Listening Effort in Patients with Sensorineural Hearing Loss using Cochlear Implant

Original Article

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ABSTRACT

Introduction: Listening effort is the mental exertion and cognitive resources needed for the recognition of speech. The patients with hearing loss have more listening effort than the normal hearing subjects, and this may increase stress and fatigue in the affected patients.

Objectives: To assess the listening effort in patients with unilateral cochlear implants (CI) and to compare it with the listening effort of the normal hearing subjects.

Patients and Methods: Our study included 27 subjects aged 18 to 45 years. They were divided into a control group (I) and a study group (II). The control group (I) consisted of 15 adults with bilateral normal peripheral hearing while the study group (II) consisted of 12 post-lingual adults wearing unilateral cochlear implants (CI). We assessed the listening effort in unilateral CI patients using subjective measures [Hospital Anxiety & Depression Scale (HADS)] and behavioral measures including both dual-task paradigm and memory tests.

Results: Unilateral CI patients showed higher SNR loss and prolonged reaction times than the control group in the dual-task paradigm. They also showed higher scores in HADS and poorer performance in the memory tests.

Conclusion: Unilateral CI patients showed more listening effort than the normal hearing subjects with a higher level of anxiety and depression. They also showed poorer performance in the memory tests, which indicates that the hearing loss may lead to memory affection.

Key Words: Cochlear implant, depression, dual-task, memory, listening effort.

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INTRODUCTION

Hearing differs from listening. Hearing is the involuntary perceiving of sound; it is a physiological process occurs at the subconscious level, and it doesn't require concentration. On the other hand, listening is the function of hearing with attention and intention; it means hearing and understanding what we hear. It occurs at the conscious level and requires concentration.[1] So, listening involves cognitive processes beyond the fundamental functions of hearing, and therefore it requires an expenditure of effort.[2,3]

Kahneman (1973)[4] stated that there is a limited supply of cognitive capacity and limited processing resources that can be shared among tasks. Speech perception may require auditory processing effort, especially in challenging listening conditions; it may require additional mental effort.[5] Listening effort is defined as the amount of mental exertion and cognitive resources needed for the recognition of speech.[6] It can also be defined as the allocation of mental resources to overcome obstacles when carrying out a listening task.[7]

The individuals with hearing impairment may need to shift more resources from the other on-going cognitive tasks to maintain optimal speech understanding, which results in increasing the listening effort[8,9,10], stress and fatigue of the affected patients, as well as the long-term consequences on the mental and physical health such as tuning out of a conversation and social events.[11] In Cochlear implant (CI) users, higher signal-to-noise (SNR) is required to achieve similar speech perception as normal hearing subjects.[12]

Listening effort can be quantified using subjective, physiologic, and behavioural techniques.[13] Assessing listening effort has several benefits, such as patient counselling and in the determination of the intervention strategies that can be used with the patient.[1]

This work was done for studying the listening effort in unilateral cochlear implant patients utilizing subjective HADS questionnaires and behavioral measures including both dual-task paradigm and memory tests.

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PATIENTS AND METHODS:

A-Subjects:

This study included 27 subjects. Their age ranged from 18 to 45 years. Subjects were divided into a control group (I) and a study group (II). The control group (I) consisted of 15 adults with bilateral normal peripheral hearing. The study group (II) consisted of 12 post-lingual adults wearing unilateral cochlear implants (CI) for not less than one year, under rehabilitation therapy and with satisfactory aided CI responses. All subjects in the study had nearly the same educational background with well-developed speech. Subjects with any general health problems or neurological complaints were excluded. Also, subjects who failed the training of the primary or the secondary task were excluded.

This study was conducted in Tanta University hospital. It was approved by the institutional ethics committee in the Faculty of Medicine, Tanta University. All the participants gave an informed written consent before participation in the study.

B-Method:

All subjects were submitted to full audiological history and otological examination.

For the control group, basic audiological evaluation including pure tone audiometry, speech audiometry was done by Madsen Astera (GN Otometrics, Madsen, Aurical, ICS) with headphones TDH 39. Acoustic immittance measurements (tympanometry/stapedial reflex) by interacoustics AT235H using low frequency 226 Hz probe tone.

