexity and familiarity with a four-point scale. The experts were asked to rate each word choice with "familiar and simple", "unfamiliar and complex", "familiar but complex", and "unfamiliar and complex". Next, words were ordered based on their familiarity and simplicity score. Eighty-four words that had the agreement of both evaluators for being familiar and simple were used as testing words in the current study (all of the words were in the KFHRC word list). Words that were evaluated by at least one of the evaluators as familiar and simple were used as choice words during the test after matching their homogeneity with testing words as far as possible. Finally, words that were rated as either unfamiliar and complex or familiar, but complex were excluded from the study.

2.3. Stimuli

The proposed test consists of monosyllabic Arabic words spoken by a male talker and recorded by audio software (Audacity Platform, Oak Park, MI, USA) via a commercially available microphone (Saramonic SR-ULM5, White Plains, NY, USA). Furthermore, 48 monosyllabic, phonetically balanced Arabic words were selected for test development. The Arabic words were randomly divided into six word lists (each with eight monosyllabic words). The words in the first three lists were embedded in white background noise (24 monosyllabic Arabic words), and the words in the remaining lists were embedded in multi-talker babble background noise (24 monosyllabic Arabic words).

Seven SNR conditions were presented for each word list in both noise types. The first word in each list was presented without background noise, and the remaining seven words were delivered with different SNR conditions. The SNR variations of the proposed Arabic word-in-noise screening test were +15, +10, +8, +6, +4, +2, and 0 dB (Figure 1). All the audio files, consisting of both the speech and background noise, have a duration of 8 s with a sampling frequency of 44,100 Hz.

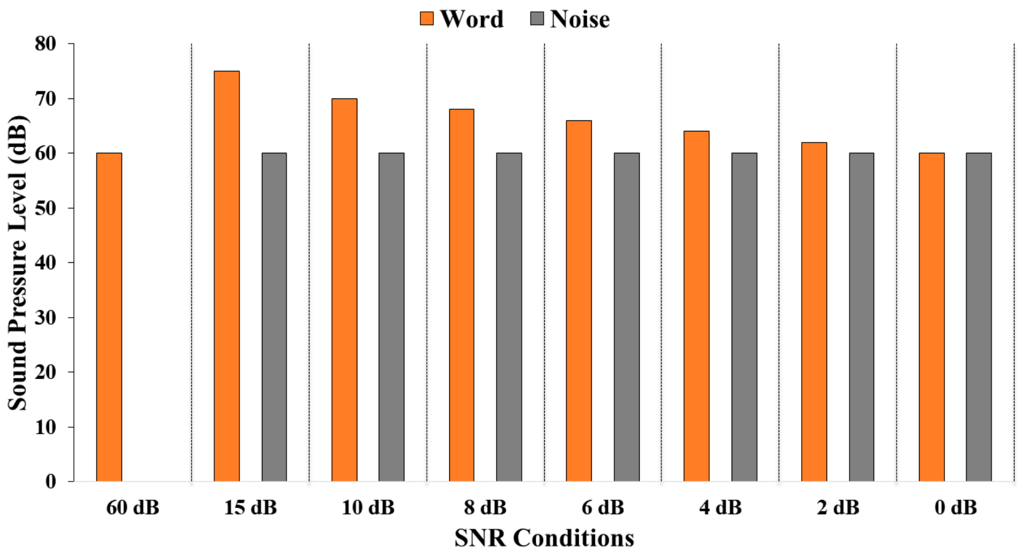

Figure 1. Illustration of the SNR conditions presented for both white noise and multitasker babble.

2.4. Experimental Procedure

Before starting each testing session, noise and speech level intensities were measured and calibrated using a digital sound level meter (Extech 407730, Waltham, MA, USA) to ensure that the ambient noise in the testing room (college research laboratory) was within an acceptable environment noise range (below 50 dB SPL) during testing, which is an important factor for such a mobile and outside of clinic hearing screening tool.

The testing procedure was administered with a headphone set (Sennheiser HD-280 pro, Wedemark, Germany), which was verified for audiometry testing [33,36]. Additionally, the output sound volume of the personal computer was measured and adjusted accordingly to ensure that the noise files used in this experiment were fixed at 60 dB using the digital sound meter before each session.

