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The relationship between age, acceptable noise level, and listening effort in middle-aged and older-aged individuals

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ABSTRACT

Objective: The purpose of the study was to evaluate listening effort in adults who experience varied annoyance towards noise.
Materials and methods: Fifty native Kannada-speaking adults aged 41–68 years participated. We evaluated the participant's acceptable noise level while listening to speech. Further, a sentence-final word-identification and recall test at 0 dB SNR (less favorable condition) and 4 dB SNR (relatively favorable condition) was used to assess listening effort. The repeat and recall scores were obtained for each condition.
Results: The regression model revealed that the listening effort increased by 0.6% at 0 dB SNR and by 0.5% at 4 dB SNR with every one-year advancement in age. Listening effort increased by 0.9% at 0 dB SNR and by 0.7% at 4 dB SNR with every one dB change in the value of Acceptable Noise Level (ANL). At 0 dB SNR and 4 dB SNR, a moderate and mild negative correlation was noted respectively between listening effort and annoyance towards noise when the factor age was controlled.
Conclusion: Listening effort increases with age, and its effect is more in less favorable than in relatively favorable conditions. However, if the annoyance towards noise was controlled, the impact of age on listening effort was reduced. Listening effort correlated with the level of annoyance once the age effect was controlled. Furthermore, the listening effort was predicted from the ANL to a moderate degree.

1. Introduction

Few individuals exhibit difficulty understanding speech in a quiet environment despite having normal hearing, but this difficulty increases multifold when competing noise shares a similar spectrum with speech (Schneider et al., 2002). Decoding speech in the presence of noise requires the person to utilize cognitive resources (Chen et al., 2022). Listening in a noisy background causes a greater expenditure of cognitive resources, which in turn makes the listener's task more difficult and effortful. Listening effort is the cognitive resource necessary for speech recognition (Picou and Ricketts, 2014). Effort in listening depends on subjective factors like motivation (Eckert et al., 2016), fatigue (Hornsby et al., 2016), and external factors like linguistic complexity (Peelle, 2018). Akeroyd (2008) reported that reduced working memory and attention contribute to difficulties in speech understanding in older adults with normal hearing, especially in adverse listening conditions.

Listening effort can be objectively assessed using the dual-task paradigm (Desjardins and Doherty, 2013; Sarampalis et al., 2009). The dual-task paradigm involves performing a primary as well as a concomitant secondary task. The primary task utilizes the required mental capacity, whereas, the secondary task operates on the spare capacity available after the primary task is performed. Therefore, listening effort is indicated based on the impairment in the secondary task (Kahneman, 1973). Older adults use greater cognitive resources to attend to speech in noisy backgrounds, with limited resources for consequent and successive tasks (Gosselin and Gagné, 2011; Tun et al., 2009). It has been observed that cognition decline can begin as early as 45 years (Degeest et al., 2015; Singh-Manoux et al., 2012). Vaughan et al. (2006) stated that listening effort can be

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a predictable factor for speech recognition in noise in older adults only if the audibility is controlled. Thus, the evaluation of auditory listening effort, including the assessment of speech perception in noise is warranted.

Age-related variations in listening effort have been documented in the past (Degeest et al., 2015; Kwak and Han, 2021; Sarampalis et al., 2009; Ward et al., 2017). Listening effort assessed using speech recognition in noise revealed that older adults must put more effort into listening than younger adults (Desjardins and Doherty, 2013; Ward et al., 2017). The attributed reason can be elucidated by the capacity theory of attention developed by Kahneman (1973). According to this theory, listeners dedicate a significant chunk of their cognitive resources just to attend to speech in a noisy environment. An available limited reserve is utilized for subsequent processing of storing information into memory, solving ambiguity by contextual cues, and finally generating a quick response to speech. The attention theory explaining the effort in listening was substantiated by Rudner et al. (2011), wherein, it was reported that participants could recognize the word in noise with more effort but could not recall the recognized word later. They suggested that more cognitive resources are allocated for the initial speech perception process, with limited resources available for subsequent recall. This is because the inherent cues in speech are partly lost and distorted due to noise. In the subsequent stage, parts of the message must be integrated with the retained processing of the initial parts of a message for later recall to comprehend the message. The outcome could either end up in a slowdown/breakdown of communication and or misperception. Rönnberg (2003) and Peelle (2018) opined that the allocation of optimum cognitive resources is necessary for speech perception.

Understanding speech in adverse listening conditions is critical for effective communication. The acceptable noise levels are a means to evaluate the impact of noise on speech perception (Nabelek et al., 2006). Annoyance towards noise can be objectively assessed using an acceptable noise level (ANL) test. The stimulus used is a running speech presented at the Most Comfortable Level (MCL) along with noise. The Background Noise Level (BNL) will be assessed objectively as the listener's ability to tolerate background noise when listening to speech. The difference between MCL and BNL will be calculated to achieve the ANL in dB. Nabelek et al. (2006) demonstrated the ANL to range from 2 to 27 dB. Yet another similar study by Plyler et al. (2011) reported the ANL values to range from −3.5 to 27 dB. In contrast, Freyaldenhoven et al. (2008) reported that the ANL values range from −2 to 18 dB. However, there are hardly any studies that have assessed the allocation of cognitive resources through listening effort in individuals who show annoyance towards noise.

The present study, therefore, incorporated an evaluation of annoyance towards noise in older adults in whom listening effort may be found to vary. Further, the relation between aging, ANL, and listening effort is not well understood. It is speculated that individuals who show annoyance towards noise may need more cognitive resources for selective attention and segregation of noise from speech. Thus, the research question formulated is whether individuals who show varied annoyance levels towards the noise exhibit differences in the magnitude of listening effort. Nevertheless, it requires empirical evidence to prove the speculation mentioned above. This study necessitates determining the listening effort in adults with varying levels of annoyance toward noise. Therefore, the hypothesis put forth is, that one who has difficulty putting up with noise may experience higher effort in listening than one who can put up with noise. The study's objective was to determine the relationship between age, ANL, and listening effort in less favorable (poor signal-to-noise ratio) and relatively favorable conditions (better signal-to-ratio). In addition, to predict the listening effort from age after controlling the factor ANL and vice versa.