Free field aided response was done for the CI group using Mixmax loudspeakers.

All subjects were submitted to

I) Subjective measure:

Hospital Anxiety and Depression Scale (HADS):

In our study, we used the HADS,[14] which was designed to assess anxiety and depression symptoms with emphasis on reducing the impact of physical illness on the total score. It is a 14-item measure, 7-items assessed anxiety (HAS) and 7-item assessed depression (HDS). Each item rated on a 4-point severity scale (from 0 to 3). The scores in each subscale were computed by summing the corresponding items, with a maximum score of 21 for each subscale. A score of 0–7 was considered as normal, 8–10 as a borderline and 11–21 as a case (anxiety or depression).

II) Behavioral measures of listening effort:

A- Dual-task paradigm test:

In the dual-task, subjects performed two tasks simultaneously wearing his/her CI. The primary task was a speech recognition task (i.e., auditory/verbal primary task), and the secondary task was a visual/motor task. The Listeners were instructed to prioritize the primary task over the secondary task. So, the primary task occupies a portion of cognitive resources, and performance on the secondary task is dependent on the cognitive spare capacity.[15]

We used the Quick SIN test as a speech recognition primary task. Quick SIN test measures the signal-to-noise ratio loss in decibels (dB SNR loss). The secondary task consisted of two tasks, easy RT task, and hard Stroop test.

1- The primary task: Quick SIN test using CD player (Thomson Cs96) and CD of pre-recorded calibrated test material of the QuickSIN test.[16] A list of six sentences was presented in four-talker babble noise. Each sentence has five keywords. The sentences were presented at pre-recorded signal to noise ratios (SNRs), which decreased in 5dB steps, from 25 (very easy) to 0 (extremely difficult). The SNRs used were: 25, 20, 15, 10, 5 and 0. The test was administered in the sound field with the signal and the noise presented from the same speaker at 0° azimuth. The presentation level was 70 dB HL.[17]

Before the test, the subject was familiarized with a preset list of 6 sentences that were distinct from the test lists. Each participant was instructed to listen to each sentence and repeat it aloud as accurately as possible, even if it required guessing. Participants were instructed that the background noise level would vary throughout the test. Each sentence has five keywords, and each correctly repeated word was given one point. So, the total possible correct words were 30 points per list. The Signal to Noise Ratio Loss (SNR loss) was determined by the formula 25.5 - Total Words Correct = SNR Loss. The SNR Loss is the SNR that the listener with hearing loss requires above the SNR, a normal-hearing listener requires to achieve 50% correct sentence identification. This formula was based on the Tillman-Olsen method for obtaining spondee thresholds.[17,18]

2- The secondary task (Stroop test): The test was done by using HP Pavilion 13-u002nx Laptop containing the material of the Stroop test. The Participants sat facing a monitor and a wireless keyboard in a sound-attenuating booth. The stimuli were presented from the laptop positioned outside the sound booth. The visual stimuli were displayed on the computer monitor in the sound booth. Participants responded by pressing a designated key on the keyboard. By using the visual stimuli of the Stroop test[19], two tasks were created; an easy task and a hard task.

For the easy task, the computer monitor showed four boxes containing RED, BLUE, GREEN, and YELLOW. The font color of the words in the virtual button box was black. Participants were asked to press the space bar on the keyboard as quickly as possible when the four boxes were shown. When the space bar was pressed, the reaction time was saved. So, the easy task was a simple visual reaction-time task. There were six reaction times recorded for each patient, one reaction time for each signal to noise ratio of the Quick SIN test from 25 to 0 SNR. When the easy task ended, the hard task began.

In the hard task, the computer monitor showed the color name, but with different font color. In this task, participants were asked to respond to the font color, instead of the word meaning (the incongruent condition of the Stroop test). The participant responded by pressing a keyboard button assigned to a given color as accurately and quickly as possible. The keyboard buttons were assigned R, B, G, and Y to font color red, blue, green, and yellow, respectively. For each subject, six reaction times and six color answers were recorded. When a given button was pressed, the corresponding virtual button on the screen was highlighted to indicate the response. In the hard task, it was required from the participants to inhibit the semantic meaning of the stimulus word and determine which button to push. This task was more demanding and would interfere more with the speech recognition than the easy task.