The flowchart of the proposed Arabic word-in-noise hearing assessment tool is shown in Figure 2. During each testing session, all participants were instructed to identify the presented Arabic words in both white noise lists (Word lists 1, 2, and 3) and multi-talker babble noise (Word lists 4, 5, and 6). Participants were instructed to listen carefully to the presented words. Moreover, the words in each list were delivered with a gradual decrease in the SNR for both the white and multi-talker babble noise (+15 to 0 dB), while the noise intensity was kept constant at 60 dB across all SNR conditions. Subjects were encouraged to guess the correct word from a multiple-choice list after each word. Participants were also able to select the last choice, "I do not know— لا أعلم" only if they did not perceive the word. In addition, the subjects would be excluded from the study if they failed to identify the first word in each word list, as they were presented without noise, and the session would be terminated. The order of the presented noise type in each session and the word lists was randomly assigned and counterbalanced across subjects to avoid an order effect.

The acquired responses were given a score of zero for wrong word identification and a score of one for correct word identification. In addition, an overall average score of three word lists was calculated for each noise type. The percent-correct word identification score was then computed and used for statistical analysis.

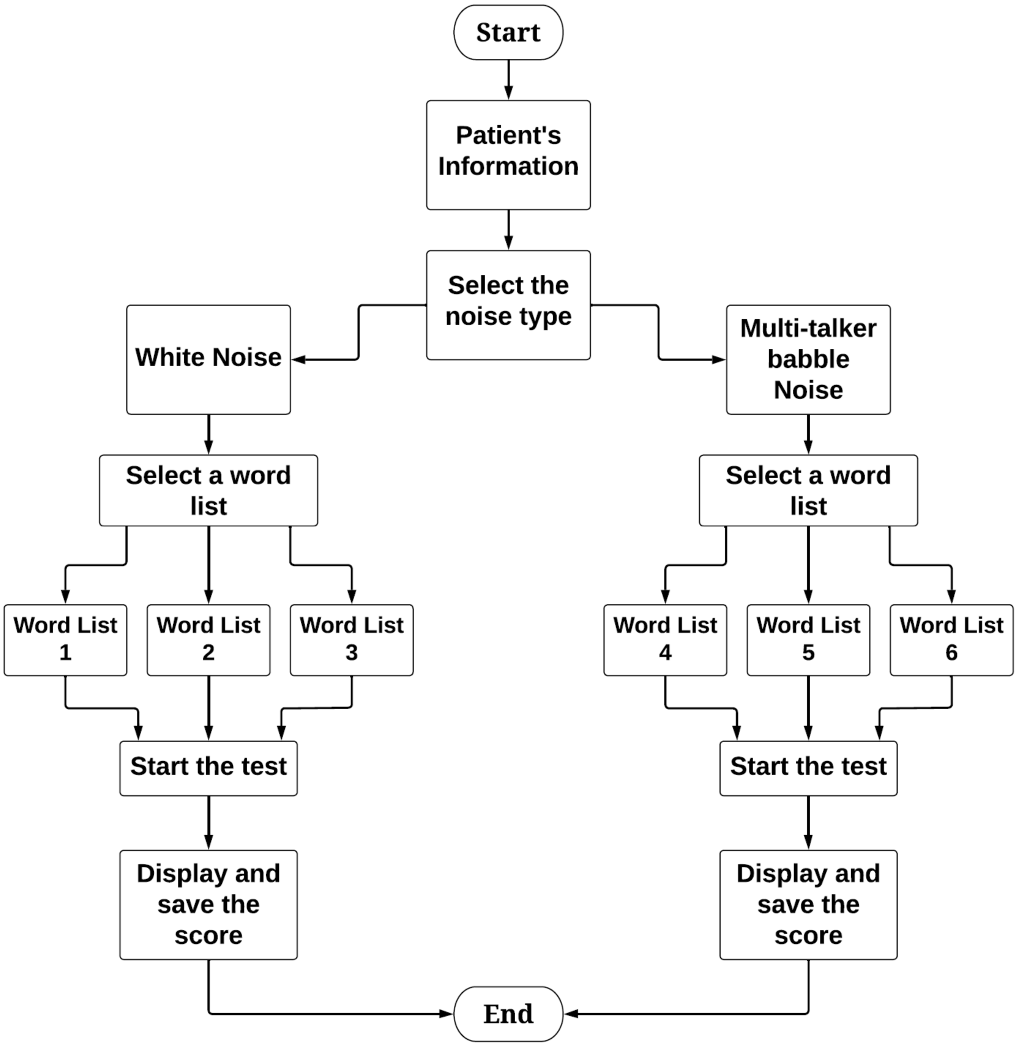

Figure 2. Flowchart of the proposed Arabic word-in-noise screening test.