2. Method

2.1. Participants

Fifty native Kannada-speaking adults aged 41 to 68 years (mean age: 54.28 years; age range = 27 years; SD = 6.47) were selected using a purposive sampling technique. All participants had normal hearing sensitivity with reference to age and gender-matched hearing thresholds, not poorer than the 95th percentile as per ISO 7029 (International Organization for Standardization. ISO, 2017). All of them had normal middle ear status suggested by ‘A’ type tympanogram with the acoustic reflexes present bilaterally at frequencies 500 Hz, 1 kHz, and 2 kHz. Otoacoustic Emissions testing was done to determine normal outer hair cell functioning. Only individuals with a bilateral presence of otoacoustic emissions were selected.

Participants whose score was 26 and above on the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005) were included. None of them had a history of noise exposure, psychological, or neurological issues, nor were they under prolonged medications. All the participants expressed their consent to participate. The study adheres to ethical guidelines for biobehavioral research involving human subjects. The ambient noise levels were as per the permissible limits (American National Standards Institute, 1991). Other than the conventional audiological evaluation (pure-tone audiometry, speech audiometry, and oto-acoustic emission test), the annoyance towards noise was also measured using an acceptable noise level test (Nabelek et al., 1991). Listening effort was measured using the sentence-final word identification and recall (SWIR) test. The ANL values and scores obtained in the primary and secondary tasks of the listening effort are given in Appendix 1.

2.2. Stimuli and generation of noise

Twenty-four lists of standardized Kannada sentences were used as the target stimuli in the SWIR test to assess listening effort (Geetha et al., 2014). Each list had ten sentences. The noise used was speech-shaped, and it was prepared using MATLAB (version-2013b). The sentences were concatenated. Speech spectrum was performed every 100 ms (short bin) and summated to obtain the long-term average speech spectrum (LTASS). White noise was passed through an Infinite impulse response (IIR) filter and fed to inverse filtering to derive the long-term average spectrum similar to the spectral characteristics of target sentences used in the study.

2.2.1. Stimulus preparation to assess listening effort

The SWIR test standardized in Kannada (Shetty and Kumar, 2018) was used. The SWIR test, developed on lines of the dual-task paradigm, was administered using a software (Shetty and Kumar, 2018). The listening effort software was loaded into the HP laptop having the specification of an i5 processor and a 64-bit operating system with the standard sound card. A new project was created in the software. The target Kannada sentences were loaded as the ‘speech files'. The speech-shaped noise generated was uploaded as the ‘noise file’. The target sentences were mixed at two SNRs- 0 dB SNR (120 sentences) and 4 dB SNR (120 sentences). The 0 dB and 4 dB SNRs were chosen to represent realistic listening conditions (Brons et al., 2014; Gustafson et al., 2014; Neher et al., 2014). Thus, in total, there were 240 target sentences.

Each block had five sentences, and therefore the recall number was ‘5’ The number of blocks per SNR was 24 (number of sentences per SNR/recall number). Therefore, the total number of blocks was 48. The inter-stimulus interval (ISI) was set to 3000 ms, which was the duration between every sentence in the primary task. The inter-block interval (IBI) was set to 10,000 ms, which was the duration between the presentation of two successive blocks. Randomized and counterbalancing of the stimuli was done among participants. A calibrated 1 KHz tone was presented at 65 dB SPL. The laptop's volume was increased until the loudspeaker (Genelec) output read 85 dB SPL in the sound level meter (B & K 2238).

2.2.2. Presentation of stimuli

The stimuli were routed through loudspeakers. Three loudspeakers positioned at 0°, +45°, and −45°, were kept 1 m from the participant. At 0° azimuth, a target standardized Kannada sentence was delivered, and the speech-shaped noise was presented via the loudspeakers at +45° and −45° azimuth. At the MCL of the participant, the listening effort was determined at 0 dB SNR (less favorable condition) and 4 dB SNR (relatively favorable condition). Participants were instructed that the sentences would be presented in multiple blocks, and each block would contain five sentences. They were asked to repeat only the last word of each sentence presented (primary task). Guessing of the word was also encouraged. They were told to remember their responses as they would be asked to recall the same later. After the presentation of five sentences, an audio beep (pure tone of 200 ms) was played, which was an indication for the recall to be initiated (secondary task). The tester documented the repeat and recall responses in the software. Breaks between the blocks were given if the participant indicated signs of fatigue.

2.3. Analyses of listening effort

A score of 1 and 0 was awarded for correct and incorrect/no response respectively, in the primary as well as the secondary tasks. The test included 24 blocks with five sentences in each block (block count per SNR). The maximum repeat score per SNR was 120. Similarly, the maximum score per block was 5. Scores were represented as a) repeat scores and b) recall scores. The formula to convert the raw score into a percentage and then into arcsine units is given elsewhere (Shetty et al., 2022).

2.4. Subjective listening effort

Three questions from the speech, spatial, and qualities of hearing scale (Gatehouse and Noble, 2004) were utilized to determine the subjective listening effort. In the current study, the questions were slightly modified but semantically similar. Participants graded their current concentration level [how well can you concentrate when listening to a sentence in the presence of noise? (1 = concentrate hard; 10 = no need to concentrate)], effort [do you have to put in a lot of effort to listen to what is being said in the sentence in the presence of noise? (1 = a lot of effort; 10 = no effort)] and ignoring the background noise [how well can you easily ignore noise while trying to listen to the sentence?] on a ten-point rating scale. The maximum possible score was ten. Participants responded to these questions after the objective listening effort test and each participant was instructed to provide a subjective estimate of listening effort.

2.5. Acceptable noise level (ANL)

For the ANL measurement, the set of instructions proposed by Nabelek et al. (1991) was adopted. The audiometer's loudspeaker was positioned at 45° azimuth and 1 m from the participant. The recorded Kannada passage was routed via the auxiliary input of the audiometer to the loudspeaker at the speech recognition threshold level. To reliably determine the participant's MCL, the level was adjusted in steps of 5 dB up to the MCL and subsequently in smaller step sizes of +1 and −2 dB. MCL was obtained as the average of two trials.