B- Memory Tests:[20]

1-Recognition Memory Test:

Five lists consisted of 11 bi-syllabic words repeated twice in a randomized manner (to form 22 bi-syllabic words list). The subject was instructed to raise his hand each time he heard a repeated word in the same list. Scoring for each list was done by subtracting the wrong responses from eleven. Final scoring was reached by calculating the mean of the 5 lists scores.

2- Memory for Content Test:

Two groups of lists (A) and (B) were developed. Each group consisted of eight lists of monosyllabic simple words. The first list comprised two words. The number of words was increased gradually to reach nine words in the eighth list.

Each subject was instructed to repeat the whole list he had just heard irrespective of its sequence. The highest number of words that the candidate could memorize was taken as his score. If the highest number was different between (A) and (B) groups of the same list, the mean of both groups was calculated.

3- Memory for Sequence Test:

Two other groups of words (A) and (B) were developed, and they were different from those used in the previous test. Each group consisted of seven lists. The first list consisted of two words, and the number of words was gradually increased throughout the seven lists to reach eight words in the last list.

The subject was instructed to repeat the whole list he had just heard with its sequence. The highest number of words that the candidate could memorize was taken as his score. If the highest number was different between (A) and (B) groups of the same list, the mean of both groups was calculated.

Statistics:

Data were analyzed using Statistical Program for Social Science (SPSS) version 20. Quantitative data were expressed as mean± standard deviation (SD). The Independent t-test was used for the comparison between the control and the study group. The Pearson correlation test was used for the correlation between HADS and the primary task in the dual paradigm in the CI group. The *p value* < 0.05 was considered statistically significant.

RESULTS:

The study included 27 subjects aged 18 to 45 years. The control group (I) consisted of 15 adults with bilateral normal peripheral hearing with the hearing threshold not exceeding 25 dBHL in the frequency range of 250-8000Hz. The mean±SD of PTA threshold in both ears was 9.79±4.25 dBHL in the frequency range of 250-8000Hz. The study group (II) consisted of 12 post-lingual adult patients with unilateral cochlear implants. They were using CI for not less than one year with satisfactory aided response (Aided free field ≤ 30dB SPL). All of them were on rehabilitation therapy. Comparing the age and the sex between the control and the study groups showed no statistically significant difference.

A) Results of Hospital Anxiety and Depression scale (HADS):

It is composed of two scales, one for anxiety (Hospital anxiety scale HAS) and the other for depression (Hospital depression scale HDS). Each scale was analyzed separately. The CI group showed statistically significant higher scores than the control group in both scales ($p<0.05$). Eight patients (66.6%) in the CI group showed scores more than 8 in both anxiety and depression scales (5 borderline and 3 cases) (Figure1).

B) Results of dual task paradigm test:

a-Results of the Primary Task (speech recognition):

Comparison of SNR loss between the control and the CI group was done to study the effect of the secondary visual tasks on speech recognition. The CI group showed a highly statistically significant increased SNR loss ($P\leq 0.01$) than the control group (Table1).

b-Results of the secondary task (Visual task):

1- Easy task (Reaction time RT):

The Reaction Times of the easy visual task were recorded. There were six reaction times, one reaction time for each SNR. The Comparison between both groups showed a significant prolongation of all RTs in the CI group (Figure 2).

2- Hard task (Stroop test) results:

A Comparison was done between the control and the study groups according to the score of the correct color answers. There was a statistically significant difference (*p value=0.017*) between the control (5.87±0.35) and the CI groups (5.58±0.51) (Table 2).

Correlation between HADS and the primary task in dual paradigm:

There was a significant positive correlation between HAS and the primary dual-task (*p value= 0.007*) (Figure 3). However, there was no significant correlation between HDS and the primary dual-task.

