RESEARCH ARTICLE

DOI: 10.5935/0946-5448.20230016

International Tinnitus Journal. 2023;27(2):97-103

Listening Effort, An Overview of App Validation and Testing by the Audiology 4 all Project

Luísa Passadouro[1],
Carla Matos Silva[2],
Cláudia dos Reis[2],
Cristina Nazaré[2],
Sergio Paulo[3],
Margarida Serrano[2,4]

ABSTRACT

Objective: To describe an application's development and validation process that aims to track hearing difficulties in adverse environments (a listening effort application).

Design: 71 subjects were evaluated, divided into two groups: 30 subjects aged between 18 and 30, and 41 subjects aged between 40 and 65. All subjects had European Portuguese as their native language; the Montreal Cognitive Assessment (MOCA) scored above 24, and all could read and write. All subjects performed the intelligibility test in noise and the test of listening effort. The two tests were randomly applied in the free field in the audiometric cabin and the application.

Results: There were no statistically significant differences between the results of the two methods (p>0.05). For the group aged between 40 and 65 years old, the ROC curve showed that intelligibility inferior to 68.5% and the number of correct answers lower than 1,5 in the listening effort test are the optimal cut-off for referral to further management. Both tests showed low sensitivity and specificity regarding individuals between 18 and 30 years old, indicating that the application is inappropriate for this age group.

Conclusions: The application is valid and can contribute to the screening and self-awareness of listening difficulties in middle age, with a reduction in the prevalence of dementia soon.

Keywords: Listening Effort, Cognitive Decline, Apps, Self-care.

[1]Polytechnic Institute of Coimbra, Applied Research Institute, Rua da Misericórdia, Lagar dos Corticos-S. Martinho do Bispo, Coimbra, Portugal
[2]Polytechnic Institute of Coimbra, Coimbra Health School, Department of Audiology, Physiotherapy and Environmental Health, Rua 5 de Outubro – S. Martinho do Bispo, Apartado, Coimbra, Portugal
[3]Sensing Evolution (Evollu), Leiria, Portugal
[4]Polytechnic Institute of Coimbra, Research Group on Sustainability Cities and Urban Intelligence, Engineering Superior Institute of Coimbra, Rua Pedro Nunes - Quinta da Nora, Coimbra, Portugal

***Send correspondence to**
Margarida Serrano
Polytechnic Institute of Coimbra, Coimbra Health School, Department of Audiology, Physiotherapy and Environmental Health, Rua 5 de Outubro – S. Martinho do Bispo, Apartado, Coimbra, Portugal, Tel: 936632390, Email: mserrano@estesc.ipc.pt

Paper submitted on July 02, 2023; and Accepted on July 17, 2023

INTRODUCTION

The increase in health literacy has promoted self-care. Health literacy describes an individual's ability to increase their potential in health care, including their ability to understand the information needed to make informed health decisions[1].

The utilization of health apps has become increasingly common and beneficial. These technological tools have the potential to monitor health, increase adherence to treatments, and promote a healthy lifestyle[2]. Despite some barriers experienced in using apps, it is clear these tools promote self-care and enable one to have greater control over health, providing autonomy and well-being[3].

Population aging is a reality all over the world. With increasing age, there is a greater prevalence of cognitive decline and hearing loss[4, 5].

Cognitive decline can range from mild cognitive impairment to dementia and is defined as a self-experienced persistent decline in cognitive capacity in comparison with a previously normal status and unrelated to an acute event, while age-, gender-, and education-adjusted performance on standardized tests is normal[6, 7]. Dementia is one of our century's public health challenges[8]. Aging, genetic, medical, and lifestyle factors contribute to the risk of dementia[9]. Around 33.3% to 40% of dementia cases are attributable to modifiable risk factors[4]. Between the ages of 40 and 65 (middle age), the modifiable risk factor with the greatest weight, 8%, in the speed with which cognitive decline is accentuated is the loss/quality of hearing[4]. Hearing loss is the result of a combination of changes in the structures of the ear, the auditory nerve, and the way the brain processes speech and sounds[5]. These changes have multiple causes, such as diseases (e.g., diabetes and circulatory problems), occupational noise exposure, ototoxic medication, and heredity[5].