After this, a speech-shaped noise was presented at 30 dB HL. The noise level was increased gradually in 5 dB steps and subsequently in 2 dB steps. This was done till the participant could simultaneously listen to the noise as well as the passage without complaining of fatigue. The Background Noise Level (BNL) was calculated as the highest level of noise one could tolerate without experiencing fatigue. These steps were repeated, and the BNL obtained from two trials were averaged. The ANL was determined by obtaining the difference between MCL and BNL in dB HL. The testing of one participant took approximately 30 minutes to complete. The mean ANL value from the study participants accounts for 2.1 dB, the minimum ANL value is −7 dB, the maximum value is 13 dB, and the range of ANL value is 20 dB.

2.6. Statistical analysis

Statistical analysis was done using SPSS software (ver.21). To verify the normal distribution of data ($p > 0.05$), the Shapiro-Wilk's test was utilized. A dependent sample *t*-test was done to compare the repeat and recall scores obtained at 0 dB and 4 dB SNR conditions. A Pearson's product-moment correlation was done to determine the relationship between age and listening effort as well as ANL and listening effort at the two SNR conditions Further, a partial correlation analysis was performed to determine the relationship between the variables while controlling one variable and following this procedure, regression analysis was done to predict one variable from the other. Additionally, a Pearson's product-moment correlation analysis was done to compute the relationship between measures of subjective and objective listening effort and MoCA scores with ANL and listening effort.

3. Results

3.1. Repeat and recall scores of the listening effort test

A dependent samples *t*-test revealed a significantly reduced repeat score at 0 dB SNR than at 4 dB SNR ($t(49) = -11.22$, $p = 0.001$). Similarly, a reduced recall score was noted at 0 dB SNR than at 4 dB SNR, which was found significant ($t(49) = -18.53$, $p = 0.001$). On comparison of repeat and recall scores at each SNR, it was observed that when the repeat score was less, their recall score

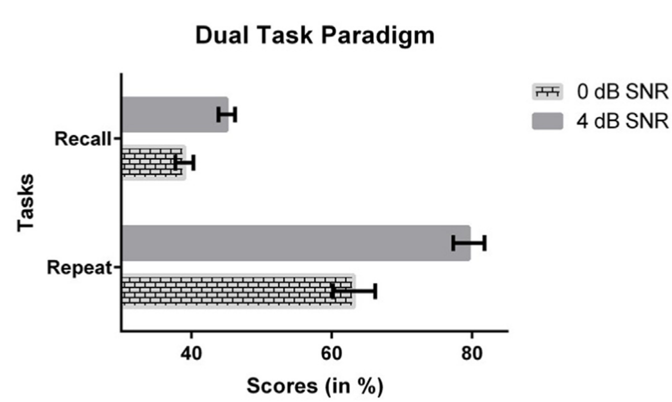

Fig. 1. Repeat and recall scores at 0 dB SNR and 4 dB SNR on the dual-task to account for listening effort.

was also found to be low (at 0 dB SNR), and vice versa at 4 dB SNR (Fig. 1). As a result, it appeared that the performance in the primary task (repeat) reflected the effort that the participants had to 'put in' in the secondary task (recall). On average, a 6% and 16% reduction in the recall and repeat scores were noted when the SNR condition changed from a relatively favorable (4 dB SNR) to a less favorable condition (0 dB SNR). Variations in performance on the secondary task served as the estimate of listening effort (Kathleen Pichora-Fuller and Singh, 2006). Thus, only the recall score was considered to document the listening effort. The 'recall' is mentioned as a listening effort throughout the document from here onwards.

3.2. *Relationship between age and listening effort*

The Pearson product-moment correlation results indicated a mild negative correlation between age and the scores on the listening effort at 0 dB SNR, [r (49) = - 0.412, N = 50, p = 0.003], and at 4 dB SNR, [r (49) = −0.383, N = 50, p = 0 0.006]. This indicated that listening effort increased (recall score reduced) with advancement in age in less favorable (0 dB SNR) and relatively favorable (4 dB SNR) conditions (Fig. 2).

3.2.1. *0 dB SNR – less favorable condition*

The partial correlation analysis results revealed no relationship between listening effort and age [r (47) = −0.121, N = 50, p = 0.408] when ANL was controlled. However, zero-order correlation revealed a moderate negative relationship between listening effort and age [r (49) = −0.418, N = 50, p = 0.003], indicating that the recall score reduced (listening effort increased) with an advance in age.

3.2.2. *4 dB SNR – relatively favorable condition*

The partial correlation results revealed no relationship between listening effort and age [r (47) = −0.135, N = 50, p = 0.354] when 'ANL' was controlled. However, zero-order correlation revealed a mild negative correlation between listening effort and age [r (48) = −0.383, N = 50, p = 0.006], indicating that the recall reduced (listening effort increased) with the advance in age.

A simple linear regression was done to assess the relationship between age and listening effort at 0 dB SNR and 4 dB SNR. The ANOVA helped us to decide whether the regression line does any better at prediction. The prediction was significant, and so we conclude that in this case, our regression line is significantly better at predicting the listening effort from age at 0 dB SNR [F (1, 48) = 10.14, p = 0.003] and 4 dB SNR [F (1, 48) = 8.27, p = 0.005]. R^2 was 0.174, at 0 dB SNR, suggesting that the relationship of this variable with age can explain about 17% of the variation in the listening effort. Whereas, at 4 dB SNR, the R^2 was 0.147, which accounts for only 15%. The slope coefficient for the listening effort score was −0.590 at 0 dB SNR and −0.492 at 4 dB SNR, so the listening effort increased by 0.6% at 0 dB SNR and 0.5% at 4 dB SNR in every one-year advance in age (Fig. 2 A and B). The equation to predict listening effort or otherwise recall score from age is given by the formula $y = a + b(x)$ (a = 71.05; b = −0.590) at 0 dB SNR and (a = 71.72; b = −0.492) at 4 dB SNR.