3. Results

The pure tone audiometry results acquired by the "uHear" phone application confirmed that all subjects had normal hearing in this with normal hearing sensitivity in both ears at 0.5, 1, 2, 4, and 6 octave kHz.

All participants completed the proposed Arabic word-in-noise test with the two types of noise (white noise and four multi-talker babble noise). The average testing time for the Arabic word-in-noise test was seven minutes (SD 2.14).

The percent-correct scores ranged from 100% to 54.17% for the white background noise and 91.57% to 50% for the multi-talker babble background noise (Figure 3). Furthermore, the across-subject and across-list mean percent-correct word recognition scores were 80.14% (SD 9.83) and 74.17% (SD 10.69) for white and multi-talker babble background noise, respectively. A statistically significant difference was seen between the resulting scores from white noise and multi-talker babble noise (paired-samples t-test, t (29) = 3.61, p = 0.001) (Figure 4).

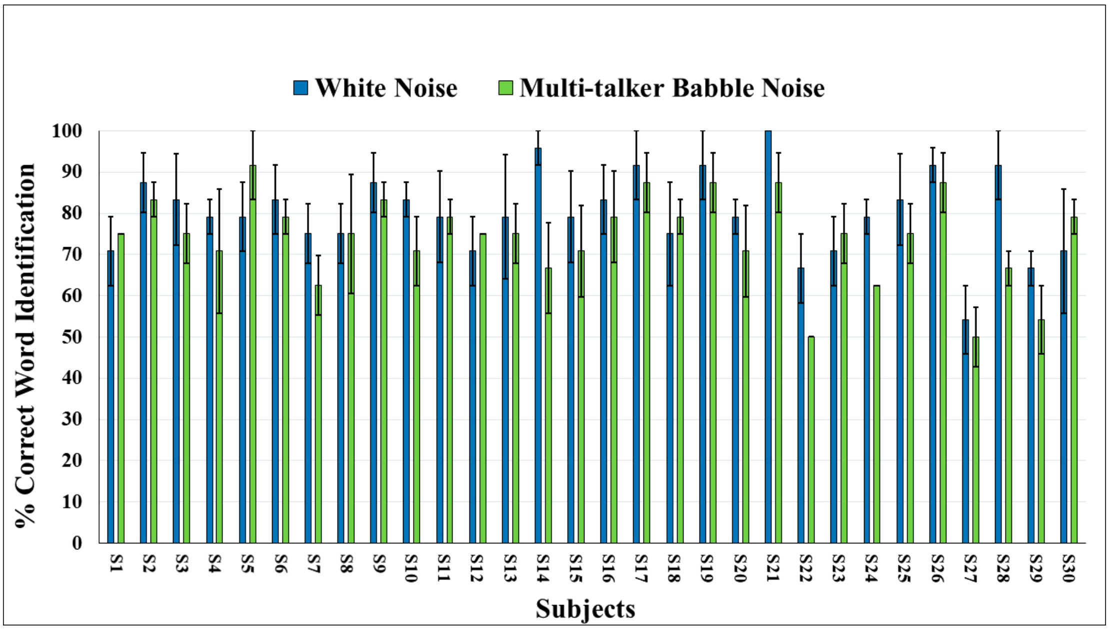

Figure 3. A cross-list mean (±SEM) percent-correct word identification score for each participant for both white noise and multi-talker babble background noise.