C) Memory Test results:

a- Memory for Recognition:

The comparison of the memory for recognition between both groups showed highly significant lower scores in the CI group (*P≤0.01*) than the control group (Figure4).

b- Memory for Content:

The comparison between the control and the CI group according to the length of the lists showed that all subjects in the control group reached the 5-word list, and 11 subjects (73.3%) could reach the 6-word list. While in the CI group, 7 subjects could reach the 4-word list, and only 2 subjects (16.7%) reached the 5-word list (Figure5).

c- Memory for Sequence:

All subjects in the control group reached the 4-word list, and 11 subjects (73.3%) could reach the 5-word list. In the CI group, all subjects reached the 3-word list, and only 2 subjects (16.7%) could reach the 4-word list (Figure5).

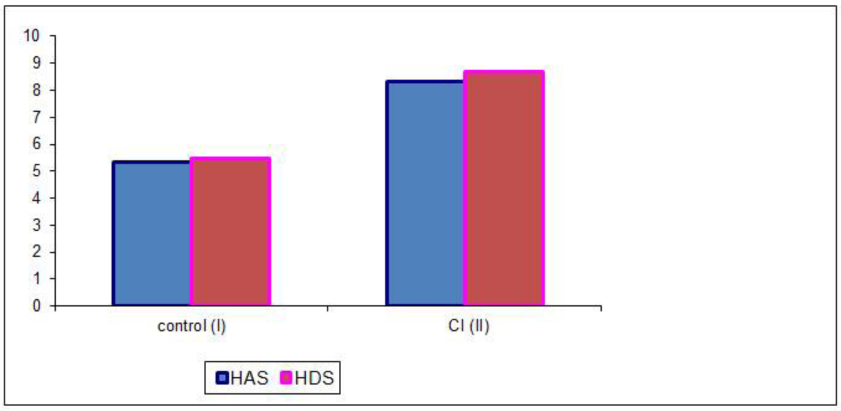

Fig. 1: Comparison of the two sections of HADS [(HAS) and (HDS)] questionnaire between control group and CI group.

Table 1: Comparison of SNR loss of the primary task between control (I) and CI (II) group.

		Range			Mean	±	SD	T .test	*p. value*
Primary Task dual	Control (I)	-3.5	–	4.5	-0.70	±	2.11	32.938	*0.001***
	CI (II)	14.5	–	23.5	20.58	±	2.64		

*significant *P≤0.05*, **highly significant *P ≤0.01*.
CI: cochlear implant,

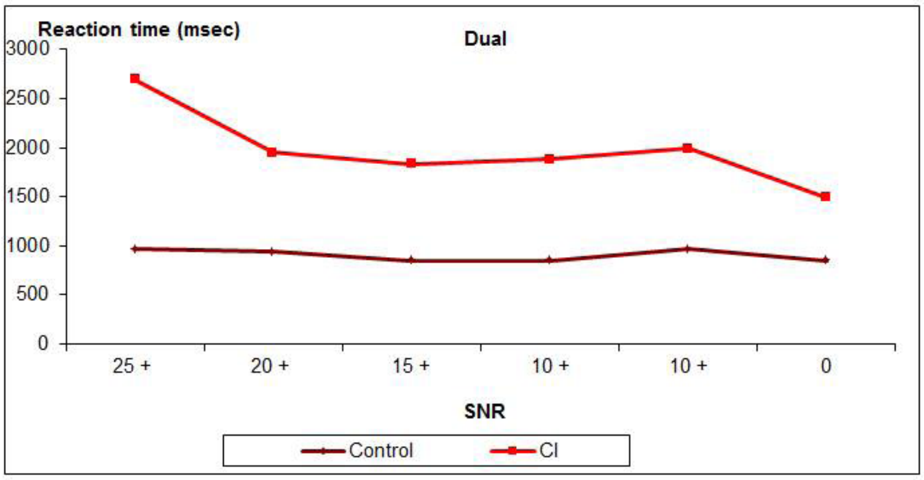

Fig. 2: Comparison of reaction times for the easy task in dual task paradigm between control and CI group at different SNRs.

Table 2: Comparison of Hard task (Stroop test) answers between control (I) and study CI (II) groups.