3.3. *Relationship between listening effort and acceptable noise level*

A Pearson product-moment correlation to examine the relationship between listening effort and the amount of annoyance towards the noise one can put up with (ANL) was performed. A negative correlation between the two variables, [r = −0.547, n = 49, p = 0.001] was found at 0 dB SNR and [r = −0.467, n = 49, p = 0.001] at 4 dB SNR, respectively. A scatterplot summarizes the results (Fig. 3 A and B). Overall, a moderate negative correlation between listening effort and ANL, irrespective of SNRs was noted. Therefore, the listening effort (recall score) reduced with an increase in ANL at each SNR.

A simple linear regression analysis was done to investigate the relationship between ANL and listening effort at 0 dB SNR and 4 dB SNR. The ANOVA helped us decide whether the regression line does any better at prediction. The predictions were significant, and so we conclude that in this case, our regression line is significantly better at predicting the listening effort from ANL at 0 dB SNR [F (1, 48) = 20.54, p = 0.000] and 4 dB SNR [F (1, 48) = 13.51, p = 0.001]. R^2 was 0.300 at 0 dB SNR, suggesting that the relationship of this variable with the ANL can explain about 30% of the variation in the listening effort. Whereas, at 4 dB SNR, the R^2 was 0.227, which accounts for only 23%. The slope coefficient for the listening effort was −0.919 at 0 dB SNR and −0.714 at 4 dB SNR, so the listening effort increased by 0.9% at 0 dB SNR and 0.7% at 4 dB SNR in every one dB change in the value of ANL (Fig. 3). The equation to predict

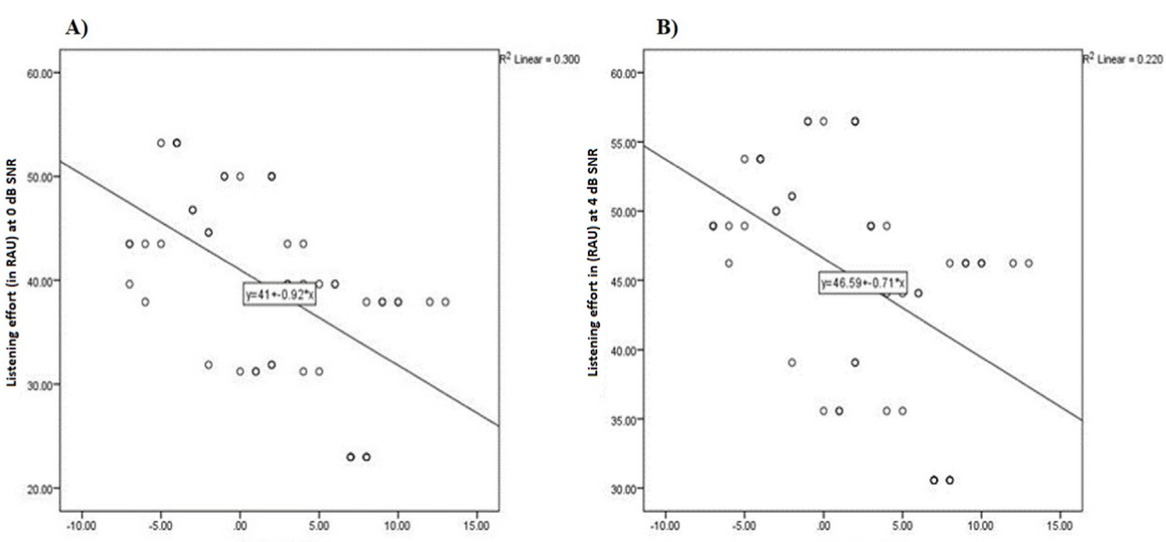

Fig. 2. Scatter plot showing the relationship between ANL and listening effort at 0 dB SNR (A) and 4 dB SNR (B).

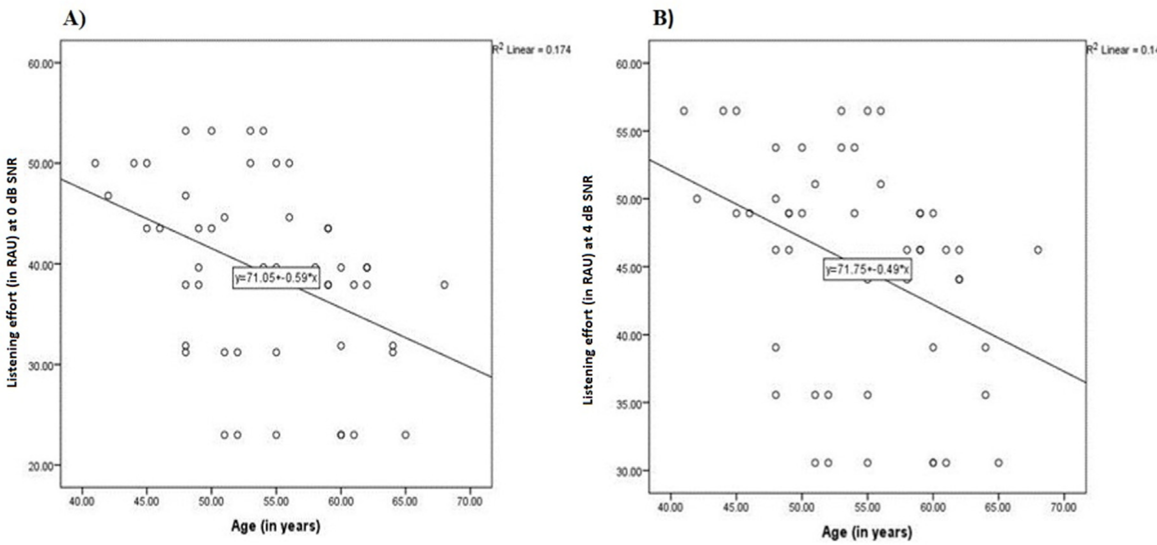

Fig. 3. Scatter plot showing the relationship between age and listening effort at 0 dB SNR (A) and 4 dB SNR (B).

listening effort or otherwise recall score from the ANL is $y = a + b(x)$ ($a = 41.05$; $b = -0.919$) at 0 dB SNR and ($a = 46.58$; $b = -0.714$) at 4 dB SNR.