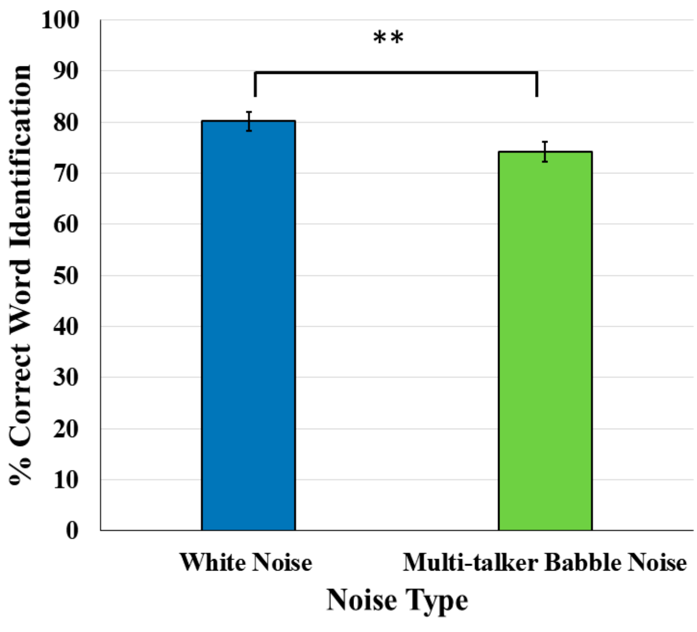

Figure 4. The across-subjects, across-list mean (±SEM) percent-correct word identification score for white noise and multi-talker babble background noise. (** $p < 0.01$).

4. Discussion

The primary goal of this research is to create and validate a computerized Arabic word-in-noise speech perception screening tool that can be used outside of the clinical setting. Outside-clinic tests are essential as they can be effective in rural areas and under political, security, or health pandemic constraints where proper healthcare services are hard to reach [33,37,38].

Developing and validating a speech perception screening tool depends on several factors, such as test duration, linguistics, and the type and intensity of noise. This study validates a proposed Arabic word-in-noise assessment test, reporting the advantages of a short testing time and affordable hardware. The proposed test also encompasses several SNR levels that vary in difficulty to enhance the accuracy of assessing speech intelligibility.

Additionally, there are two main categories of background noise, known as masking noises: stationary or fluctuant [39]. Noise with a changing intensity over time is fluctuant, whereas stationary noise has a fixed intensity over time. Furthermore, speech-in-noise audiometry tests often incorporate white noise or speech spectrum noise as a masking noise [39,40]. Although it does not reflect daily life situations, stationary white noise is most commonly used in speech-in-test clinical testing for its simplicity and ease of calibration [39]. In contrast, spectrum noise, such as multi-talker babble noise, is more representative of daily life situations. Thus, the two types of background noises were tested in this pilot study to investigate their impact on speech perception in healthy individuals. The results indicate that the performance of people with normal hearing was significantly higher in the presence of white noise (80.14%) compared to multi-talker babble noise (74.17%). This implies that listeners with normal hearing are affected differently by the type of background noise, which is in line with other studies showing that word recognition scores are lower in the presence of multi-talker babble noise [41–43].

The results of the present investigation also suggest that the use of white background noise is less challenging and more consistent compared to multi-talker babble noise, at least for Arabic-speaking adults with normal hearing. The use of white background noise could also be more favorable over multi-talker babble noise as the test is developed to be used out of the sound booth and clinical setup where environmental noise is less controlled. However, further investigations are needed to confirm the effect of background noise in diverse practical settings.

In comparison with the few existing Arabic speech-in-noise and word-in-noise tests (Arabic matrix test, Speech Perception of Words in Noise test, and the PAAST), the versatile Arabic word-in-noise test proposed in this study has some design advantages. First, the proposed test is a word-based screening tool that is much easier to complete and comprehend than the sentence-based tests used in the Arabic matrix test. Additionally, this versatile test has its testing words embedded in varying SNR levels, which enable primary care personnel to have a better screening result compared to the paradigm of a zero SNR variation between the presented word and the background noise as in the Speech Perception of Words in Noise test. Finally, the PAAST screening test has a limited targeted population where the word lists in the study can be recognized by school-age children, youth, and elderly populations.

The current study had some limitations, including the lack of enrollment of an age-matched group with hearing loss. Thus, further studies are required on age-matched individuals with hearing loss to validate the sensitivity and specificity of the versatile Arabic word-in-noise hearing screening tool used in this study. Additionally, the recruited sample size was relatively small and included only male participants. However, several studies have indicated a significant gender effect on speech intelligibility [44,45]. Moreover, the stimulation paradigm used in this study used a binaural approach in which words were delivered to both ears simultaneously. This technique might be a disadvantage in hearing screening if one ear has a hearing deficiency. That is, the binaural paradigm might mask a single-ear deficiency. Monaural stimulation for each ear separately could enhance the performance and detection of a unilateral hearing difficulty. Furthermore, although the performance of the uHear mobile application to assess hearing sensitivity has been validated in previous studies [29,46], performing a clinical pure-tone audiometry test and an otological examination prior to the screening with the Arabic WIN test would eliminate the possibility of existing of hearing issues.