Stroop test		Mean	±	SD	T .test	*p. value*
Dual	Control (I)	5.87	±	0.35	2.468	*0.017**
	CI (II)	5.58	±	0.51		

*significant *P≤0.05*, **highly significant *P≤0.01*.
CI: cochlear implant

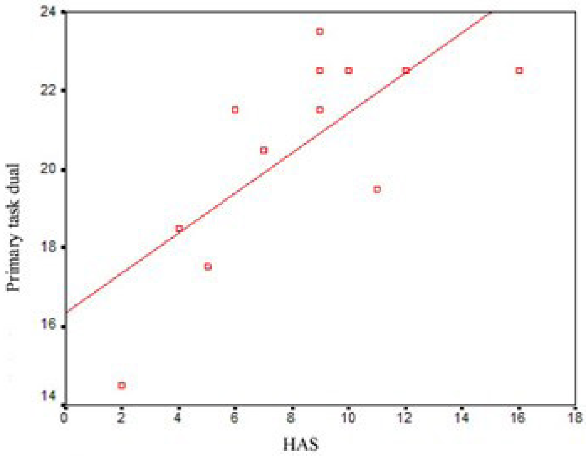

Fig. 3: Correlation between primary dual task and HAS showed a significant positive correlation.

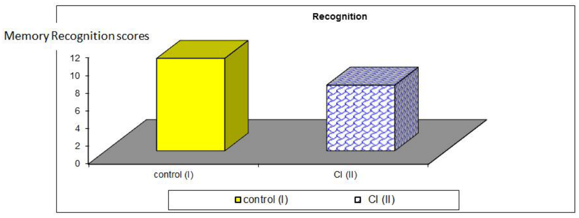

Fig. 4: Comparison of memory for recognition scores between control (I) and CI (II) groups

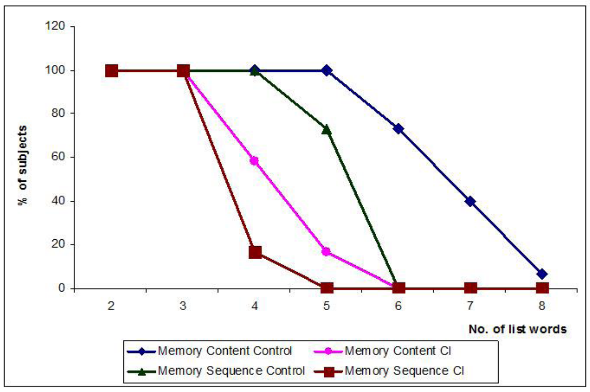

Fig. 5: Comparison of memory for content and memory for sequence scores between control (I) and CI (II) group according to length of lists.

DISCUSSION

Both auditory and cognitive factors are required for optimal speech understanding.[2, 3, 21, 22] Listening effort was defined as the mental exertion required for attending and understanding an auditory message. It can be measured using subjective, physiological, and behavioral measures.[15]

In our study, we assessed listening effort in cochlear implant (CI) patients using dual-task paradigm and memory tests as behavioral measures. We also used the Hospital Anxiety and Depression Scale (HADS) as a subjective measure to assess anxiety and depression associated with the listening effort in those patients.

Hospital Anxiety and Depression scale (HADS):

Cochlear implant patients wearing unilateral devices showed statistically significant higher anxiety and depression scores than the normal hearing subjects (Figure1). Kochkin *et al*. (2000)[23] demonstrated that hearing loss greatly affects sound localization and speech perception in noise leading to more anxiety during communication with others. Li *et al*. (2014)[24] and Dawes *et al*. (2015)[25] demonstrated that there was a strong correlation between mental and hearing health. They concluded that hearing loss leads to difficulty in communication, stress, fatigue, and social isolation with subsequent depression. Patients with hearing loss reported increased listening effort especially in difficult situations, coupled with accounts of fatigue and stress indicate there are many negative aspects of hearing loss in those patients.[23] The CI patients have low quality of life, experienced more stress and more difficulties in coping with their situation especially with the unrealistic expectation of the performance of the cochlear implant.[26]

Dual-task paradigm

The dual-task paradigm is one of the most widely used measures to quantify the listening effort.[27] The difficulty of the speech recognition task varied during the test session. The individuals with hearing impairment may need to shift more resources from the other on-going cognitive tasks to maintain optimal speech understanding, which results in increasing the listening effort.[8,9,10] The change in the performance of the secondary task is taken as an index of the shift in the allocation of cognitive resources for speech processing.[4]