The installation of hearing loss is progressive, and without the individual realizing it, the difficulty in understanding speech in noisy environments is one of the first complaints to be felt[5]. The signal-to-noise ratio is the most effective physical characteristic factor for speech perception in noise[8-12]. The complaint of difficulties in understanding speech in noise starts in middle age and cannot be explained only by the hearing thresholds that the subjects present[13]. These subjects need greater effort in listening to perform as well as young subjects, even if their hearing thresholds are only slightly increased or even within the normal range[13].

Hearing loss, even slight, increases the cognitive load as it requires greater effort to listen and understand what is being said. This effort will reduce the resources for auditory memory, as these are finite and shared between listening and memory. The individual, due to the effort and the auditory fatigue, ends up isolating himself, which increases the risk of cognitive decline. The reduction of cognitive decline depends on good hearing, however functional cognitive resources such as attention and working memory also play a key role[14-16].

Listening effort can be quantified using physiologic (heart rate, pupillometry, skin conductance), subjective (e.g., SSQ-Speech, Spatial and Qualities of Hearing Scale), and behavioral techniques (dual-task paradigm test), but there is no consensus on the proper way to measure it. Increased heart rate variability, pupil dilation, and skin conductance mean greater listening effort[17].

The SSQ was designed to measure a range of hearing disabilities by rating the difficulty experienced in different situations on a 10-point visual analog scale. However, of the forty-nine questions about listening to speech, localization of sounds, and different sound qualities, only two are frequently referred to in the literature as measures of effort during listening. The dual-task paradigm consists of a speech recognition task simultaneous with a secondary task, such as remembering or recalling what you heard, and assumes that performance in both the primary and secondary tasks requires the allocation of cognitive resources that are common to both tasks; that is, as cognitive resources are limited, a worse performance in the secondary task presupposes a greater use of cognitive resources in the primary task of speech recognition, which corresponds to a greater listening effort[16, !7].

Apps appear on the market more and more for hearing screening, auditory processing, and tinnitus assessment, among others, which allows for greater awareness of hearing problems and their impact on people's quality of life[18-22]. This study aims to describe the process of developing and validating an app that screens for listening difficulties in adverse environments (the listening effort app).

MATERIALS AND METHODS

Ethics: Ethical approval was obtained from the Ethics Committee of Polytechnic Institute of Coimbra (approval number 94_CEIPC/2021) before the commencement of the data collection. All participants provided written and verbal informed consent.

Listening Effort App: The development and validation of the app required four steps:

- Construction and study of phonetically balanced disyllabic word lists in European Portuguese.

- Development of the listening effort test.

- Development of the app by the EVOLLU team following previously studied parameters.

- Validation of the app by comparing its results with the obtained results with the audiometer in an audiometric booth.

Construction and Study of Phonetically Balanced Disyllabic Word Lists in European Portuguese: With the support of a linguist, five lists of sixteen disyllabic phonetically balanced words were constructed in European Portuguese.

The constructed lists were recorded by a female native speaker of European Portuguese and marked in the Adobe® Audition program.

A noise bubble was also constructed with European Portuguese speakers.

For the development of the app, it was important to know the signal-to-noise ratio at which 50% of discrimination was reached in the constructed lists.

Bubble noise has been added to previously recorded word lists.

The five lists without and with signal-to-noise ratios of -5, 0, and +5 were tested. Two groups of subjects with normal hearing were evaluated: a group of 26 subjects aged between 18 and 25 years (mean age of 20.77) and a group of 28 subjects aged between 50 and 65 years (mean age of 55.71).

The study was conducted in a free field at an intensity of 65 dB in the Audiology Laboratory of the Coimbra Health School. After analyzing the results, it was decided to eliminate one of the lists in which different results were obtained from the other four and to assess the +2 signal-to-noise ratio in a group of subjects between 50 and 65 years old. In the set of four lists, it was found that an intelligibility of approximately 50% was reached in the signal-to-noise ratio of 0 in the group of subjects between 50 and 65 years old. Intelligibility was higher in the group between 18 and 25 years old (Table 1).