5. Conclusions

In summary, the present results demonstrate the feasibility of developing a versatile Arabic word-in-noise screening tool, which has the potential to be used effectively to screen for speech perception difficulties. The tool can recommend that subjects scoring below a certain threshold consult a professional hearing specialist. Determination of the threshold level requires more investigation. In addition, further testing of the proposed hearing screening tool on different age groups is needed to identify and validate its efficacy and the best-targeted age group.

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References

1. World Health Organization. Deafness and Hearing Loss. Available online: https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss (accessed on 30 November 2022).
2. Tuczyńska, M.; Staszewski, R.; Matthews-Kozanecka, M.; Baum, E. Impact of Socioeconomic Status on the Perception of Accessibility to and Quality of Healthcare Services during the COVID-19 Pandemic among Poles—Pilot Study. *Int. J. Environ. Res. Public Health* **2022**, *19*, 5734. [CrossRef]
3. Knudsen, L.V.; Öberg, M.; Nielsen, C.; Naylor, G.; Kramer, S.E. Factors Influencing Help Seeking, Hearing Aid Uptake, Hearing Aid Use and Satisfaction with Hearing Aids: A Review of the Literature. *Trends Amplif.* **2010**, *14*, 127–154. [CrossRef] [PubMed]
4. Garramiola-Bilbao, I.; Rodríguez-Álvarez, A. Linking hearing impairment, employment and education. *Public* **2016**, *141*, 130–135. [CrossRef] [PubMed]
5. Jung, D.; Bhattacharyya, N. Association of Hearing Loss with Decreased Employment and Income among Adults in the United States. *Ann. Otol. Rhinol. Laryngol.* **2012**, *121*, 771–775. [CrossRef]
6. Li, C.-M.; Zhang, X.; Hoffman, H.; Cotch, M.F.; Themann, C.L.; Wilson, M.R. Hearing Impairment Associated with Depression in US Adults, National Health and Nutrition Examination Survey 2005–2010. *JAMA Otolaryngol. Neck Surg.* **2014**, *140*, 293. [CrossRef]
7. Davis, A.; Smith, P.; Ferguson, M.; Stephens, D.; Gianopoulos, I. Acceptability, benefit and costs of early screening for hearing disability: A study of potential screening tests and models. *Health Technol. Assess.* **2007**, *11*, 1–294. [CrossRef]
8. Hatton, J.L.; Rowlandson, J.; Beers, A.; Small, S. Telehealth-enabled auditory brainstem response testing for infants living in rural communities: The British Columbia Early Hearing Program experience. *Int. J. Audiol.* **2019**, *58*, 381–392. [CrossRef] [PubMed]
9. Alhussaini, K.; Bohorquez, J.; Delgado, R.E.; Ozdamar, O. Auditory brainstem, middle and late latency responses to short gaps in noise at different presentation rates. *Int. J. Audiol.* **2018**, *57*, 399–406. [CrossRef]
10. Behar, A. Audiometric Tests without Booths. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3073. [CrossRef]
11. Ashoor, A.A.; Prochazka, T. Saudi Arabic Speech Audiometry. *Int. J. Audiol.* **1982**, *21*, 493–508. [CrossRef]
12. Tatham, M.; Morton, K. *A Guide to Speech Production and Perception*; Edinburgh University Press: Edinburgh, UK, 2011. [CrossRef]
13. Chermak, G.D.; Hall, J.W.; Musiek, F.E. Differential Diagnosis and Management of Central Auditory Processing Disorder and Attention Deficit Hyperactivity Disorder. *J. Am. Acad. Audiol.* **1999**, *10*, 289–303. [CrossRef] [PubMed]
14. Inoue, T.; Higashibara, F.; Okazaki, S.; Maekawa, H. Speech perception in noise deficits in Japanese children with reading difficulties: Effects of presentation rate. *Res. Dev. Disabil.* **2011**, *32*, 2748–2757. [CrossRef] [PubMed]
15. Haesen, B.; Boets, B.; Wagemans, J. A review of behavioural and electrophysiological studies on auditory processing and speech perception in autism spectrum disorders. *Res. Autism Spectr. Disord.* **2011**, *5*, 701–714. [CrossRef]
16. Portnuff, C.; Bell, B. Effective Use of Speech-in-Noise Testing in the Clinic. *Hear. J.* **2019**, *72*, 40. [CrossRef]
17. Pisoni, D.B. Word Identification in Noise. *Lang. Cogn. Process.* **1996**, *11*, 681–688. [CrossRef]
18. Holder, J.; Sheffield, S.W.; Gifford, R. Speech Understanding in Children with Normal Hearing. *Otol. Neurotol.* **2016**, *37*, e50–e55. [CrossRef]