3.3.1. 0 dB SNR – less favorable condition

A partial correlation was performed to evaluate the relationship between an individual's listening effort and ANL when the factor 'age' was controlled. The results indicated a moderate negative correlation between listening effort and annoyance towards the noise (ANL) [r (47) $= -0.405$, N = 50, $p = 0.004$]. It is inferred that the difference in ANL values increases the listening effort when the factor 'age' is controlled. A residue of what is leftover when controlling the variable 'age' is scatter plotted with ANL and the recall score is depicted in Fig. 4.

Besides, a linear regression was administered on the residue of the ANL and the listening effort when controlling the factor 'age.' The prediction was significant, and so we conclude that in this case, our regression line is significantly better at predicting the listening effort from an individual's annoyance towards noise [F (1, 49) $= 9.422$, $p = 0.004$]. The R^2 was 0.164, suggesting that annoyance accounts for 16% of the variation in the listening effort. The slope coefficient for the recall score was -0.785, so the listening effort increased by 0.8% in every one dB increase in ANL by the study participants. The equation to predict listening effort or

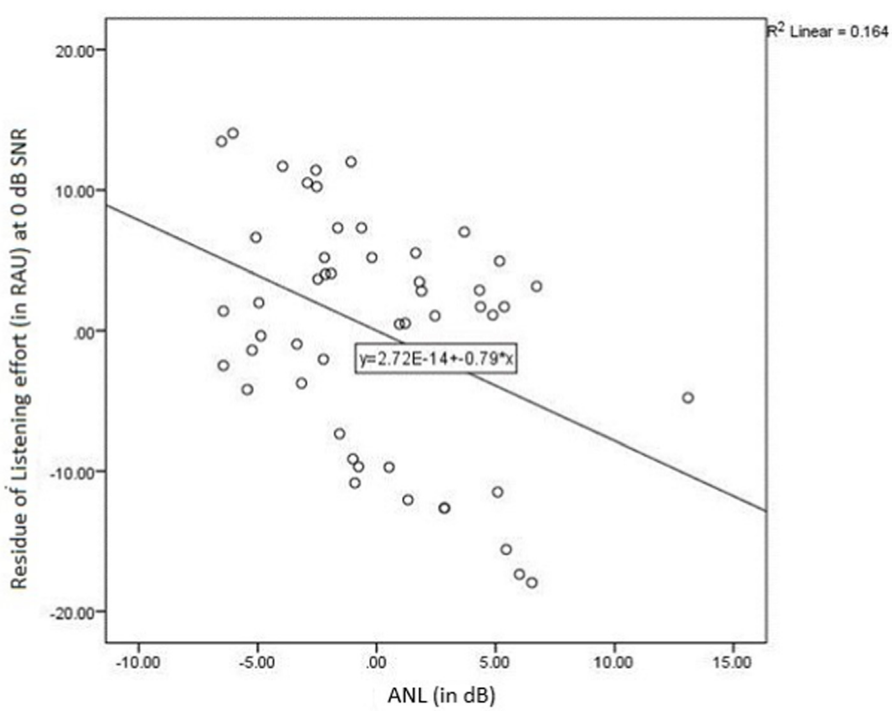

Fig. 4. Scatter plot showing the relationship between the residue of listening effort and the residue of annoyance value after controlling the factor 'age' in less favorable condition.

otherwise recall score from the ANL is $y = a + b(x)$ ($a = 1.27$; $b = -0.78$).

3.3.2. 4 dB SNR – relatively favorable condition

A partial correlation was performed to inspect the relationship between an individual's listening effort and ANL when controlling the factor 'age.' Results revealed a mild negative correlation between listening effort and annoyance towards the noise (ANL) [r (47) = −0.319, N = 50, $p = 0.025$]. It is inferred that the difference in ANL values increased the listening effort when the factor 'age' was controlled. A residue of what is leftover on the controlled variable 'age' is scatter plotted with the ANL, and the recall score is depicted in Fig. 5.

In addition, a linear regression was administered on the residue of the ANL and the listening effort. The prediction was significant, and so we conclude that in this case, our regression line was significantly better at predicting the listening effort score from an individual's annoyance towards noise [F (1, 49) = 5.446, $p = 0.024$]. R^2 was 0.102, suggesting that about 10% of the variation in the listening effort can be accounted for by this variable's relationship with annoyance when controlling the factor 'age'. The slope coefficient for the listening effort was −0.571, so the listening effort increased by 0.6% in every one dB increase in the ANL by the study participants. The equation to predict the listening effort or otherwise recall score from the ANL is $y = a + b(x)$ ($a = 1.01$; $b = -0.57$).

3.4. Predicting listening effort from age and ANL

A multiple regression analysis was conducted to investigate the relationship of age and ANL with the listening effort for the less favorable and more favorable conditions. Irrespective of condition, as shown in Fig. 6 A and B, the age and the ANL were negatively correlated with the score of listening effort indicating that those with advanced age and higher scores on ANL tended to have reduced recall scores or otherwise effort in listening. The multiple regression model with two predictors (age and ANL) to predict the listening effort produced $R^2 = 0.557$, F (2, 49) = 10.55, $p = 0.000$ for 0 dB SNR and $R^2 = 0.484$, F (2, 49) = 7.176, $p = 0.002$ for 4 dB SNR. About 50% and 48% of the variation in the listening effort could be accounted for by the two variables for 0 dB SNR and 4 dB SNR respectively. The slope coefficient for the listening effort was −0.182 for age and −0.785 for ANL at 0 dB SNR-the listening effort increased by 0.2% with age and by 0.8% with ANL. Whereas the slope coefficient at 4 dB SNR for the listening effort was −0.195 for age and −0.571 for ANL, so the listening effort increased by 0.2% accounted from age in every one-year advancement in age and 0.6% considered from annoyance towards noise for every one dB change in the values of ANL. The equation to predict listening effort or otherwise recall score from the age and ANL is $y = a + b1(x1) + b2(x2)$ ($a = 50.59$; $b1$ (age) = -0.182 and $b2$ (ANL) = −0.785) at 0 dB SNR and ($a = 56.86$; $b1$ = - 0.195 (age) and b2 = −0.571 (ANL)) at 4 dB SNR.