Development of the Listening Effort Test: To measure listening effort, a dual-task paradigm test was developed, adapted from the study by Sommers & Phelps, 2016 in which researchers placed subjects exposed to word lists of different dimensions. At the end of each list, subjects repeated the last three words that had been pronounced. The lowest number of correct answers in the antepenultimate word presupposes greater listening effort [22]. For this test, sixty-eight disyllabic words were recorded by a female speaker of European Portuguese and tagged in the Adobe® Audition program, to which bubble noise was added at a ratio of +5.

Development of the App by the Evollu Team: The app consists of the intelligibility in noise test, the listening effort test, and six questions, two of which are adapted from the Portuguese version of the Speech, Spatial and Qualities of Hearing Scale (P-SSQ) referred to as listening effort assessment questions: do you have to concentrate very much when listening to someone or something? And do you have to put in a lot of effort to hear what is being said in conversation with others?[18]

The intelligibility in noise test consists of the four previously constructed phonetically balanced lists with a signal-to-noise ratio of zero. Only one list is displayed in each app view. In each list, the app plays one word at a time, and after each word, it displays a screen with four words, of which one is the emitted word and the other three are words like the emitted one. The subject must choose the word he has heard. At the end of the 16 words, the app displays a screen with the percentage of correct answers.

The listening effort test consists of lists of words, with a signal/noise ratio +5, randomly generated from 68 previously defined words. The word lists generated by the app have different numbers of words and each test is made up of three lists. At the end of the emission of the list of words, the application displays a screen with nine words, where the subject must choose the last three words of the emitted list. At the end of each test, the app displays the percentage of correct answers corresponding to the antepenultimate word.

Validation of the App

Subjects: After a pre-test with five subjects between 40 and 65 years old in which the intelligibility in the noise test had a signal-to-noise ratio of 0, it was decided to change this ratio to +2. The subjects complained that it was difficult to understand, which caused frustration when using the app. The signal-to-noise ratio of +2 was decided based on the results of the intelligibility study at different signal-to-noise ratios (Table 1).

Then, with a signal-to-noise ratio of +2 at intelligibility in the noise test, two groups were evaluated: 30 subjects aged between 18 and 30 years and 41 subjects aged between 40 and 65 years. All subjects had European Portuguese as their native language; the Montreal Cognitive Assessment (MOCA) scored above 24, and all could read and write autonomously.

Procedures: All subjects performed the research on hearing thresholds by air conduction at 500, 1000, 2000, 4000, 6000, and 8000 Hz. In this test, a GSI Audiostar Pro audiometer with Radioear DD 65 v2 headphones was used. Subsequently, an intelligibility test of a list of

Table 1: Descriptive intelligibility statistics for Each Signal-to-Noise Ratio (SNR).

		N	Mean	Std. Deviation	Minimum	Maximum
18-25 years old	Silence	21	94,83	5,37	87,50	100,00
	SNR -5	16	45,70	28,48	,00	100,00
	SNR 0	22	63,64	14,64	37,50	87,50
	SNR +5	14	78,54	14,47	50,00	100,00
50-65 years old	Silence	20	87,19	9,28	68,75	100,00
	SNR -5	18	28,69	38,71	,00	97,75
	SNR 0	20	52,51	11,01	31,25	68,75
	SNR +2	28	72,34	13,88	43,75	93,75
	SNR +5	11	77,80	9,88	62,50	93,75

twenty-five words in silence, the intelligibility in noise test, and the test of listening effort were performed in a free field. All tests in free field were performed at 65 dB with the individual seated in the middle of the audiometric booth of 2 by 3 meters, the stimulus was emitted at 135º and 225º, in relation to the individual through two Wharfedale speakers connected to a GSI Audiostar Pro audiometer. This audiometer is properly calibrated for all transducers used. The intelligibility in noise test and the test of listening effort were randomly applied in a free field in the audiometric booth and in the app.

RESULTS

The mean Pure Tone Average (PTA) of frequencies 500, 1000, 2000, and 4000 Hz in the better ear of subjects between 18 and 30 years old was 2.08 dB (a median of 1.8750 dB).

The mean PTA of frequencies 500, 1000, 2000, and 4000 Hz in the better ear of subjects between 50 and 65 years of age was 12.20 dB (median 10 dB).