19. Schafer, E.C. Speech perception in noise measures for children: A critical review and case studies. *J. Educ. Audiol.* **2010**, *16*, 4–15.
20. Mendel, L.L.; Widner, H. Speech perception in noise for bilingual listeners with normal hearing. *Int. J. Audiol.* **2015**, *55*, 126–134. [CrossRef]
21. Hjertman, H.; Hällgren, M.; Mäki-Torkko, E.; Stenfelt, S. The Swedish hearing in noise test for children, HINT-C. *Int. J. Pediatr. Otorhinolaryngol.* **2020**, *141*, 110509. [CrossRef]
22. Wilson, R.H. Development of a Speech-in-Multitalker-Babble Paradigm to Assess Word-Recognition Performance. *J. Am. Acad. Audiol.* **2003**, *14*, 453–470. [CrossRef]
23. Kollmeier, B. The Arabic Matrix Test: Cochlear and HörTech Introduce Reliable Speech Audiometry to the Arabic Speaking World. 2014. Available online: http://www.cochlear.com/wps/wcm/connect/uk/for-professionals/sound-connection/the-arabic-matrix-test (accessed on 22 August 2019).
24. Rahman, T.T.A. Development and standardization of Arabic words in noise test in Egyptian children. *Int. J. Pediatr. Otorhinolaryngol.* **2018**, *108*, 1–7. [CrossRef] [PubMed]
25. Alkahtani, R.A. The Development of the Paediatric Arabic Auditory Speech Test for iPad. *ENT & Audiology News*. 1 May 2019. Available online: https://www.entandaudiologynews.com/reviews/tech-reviews/post/the-development-of-the-paediatric-arabic-auditory-speech-test-for-ipad (accessed on 30 November 2022).
26. Irace, A.L.; Sharma, R.K.; Reed, N.S.; Golub, J.S. Smartphone-Based Applications to Detect Hearing Loss: A Review of Current Technology. *J. Am. Geriatr. Soc.* **2020**, *69*, 307–316. [CrossRef] [PubMed]
27. Corona, A.P.; Ferrite, S.; Bright, T.; Polack, S. Validity of hearing screening using hearTest smartphone-based audiometry: Performance evaluation of different response modes. *Int. J. Audiol.* **2020**, *59*, 666–673. [CrossRef] [PubMed]
28. Yousuf, S.; Hussein, S.Y.; Swanepoel, D.W.; Mahomed, F.; de Jager, L.B. Community-based hearing screening for young children using an mHealth service-delivery model. *Glob. Health Action* **2018**, *11*, 1467077. [CrossRef] [PubMed]
29. Anuar, K.B.; Rani, M.; Hitam, S.B.; Noh, A.B. Exploring Uhear Hearing Application as a mobile screening tool for the underprivileged. *Rawal Med. J.* **2018**, *43*, 717–720.
30. Davis, L.; Hwa, T.P.; Eliades, S.J.; Bigelow, D.C.; Ruckenstein, M.J.; Brant, J.A. Pure tone audiometry as assessed by a commercially-available mobile phone application compared to formal audiometry. *Am. J. Otolaryngol.* **2022**, *43*, 103552. [CrossRef]
31. Rye, P.; Andersen, R.O.; Ravn, G.; Hammershøi, D. Comparison of Speech Reception Thresholds for diotic, dichotic and antiphasic headphone presentations of digits-in-noise triplets using Dantale I material. In *Conference Proceedings of the Euroregio/BNAM 2022 Joint Acoustic Conference*; The European Acoustics Association (EAA): Lyon, France, 2022; pp. 383–391.
32. Bauer, M.A.; Sales, A.; Teixeira, A.R.; Morsch, P.; Lessa, A.H.; Bós, J.G. Development and accuracy of a hearing screening application. *Braz. J. Otorhinolaryngol.* **2021**, *87*, 711–717. [CrossRef]
33. Alhussaini, K.; Saleh, S.; Aleid, A.; Alkhalaf, S.; Badghaish, R.; Altinawi, A.; Alwasel, A. Software Application toward Accessible Hearing Care Assessment: Gap in Noise Test. *J. Health Eng.* **2022**, *2022*, 1–6. [CrossRef]