The results of the Quick SIN test in the dual paradigm revealed that the CI group showed more SNR loss than the normal hearing subjects (Table1). This can be explained as if the incoming signal is compromised (for example due to masking noise, or hearing loss), the phonological elements may fail to match the existing representations in the long term memory.[28] This mismatch will trigger a loop of explicit processing to either restore missing information and retry matching or to guess the meaning if no match can be found.[29] Interpreting a degraded speech signal is slow, effortful, requires cognitive processing, and depends on the working memory capacity.[30,31]

All the six RTs in the easy visual secondary task were longer in the CI group than the normal hearing subjects (Figure 2). Our results showed in the RTs curve across SNRs from +25 to +0 shorter RT in the most unfavorable condition (+0 SNR) than at +25 SNR condition. This can be explained by the tendency of the patients experienced cognitive overload and disengaged themselves from the listening task and exerted more effort on the secondary task to pursue reward. Our results agreed with Wu *et al*. (2016).[32] Their results showed shorter RT at the unfavorable SNRs and the RT increased as SNR changed from favorable to intermediate SNRs, and then decreased as SNRs moved from intermediate to unfavorable SNRs. They concluded that although dual-task tests are widely used, it is less clear at what speech intelligibility level the test will be most sensitive to changes in listening effort. Dual-task measures conducted in conditions wherein the primary speech recognition task is too easy (e.g., quiet) or too difficult (e.g., high-level background noise) may not be sensitive.[33]

Also, there was a statistically significant difference between both groups in the Stroop test results (Table 2). This can be explained by the increased processing required by the CI group, to hear, recognize and repeat the sentence in the background noise, and to respond to the visual task at the same time. This leads to consuming much of the cognitive capacity and increases the listening effort during performing the dual-task leading to prolonged RTs.[34] Our results agreed with Perreau *et al*. (2017)[1] and Huges and Galvin (2013)[12] who compared the listening effort between normal hearing listeners and CI patients using the dual-task paradigm. They reported that the CI patients showed greater listening effort than the normal hearing subjects.

The theory of limited cognitive resources explains how listening effort can be measured by using the dual-task paradigm.[4] In the dual-task paradigms, speech recognition in noise (primary task) uses the majority of the mental capacity, as the participants are instructed to maximize their speech recognition abilities.[35] As the speech recognition task becomes more difficult throughout the test by decreasing the signal to noise ratio, a change in cognitive resource allocation occurs, and fewer resources are available to perform the secondary task.[4,36] According to this, the decrease in secondary task performance is associated with increased listening effort.[37]

Correlation between HADS and the primary task in dual paradigm

There was a significant positive correlation between HAS and the primary dual-task in CI patients (Figure3). As the hearing loss and SNR loss increases, the listening effort, and the associated anxiety and stress increases. This agreed with (Etymotic research, 2001; Li *et al*., 2014 and Dawes *et al*., 2015).[17,24,25]

3- Memory tests:

Results of the Memory for recognition test revealed that the CI group showed lower scores than the normal hearing subjects (Figure 4). Both Memory for content and Memory for sequence tests showed poorer responses in the CI patients than in the control group (Figure5).

These results agreed with Gate *et al*. (2011),[38] who suggested that the hearing loss could affect the auditory memory. The increased listening effort in patients with hearing loss increases the cognitive load and reduces the neural resources available to other cognitive processes such as working memory. Rakerd *et al*., (1996)[39] suggested that hearing loss limits access to acoustic information even with amplification. With hearing impairment, the recognition of speech needs more mental effort, which make its memorization much more difficult than in the normal hearing subject.[40] Also, communication difficulties that result from hearing loss lead to prolonged social isolation that affects the cognitive function.[41,42] Spielberger *et al*., (1979)[43] suggested that memory is affected by stress and fatigue associated with hearing impairment.

The limitations of our study included the small number of the study group, also we did not assess the listening effort in patients with bilateral cochlear implantation. So, we recommend studying the listening effort in patient with CI with larger sample size and comparing the listening effort between patients with unilateral and bilateral CI.