The free-field intelligibility of a list of twenty-five words in silence at 65 dB showed a mean score of 97.07% in the group aged between 18 and 30 years old and a mean score of 95.76% in the group aged 40 and 65 years old.

We then proceeded to present the results obtained in the audiometric booth and the results obtained with the app in the intelligibility in noise test and the listening effort test.

In the application of intelligibility tests in noise and listening effort, audiometric booth versus app, there were no statistically significant differences between the results of the two methods, $p > 0.05$ (Table 2).

After verifying the non-existence of statistically significant differences between the results of the app and the results obtained in the booth, a cut-off study was conducted for the results obtained in the app, both in the intelligibility in noise test and the test of listening effort. In the intelligibility in noise test, the value of the state variable was considered to be a value lower than the PTA median in each of the studied groups. In the listening effort test, the value of the state variable was valued below 10 in the sum of the responses on the visual analog scales of the two questions that assess listening effort in the app.

In the intelligibility in noise test, for the group aged between 18 and 30 years, the ROC curve shows that an intelligibility inferior to 81% is the optimal cut-off for being referred for further management, with a sensitivity of 47% and specificity of 47% (AUC = 0.54), as shown in Figure 1.

In the intelligibility in noise test, for the group aged between 40 and 65 years, the ROC curve shows that an intelligibility inferior to 68.5% is the optimal cut-off for being referred for further management, with a sensitivity of 65% and specificity of 60% (AUC = 0.63), as shown in Figure 2.

In the listening effort test, for the group aged between 18 and 30 years, the ROC curve shows that the number of correct answers lower than 2.5 is the optimal cut-off for being referred to for further management, with a sensitivity of 42% and specificity of 59% (AUC = 0.51), as shown in Figure 3.

In the listening effort test, for the group aged between 40 and 65 years, the ROC curve shows that the number of correct answers lower than 1.5 is the optimal cut-off for being referred for further management, with a sensitivity of 70% and specificity of 44% (AUC = 0.66), as shown in Figure 4.

DISCUSSION

After analyzing the results, it was decided that, for subjects aged between 40 and 65 years, the intelligibility in noise test had as a cut-off point to refer to for further management a percentage of correct answers below 68.75% (11 words), and the listening effort test had as a cut-off point to refer to for further management a percentage of correct answers below 66.7% (2 antepenultimate words). Regarding individuals between 18 and 30 years old, both tests showed low sensitivity and specificity (Figures 1 and 3), indicating that the application is inappropriate for this age group.

The subjects mentioned that the app was easy to use and that the tests mirrored the listening difficulties experienced in everyday life. Most participants found the app easier than the tests performed in an audiometric

Table 2: Statistical results of the intelligibility in noise test and the listening effort test, in an audiometric booth and the app.

		Intelligibility in Noise (%)			Listening Effort (hits/3)		
		Booth	app	p	Booth	app	p
18-30 years old	N	30	30	0,672	30	30	0,062
	Mean	79,77	78,97		2,47	2,10	
	Median	81.00	81.00		3.00	2.00	
	Standard Deviation	8.56	8.72		.78	.92	
	Minimum	62.00	62.00		1.00	.00	
	Maximum	93.00	94.00		3.00	3.00	
40-65 years old	N	41	41	0,378	41	41	0,090
	Mean	69,29	71,85		2,05	1,76	
	Median	75.00	73.00		2.00	2.00	
	Standard Deviation	14.76	8.64		.80	.92	
	Minimum	43.75	47.00		.00	.00	
	Maximum	93.00	89.00		3.00	3.00	

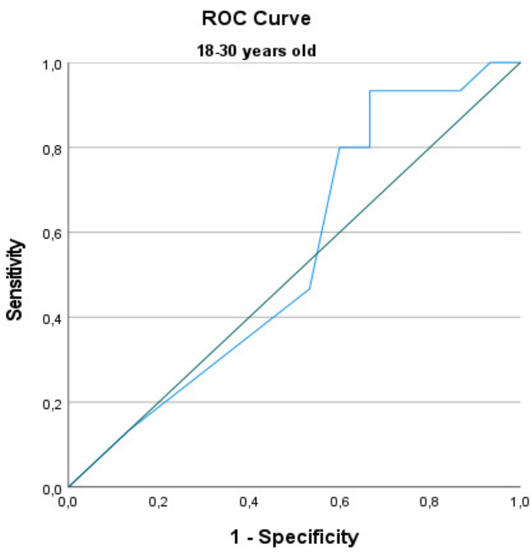

Figure 1: ROC curve of the intelligibility in noise test in the group aged between 18 and 30 years old.