34. Govender, S.M.; Mars, M. Assessing the efficacy of asynchronous telehealth-based hearing screening and diagnostic services using automated audiometry in a rural South African school. *South Afr. J. Commun. Disord.* **2018**, *65*, 9. [CrossRef]
35. Zokoll, M.A.; Hochmuth, S.; Warzybok, A.; Wagener, K.C.; Buschermöhle, M.; Kollmeier, B. Speech-in-Noise Tests for Multilingual Hearing Screening and Diagnostics1. *Am. J. Audiol.* **2013**, *22*, 175–178. [CrossRef]
36. Van Der Aerschot, M.; Swanepoel, D.W.; Mahomed-Asmail, F.; Myburgh, H.C.; Eikelboom, R. Affordable headphones for accessible screening audiometry: An evaluation of the Sennheiser HD202 II supra-aural headphone. *Int. J. Audiol.* **2016**, *55*, 616–622. [CrossRef]
37. Alhussaini, K.; Alkhalaf, S.; Aleid, A. Software application for auditory temporal resolution screening outside the clinic. In Proceedings of the 2020 IEEE 5th Middle East and Africa Conference on Biomedical Engineering (MECBME), Amman, Jordan, 27–29 October 2020; IEEE: Piscataway, NJ, USA, 2020. [CrossRef]
38. Ceccato, J.-C.; Duran, M.-J.; Swanepoel, D.W.; Smits, C.; De Sousa, K.C.; Gledhill, L.; Venail, F.; Puel, J.-L. French Version of the Antiphasic Digits-in-Noise Test for Smartphone Hearing Screening. *Front. Public Health* **2021**, *9*, 725080. [CrossRef]
39. Reynard, P.; Lagacé, J.; Joly, C.-A.; Dodelé, L.; Veuillet, E.; Thai-Van, H. Speech-in-Noise Audiometry in Adults: A Review of the Available Tests for French Speakers. *Audiol. Neurotol.* **2021**, *27*, 185–199. [CrossRef]
40. Wagener, K.C.; Brand, T. Sentence intelligibility in noise for listeners with normal hearing and hearing impairment: Influence of measurement procedure and masking parameters La inteligibilidad de frases en silencio para sujetos con audición normal y con hipoacusia: La influencia del procedimiento de medición y de los parámetros de enmascaramiento. *Int. J. Audiol.* **2005**, *44*, 144–156. [CrossRef]
41. Lee, S.H.; Shim, H.J.; Yoon, S.W.; Lee, K.W. Effects of Various Background Noises on Speech Intelligibility of Normal Hearing Subjects. *Korean J. Otolaryngol. Neck Surg.* **2009**, *52*, 307. [CrossRef]
42. Goldsworthy, R.L.; Markle, K.L. Pediatric Hearing Loss and Speech Recognition in Quiet and in Different Types of Background Noise. *J. Speech, Lang. Hear. Res.* **2019**, *62*, 758–767. [CrossRef]
43. Kattel, B.P.; Fasanya, B.K.; Letowski, T.R.; Hargrove, S.K. The effect of types of background noise on the acceptable noise levels of individuals with normal hearing. In Proceedings of the 13th Annual International Conference of Industrial Engineering. Theory, Applications and Practice, Las Vegas, NV, USA, 7–10 September 2008.
44. Yumba, W.K. Influences of listener gender and working memory capacity on speech recognition in noise for hearing aid users. *Speech Lang. Hear.* **2020**, *25*, 112–124. [CrossRef]

45. Prodi, N.; Visentin, C.; Borella, E.; Mammarella, I.C.; Di Domenico, A. Noise, Age, and Gender Effects on Speech Intelligibility and Sentence Comprehension for 11- to 13-Year-Old Children in Real Classrooms. *Front. Psychol.* **2019**, *10*, 2166. [CrossRef]
46. Szudek, J.; Ostevik, A.; Dziegielewski, P.; Robinson-Anagor, J.; Gomaa, N.; Hodgetts, B. Can Uhear me now? Validation of an iPod-based hearing loss screening test. *J. Otolaryngol. Head Neck Surg.* **2012**, *41*, S78.