CONCLUSION

Patients wearing unilateral CI have more listening effort than the normal hearing subjects associated with a high level of anxiety and depression. Cochlear implant patients have limited spectral resolution due to device limitation, in addition, patients with unilateral CI have difficulty in localization and discrimination of speech in noise. All these factors increase the listening effort in those patients. The increased listening effort in unilateral CI patients was evidenced by the higher SNR loss, prolonged reaction times and decreased scores in the Stoop test than the control group in the dual-task paradigm.

CONFLICT OF INTEREST

There are no conflicts of interest.

REFERENCES

1. Perreau AE, Wu YH, Tatge B *et al*. Listening Effort Measured in Adults with Normal Hearing and Cochlear Implants. J Am Acad Audiol. 2017;28(8): 685-697.

2. Kiessling J, Pichora-Fuller K, Gatehouse S *et al*. Candidature for and delivery of audiological services: special needs of older people. Int. J. Audiol. 2003;42(2):S92-S101.

3. Rönnberg J, Holmer E, Rudner M. Cognitive hearing science: Three memory systems, two approaches, and the ease of language understanding model. J. Speech Lang. Hear. Res. (2021); 64, 359–370.

4. Kahneman D. Attention and effort. Englewood Cliffs, NJ: Prentice-Hall, Inc. 1973. Quoted from Journal of Psychology, Vol.7 No.10, September 22, 2016.

5. Ayasse ND and Wingfield A. ATipping Point in Listening Effort: Effects of Linguistic Complexity and Age-Related Hearing Loss on Sentence Comprehension. Trends Hear. 2018;22: 1–14.

6. Guijo LM, Horiuti MB, Cardoso ACV. Measurement of listening effort using of a dual-task paradigm of Brazilian Portuguese: a pilot study. Codas. 2019;31(4):e20180181.

7. Pichora-Fuller M, Kramer S. Eriksholm Workshop on Hearing Impairment and Cognitive Energy. Ear Hearing. 2016;37:1S-4S.

8. McCoy S, Tun P, Cox L *et al*. Hearing loss and perceptual effort: Downstream effects on older adults' memory for speech. Q J Exp Psychol. 2005;58:22–33.

9. Picou E, Ricketts T, Hornsby B. Visual Cues and Listening Effort: Individual variability. J. Speech Lang. Hear. Res. 2011;54:1416-1430.

10. Peelle J, Troiani V, Grossman M *et al*. Hearing loss in older adults affects neural systems supporting speech comprehension. J Neurosci. 2011;31:12638-12643.

11. Francis AL, Love J. Listening effort: Are we measuring cognition or affect, or both? WIREs Cogn Sci. 2019;e1514.

12. Hughes K, Galvin K. Measuring listening effort expended by adolescents and young adults with unilateral or bilateral cochlear implants or normal hearing. Cochlear Implants Int. 2013; 14(3):121–129.

13. Mackersie C, Cones H. Subjective and psychophysiological indexes of listening effort in a competing-talker task. J Am Acad Audiol. 2011;22:113–122.

14. Terkawi AS, Tsang S, AlKahtani GJ *et al*. Development and validation of Arabic version of the Hospital Anxiety and Depression. Scale Saudi J Anaesth. 2017;11(1): 11–18.

15. McGarrigle R, Munro K, Dawes P *et al*. Listening effort and fatigue: What exactly are we measuring? A British Society of Audiology Cognition in Hearing Special Interest Group 'White paper'. Int J Audiol. 2014;53:433-445.

16. Elrifaey M, Elgharib A, Elmehalawy T *et al*. Development and Standardization of Arabic Quick Speech in Noise Test. Adv Arab Acad Audio-Vestibul J. 2017; p126 (under press).

17. Etymotic Research, 2001. QuickSIN Speech in Noise Test Version 1.3. Elk Grove.

18. Killion MC, Niquette PA, Gudmundsen GI *et al*. Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. J Acoust Soc Am. 2004;116:2395-405

19. Stroop J. Studies of interference in serial verbal reactions. J Exp Psychol. 1935;18(6):643-662.

20. Tawfik S, Sadek I, Abdel Maksoud A *et al*. Auditory attention and memory tests for children: development, standardization and application. Egypt J Otolaryngol. 2002;19 (2): 31-43.