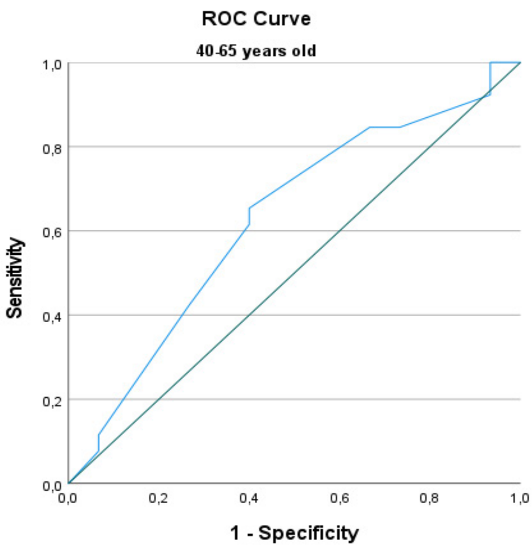

Figure 2: ROC curve of the intelligibility in noise test in the group aged between 40 and 65 years old.

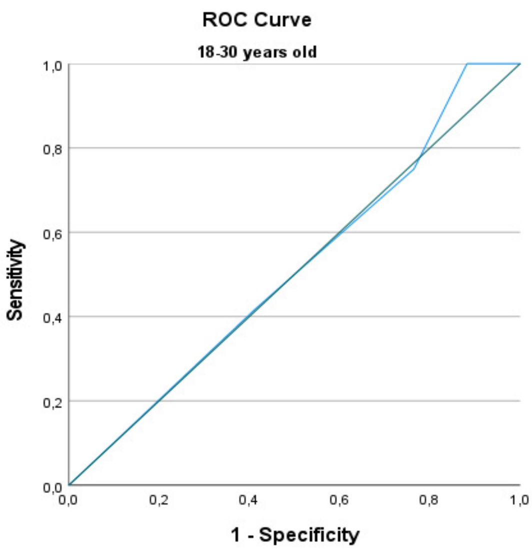

Figure 3: ROC curve of the listening effort test in the group aged between 18 and 30 years old.

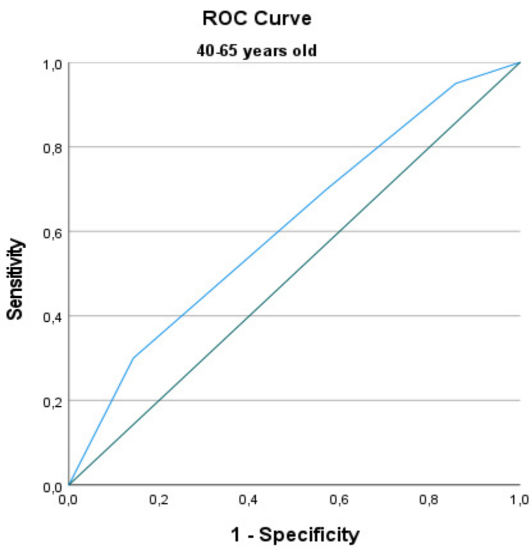

Figure 4: ROC curve of the listening effort test in the group aged between 40 and 65 years old.

booth. In the app, there was visual support that helped them remember. In this study, it can be concluded that the app is valid and can contribute to screening and self-awareness of listening difficulties in middle age. It is at this age (middle age) that hearing loss is assumed to be the modifiable risk factor with the greatest weight (8%) for slowing down cognitive decline. Thus, the app can contribute to reducing the prevalence of dementia soon.

FUNDING

This work is co-financed by the European Regional Development Fund (ERDF), through the partnership agreement Portugal 2020 - Regional Operation Program CENTRO2020, under the project CENTRO-01-0247-FEDER-047083 A4A: Audiology for All.