3.5. Relationship between MoCA scores and listening effort/ANL

A Pearson product-moment correlation test was performed between the MoCA score and listening effort (at 0 dB SNR and 4 dB SNR)/acceptable noise level (Fig. 7). The results revealed a significant moderate positive relationship between MoCA score and listening effort at 0 dB SNR [r (47) = 0.685, N = 50, $p = 0.001$] and 4 dB SNR [r (47) = 0.646, N = 50, $p = 0.001$]. In addition, the correlation between the MoCA score and ANL revealed a significant strong negative relationship [r (48) = −0.750, N = 50, $p = 0.001$].

3.6. Objective and subjective effort in listening

The participant's listening effort obtained at the two SNRs and their subjective effort documented from the three questions were correlated using a Pearson product-moment correlation coefficient test. At favorable condition (4 dB SNR), the listening effort had no

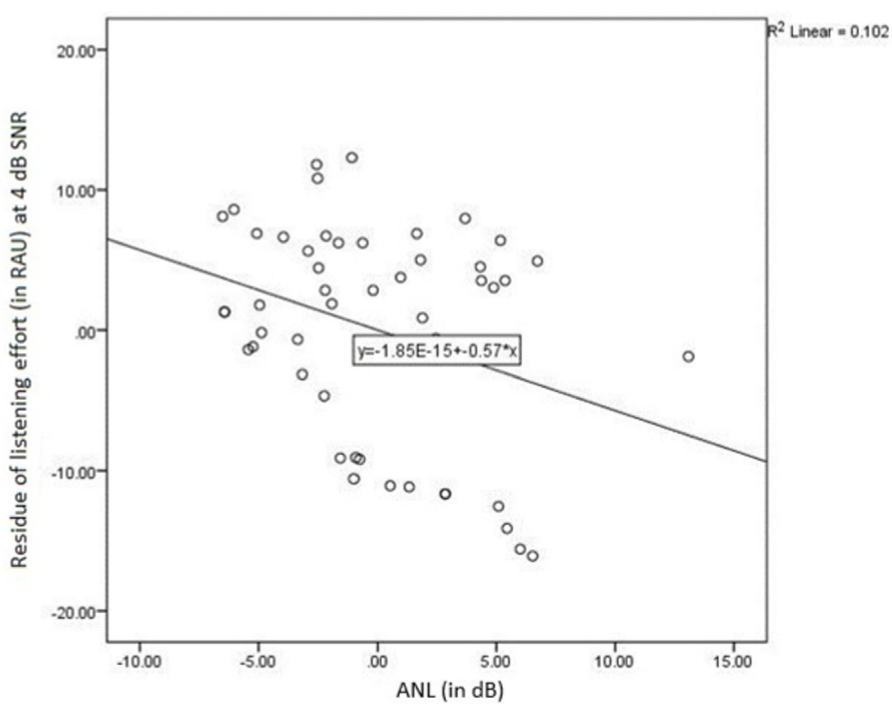

Fig. 5. Scatter plot showing the relationship between the residue of listening effort and the residue of annoyance value after controlling the factor 'age' in relatively favorable conditions.

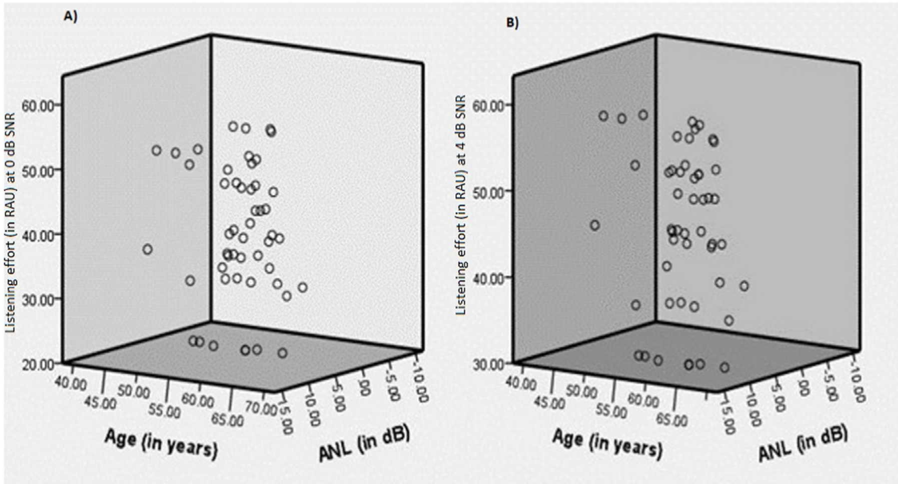

Fig. 6. A 3-D scatter plot showing the relationship between age (x-axis) and ANL (z-axis) on the listening effort (y-axis) at 0 dB SNR (A) and 4 dB SNR (B)).