21. Worrall L, Hickson L. Communication disability in aging from prevention to intervention. New York: Thomson, Delmar Learning, 2003.

22. Humes L. The contributions of audibility and cognitive factors to the benefit provided by amplified speech to older adults. J Am Acad Audiol. 2007;18(7):590-603.

23. Kochkin S, MarkeTrak V. Hearing aid industry markset tracking survey. HIA Marketing Seminar, Minneapolis, 2000.

24. Li CM, Zhang X, Hoffman HJ et al. Hearing impairment associated with depression in US adults, National Health and Nutrition Examination Survey 2005-2010. JAMA Otolaryngol. 2014;140(4): 293-302.

25. Dawes P, Emsley R, Cruickshanks KJ *et al*. Hearing loss and cognition: the role of hearing AIDS, social isolation and depression. PloSone. 2015;10(3):e0119616.33.

26. McRackan TR, Reddy P, Costello MS, Dubno JR. Role of Pre-Operative Patient Expectations in Adult Cochlear Implant Outcomes. Otol Neurotol. 2021; 42(2): e130–e136.

27. Gosselin P, Gagne J. Use of a dual-task paradigm to measure listening effort. Can J Speech-Lang Pathol Audiol. 2010;34:43-51.

28. Mattys S, Davis M, Bradlow A *et al*. Speech recognition in adverse conditions: A review. Lang Cogn Process. 2012;27(7-8):953-978.

29. Rönnberg J, Lunner T, Zekveld A *et al*. The ease of language understanding (ELU): model: Theoretical, empirical, and clinical advances. Front Neurosci. 2013;7:31.

30. Rönnberg J. Cognition in the hearing impaired and deaf as a bridge between signal and dialogue: a framework and a model. Int J Audiol. 2003;42(1):S68–S76.

31. Rönnberg J, Rudner M, Foo C. Cognition counts: A working memory system for ease of language understanding (ELU): Int J Audiol. 2008;47(2):S99–105.

32. Picou EM, Ricketts TA. The effect of changing the secondary task in dual-task paradigms for measuring listening effort. Ear Hear. 2014;35(6):611-22.

33. Wu Y, Stangl E, Zhang X, Perkins J, Eilers E. Psychometric functions of dual-task paradigms for measuring listening effort. Ear Hear. 2016; 37(6): 660–670.

34. Picou EM, Ricketts TA, Hornsby BW. How hearing aids, background noise, and visual cues influence objective listening effort. Ear Hear. 2013; 34:e52–e64.

35. Wu Y, Aksan N, Rizzo M *et al*. Measuring listening effort: Driving simulator versus simple dual task paradigm. Ear and Hearing. 2014;35:623-632.

36. Pashler H. Dual-task interference in simple tasks: data and theory. Psychol Bull. 1994;116(2): 220–244.

37. Sun PW, Hines A. Listening Effort Informed Quality of Experience Evaluation. Front. Psychol. (2022); 12:767840.

38. Gates NJ, Sachdev PS, Fiatarone Singh MA *et al*. Cognitive and memory training in adults at risk of dementia: a systematic review. BMC Geriatr. 2011 Sep 25;11:55.

39. Rakerd B, Seitz PF, Whearty M. Assessing the cognitive demands of speech listening for people with hearing losses. Ear Hear. 1996;17(2):97-106.

40. Panza F, Solfrizzi V, Seripa D *et al*. Age-related hearing impairment and frailty in Alzheimer's disease: interconnected associations and mechanisms. Front Aging Neurosci. 2015;7: 113.

41. Kiely K, Anstey K, Luszcz A. Dual sensory loss and depressive symptoms: The importance of hearing, daily functioning, and activity engagement. Front Hum Neuroscience. 2013;7:837.

42. Panza F, Lozupone M, Sardone R *et al*. Sensorial frailty: age-related hearing loss and the risk of cognitive impairment and dementia in later life. Ther Adv Chronic Dis. 2019;10: 2040622318811000.

43. Spiellberger W. The effect of trait anxiety and situational stress on working memory capacity. J Res Pers. 1979;26:235-241.