REFERENCES

1. Ou H. A Pilot Study to Develop the Rapid Estimate of Adult Literacy in Audiology. Health Lit Res Pract. 2022;6(2):e88-95.
2. Liu N, Yin J, Tan SS, Ngiam KY, Teo HH. Mobile health applications for older adults: a systematic review of interface and persuasive feature design. J Am Med Inform Assoc. 2021;28(11):2483-501.
3. Vaportzis E, Giatsi Clausen M, Gow AJ. Older adults perceptions of technology and barriers to interacting with tablet computers: a focus group study. Front Psychol. 2017;8:1687.
4. Livingston G, Huntley J, Sommerlad A, Ames D, Ballard C, Banerjee S, et al. Dementia prevention, intervention, and care: 2020 report of the Lancet Commission. Lancet. 2020;396(10248):413-46.
5. Paplou V, Schubert NM, Pyott SJ. Age-related changes in the cochlea and vestibule: Shared patterns and processes. Front Neurosci. 2021;15:680856.
6. Jessen F, Amariglio RE, Van Boxtel M, Breteler M, Ceccaldi M, Chételat G, et al. A conceptual framework for research on subjective cognitive decline in preclinical Alzheimer's disease. Alzheimers Dement. 2014;10(6):844-52.
7. Jessen F, Amariglio RE, Buckley RF, van der Flier WM, Han Y, Molinuevo JL, et al. The characterisation of subjective cognitive decline. Lancet Neurol. 2020;19(3):271-8.
8. World Health Organization. Global action plan on the public health response to dementia. Geneva: World Health Organization. 2017–2025. 978-92-4-151348-7.
9. Healy EW, Yoho SE. Difficulty understanding speech in noise by the hearing impaired: underlying causes and technological solutions. Annu Int Conf IEEE Eng Med Biol Soc. 2016:89-92. IEEE.
10. Alty J, Farrow M, Lawler K. Exercise and dementia prevention. Pract Neurol. 2020;20(3):234-40.
11. Shojaei E, Ashayeri H, Jafari Z, Dast MR, Kamali K. Effect of signal to noise ratio on the speech perception ability of older adults. Med J Islam Repub Iran. 2016;30:342.
12. Smits C. Improving the efficiency of speech-in-noise hearing screening tests. Ear Hear. 2017;38(6):e385-8.
13. Helfer KS, Jesse A. Hearing and speech processing in midlife. Hear Res. 2021;402:108097.
14. Lin FR, Metter EJ, O'Brien RJ, Resnick SM, Zonderman AB, Ferrucci L. Hearing loss and incident dementia. Arch Neurol. 2011;68(2):214-20.
15. Wayne RV, Johnsrude IS. A review of causal mechanisms underlying the link between age-related hearing loss and cognitive decline. Ageing Res Rev. 2015;23:154-66.
16. Peelle JE. Listening effort: How the cognitive consequences of acoustic challenge are reflected in brain and behavior. Ear Hear. 2018;39(2):204.
17. Guijo LM, Horiuti MB, Nardez TM, Cardoso AC. Listening effort and working memory capacity in hearing impaired individuals: an integrative literature review. Revista CEFAC. 2018;20:798-807.
18. Gatehouse S, Noble W. The speech, spatial and qualities of hearing scale (SSQ). Int J Audiol. 2004;43(2):85-99.
19. Miranda-Gonsalez EC, Almeida KD. Hearing disability measured by the Speech, Spatial and Qualities of Hearing

Scale (SSQ): pilot study of a short version in Brazilian Portuguese. Audiol-Comm Res. 2017;22.

20. Murdin L, Sladen M, Williams H, Bamiou DE, Bibas A, Kikidis D, et al. EHealth and its role in supporting audiological rehabilitation: Patient perspectives on barriers and facilitators of using a personal hearing support system with mobile application as part of the EVOTION study. Front Public Health. 2022;9:669727.

21. Frisby C, Eikelboom R, Mahomed-Asmail F, Kuper H, Swanepoel DW. m-Health applications for hearing loss: a scoping review. Telemed J E Health. 2022;28(8):1090-9.

22. Sommers MS, Phelps D. Listening effort in younger and older adults: A comparison of auditory-only and auditory-visual presentations. Ear Hear. 2016;37(Suppl 1):62S.