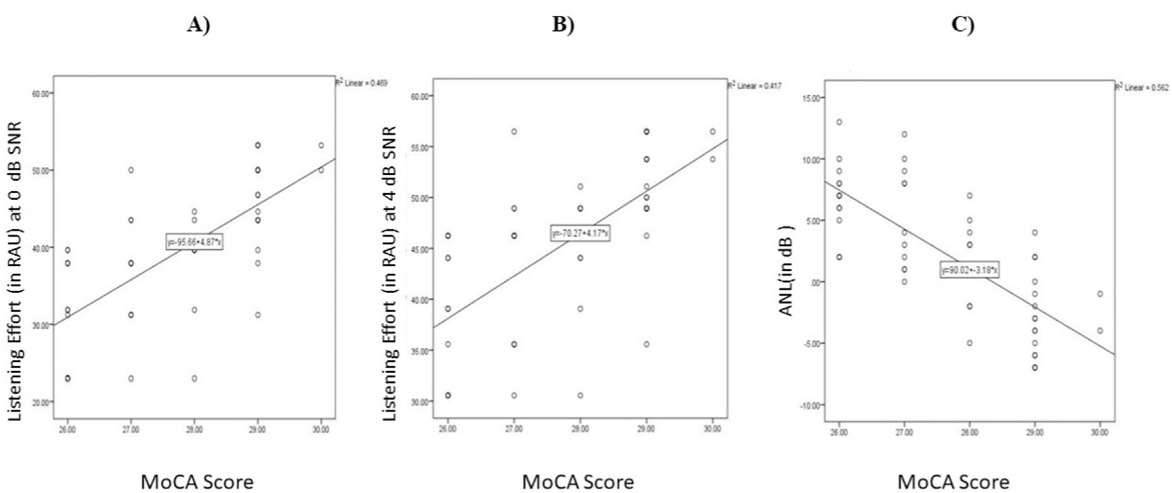

Fig. 7. Scatter plot between MoCA Score and listening effort at 0 dB SNR (A), 4 dB SNR (B), and ANL (C).

relationship with each of the questions that assessed subjective effort in listening such as concentration [r (47) = 0.101, N = 50, p = 0.485], effort [r (47) = 0.202, N = 50, p = 0.395] and ignoring the background noise [r (47) = −0.100, N = 50, p = 0.490]. However, at less favorable condition (at 0 dB SNR), the results revealed a significantly strong positive relationship between listening effort and questions of subjective listening effort reflected in concentration [r (47) = 0.869, N = 50, p = 0.001] and effort [r (47) = 0.754, N = 50, p = 0.001]. Additionally, a significantly strong negative relationship was noticed between listening effort and questions related to ignoring the background noise [r (47) = - 0.897, N = 50, p = 0.001].

4. Discussion

The most common complaint by older adults is an inability to understand speech in unfavorable listening conditions, and they often criticize when speech becomes unintelligible, especially in background noise. When the noise distorts an essential cue in speech, the cognitive reserve at higher centers uses most of the resources to make up for the loss of information at the peripheral system, making listening more effortful. The listening effort increased with the advance in age, and its effect was more when the listening condition changed from favorable to less favorable condition. The age-related cognitive and sensory decline starts at 40 years and above (McCoy et al., 2005; Singh-Manoux et al., 2012; Tun et al., 2009; Wingfield and Tun, 2001). In the present study, a mild negative correlation was found between listening effort and age and predicted the listening effort by 17% at 0 dB SNR and 15% at 4 dB SNR from the age. The listening effort increased by 0.6% at 0 dB SNR and 0.5% at 4 dB SNR with every one-year advance in age by the study participants (age ranged from 41 to 68 years). The findings of the study are partly in consensus with the previous research which reports increased listening effort in older adults when compared to younger adults (Desjardins and Doherty, 2013; Gosselin and Gagné, 2011; Tun et al., 2009). The study participants had normal to near-normal lower-level sensory processes as a function of age. Those individuals who had shown higher effort in listening may require a greater expenditure of cognitive resources to decode information in the presence of noise. This could be because allocating cognitive resources is fundamental as the attention is being simultaneously utilized for hearing, rehearsing, putting the information into short-term memory, and recalling it for later use. Although the current study did not involve objective tests to assess aspects of cognition such as attention, working memory, and processing speed, the relationship between MoCA scores and listening effort at 0 dB SNR and 4 dB SNR revealed a significant moderate positive correlation. It was inferred that those with a lower score on MoCA put more effort into listening. Additionally, a significantly strong negative correlation was observed between ANL and MoCA scores. To purport, individuals with lower ANL values had better generic cognitive functioning abilities as evidenced by a higher MoCA score. That is, those individuals with a lower value of ANL had good working memory capacity to concurrently store and process auditory linguistic information.

Consequently, when the listening condition was less favorable, a higher cognitive load was required to decipher the information to compensate for the peripheral processing due to the loss of information where cues are masked by noise. Thus, listening becomes more effortful, as reflected in the recall score. When we analyzed the pattern of recall scores, it was found that those individuals who had reduced recall scores could recall a few initial words (primacy effect) and the last word (recency effect). However, they found it difficult to recall the middle words (asymptote). The results on the pattern of recall score are in agreement with the findings of Lunner et al. (2016). The attributed reason could be that more cognitive resources were available to segregate speech from noise. With the available resources, they had managed to rehearse a few initial words and put them in the short-term memory for later recall and were left with relatively lower or no reserve to recall the middle order words, which were recognized in the primary task. Also, studies done in the past have suggested a dual-component model of recall involving both the short-term and long-term memory processes which explain the primary and recency effect (Atkinson and Shiffrin, 1968; Griffin et al., 2017; Murdock, 1962; Unsworth et al., 2010).

A moderate negative correlation between listening effort and ANL was found irrespective of SNRs. The listening effort increased by 0.9% at 0 dB SNR and 0.7% at 4 dB SNR for every one dB change in the value of ANL. The result suggested that individual differences in the ability to put up with noise may likely affect the listening effort. That is, those individuals who put up with less noise were found to have increased listening effort. Further, a significant relationship between ANL (higher ANL values) and the subjective rating of listening effort was found. It was revealed that those individuals with higher ANL found it difficult to concentrate and were unable to ignore the noise to attend to the speech. It led them to exaggerate more effort to listen. The correlation between the MoCA score and ANL revealed a significantly strong negative relationship. The reason could be a weaker cognitive control process of inhibition (Gorfein and MacLeod, 2007). That is, those individuals with higher ANL values were unable to suppress irrelevant signals when attending to speech which requires central cognitive processes. These individuals could have found it difficult to simultaneously allocate attention for attending to speech, putting it into short-term memory, rehearsing, and understanding speech in noise. Nevertheless, individuals who could put up with more noise were good at allocating the mental resources to segregate speech from noise. The remaining available resources were utilized effectively to perform successive cognitive tasks to follow the speech effortlessly. It signifies that those who are less annoyed by noise counteract the impact of challenging listening conditions.

After the factor 'ANL' was controlled using partial correlation, there was no relation between listening effort and age. This was true for each of the SNRs. However, at 0 dB SNR, a moderate and at 4 dB SNR, a mild negative correlation was noted between listening effort and annoyance towards the noise, when controlled the factor 'age.' The listening effort increased by 0.8% at 0 dB SNR and 0.6% at 4 dB SNR in every one dB increase in the ANL among the study participants. It was inferred that annoyance towards the noise was the predictive component of listening effort rather than the age among the study cohort. Those individuals with high ANL scores recruited more resources just to attend to the stimulus and were left with lower resources for storage and processing the input signal in their short-term memory. Studies have reported that individuals with a high working memory capacity are better at making up for the distorted signal in adverse listening situations. They are able to do so without exhausting the working memory capacity and therefore experience lesser effort in listening (Rönnberg et al., 2013; Rudner et al., 2012) The above-explained phenomenon was more pronounced linearly with every one dB increase in annoyance towards the noise.

In addition to assessing objective listening effort, documenting the listening effort subjectively will help in determining the link between the two measures. Assessment of subjective listening effort has been suggested to delineate the role of working memory capacity in understanding speech in adverse listening conditions (Rönnberg et al., 2013).

5. Conclusions

Irrespective of advances in age, one who was unable to put up with noise experienced greater listening effort than one who could put up with noise. Major cognitive resources were utilized to attend to the target speech and segregate the noise. A minimal reserve available for pertinent operations in the cognitive mechanism was unable to be accomplished effectively due to annoyance towards the noise. The products of primary and asymptotes (earlier) processing may not be available when recent (later) processing is complete.

6. Implication

Cognitive functions are essential for speech communication. The listening effort was the best possible test to assess cognitive function meant for speech perception with less time in routine clinical practice. Due to time constraints in routine clinical practice, testing ANL may be an efficient way of measuring listening effort. The ANL measurement is thus helpful in understanding speech recognition difficulties in noise among adults. Measuring annoyance towards noise to predict listening effort in adults with hearing loss may provide better insights into success with hearing aids in these individuals.

Declaration of competing interest

The authors declare no conflict of interest.

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APPENDIX 1

Table representing the participant's age (in years), pure-tone average (PTA; in dBHL), speech recognition threshold (SRT; in dBHL), ANL (in dB) with the data of primary and secondary task scores of listening effort at 0 dB SNR and 4 dB SNR (in %), and MoCA scores.

Sl. No	Age (years)	PTA (dB HL)	SRT (dB HL)	ANL (dB)	Secondary task		Primary task		MoCA Scores
					Recall – 0 dB SNR (%)	Recall- 4 dB SNR (%)	Repeat – 0 dB SNR (%)	Repat -4dB SNR (%)	
1	51	15	20	−2.00	44.61	51.07	91.67	90.83	29
2	46	10	15	−7.00	43.52	48.93	56.67	87.50	29
3	49	10	20	−7.00	39.63	48.93	45.83	85.00	29
4	61	16.25	25	−7.00	22.99	30.56	31.67	52.50	26
5	60	17.5	25	8.00	22.99	30.56	31.67	52.50	26
6	51	11.25	20	7.00	22.99	30.56	31.67	52.50	26
7	59	12.5	20	9.00	37.92	46.24	77.50	86.67	27
8	68	21.25	30	13.00	37.92	46.24	77.50	86.67	26
9	62	22.5	30	6.00	39.63	44.06	76.67	86.67	26
10	52	15	20	0.00	31.22	35.57	54.17	70.00	27
11	48	7.5	15	−2.00	31.87	39.06	20.83	46.67	28
12	48	5	10	12.00	37.92	46.24	77.50	86.67	27
13	44	5	10	2.00	50.00	56.48	82.50	93.33	27
14	59	16.25	25	4.00	43.52	48.93	56.67	87.50	27
15	56	16.25	25	2.00	50.00	56.48	82.50	93.33	29
16	42	11.25	20	−3.00	46.78	50.00	84.17	90.83	29
17	55	21.25	30	5.00	39.63	44.06	76.67	86.67	28
18	41	13.75	20	2.00	50.00	56.48	82.50	93.33	29
19	62	25	30	4.00	39.63	44.06	76.67	86.67	28
20	60	21.25	30	8.00	22.99	30.56	31.67	52.50	26
21	59	16.25	25	3.00	43.52	48.93	56.67	87.50	27
22	51	13.75	20	1.00	31.22	35.57	54.17	70.00	27
23	54	17.5	25	3.00	39.63	48.93	45.83	85.00	28
24	49	13.75	20	−6.00	37.92	46.24	77.50	86.67	29
25	55	15	25	1.00	31.22	35.57	54.17	70.00	27
26	59	16.25	25	10.00	37.92	46.24	77.50	86.67	26
27	58	20	30	6.00	39.63	44.06	76.67	86.67	26
28	50	16.25	25	−4.00	53.22	53.76	88.33	94.17	29
29	48	11.25	20	−3.00	46.78	50.00	84.17	90.83	29
30	65	16.25	20	7.00	22.99	30.56	31.67	52.50	28
31	49	15	25	−7.00	43.52	48.93	56.67	87.50	29
32	56	16.25	25	−2.00	44.61	51.07	91.67	90.83	28
33	53	20	30	−1.00	50.00	56.48	82.50	93.33	29
34	60	20	25	2.00	31.87	39.06	20.83	46.67	26
35	48	15	25	−4.00	53.22	53.76	88.33	94.17	30
36	60	16.25	25	3.00	39.63	48.93	45.83	85.00	28
37	45	13.75	20	−6.00	43.52	48.93	56.67	87.50	29
38	52	12.5	20	7.00	22.99	30.56	31.67	52.50	26
39	54	13.75	20	−4.00	53.22	53.76	88.33	94.17	29
40	55	16.25	25	8.00	22.99	30.56	31.67	52.50	27
41	53	22.5	30	−5.00	53.22	53.76	88.33	94.17	29
42	45	13.75	20	−1.00	50.00	56.48	82.50	93.33	30
43	64	25	35	5.00	31.22	35.57	54.17	70.00	26
44	62	21.25	35	8.00	37.92	46.24	77.50	86.67	27
45	58	21.25	30	9.00	37.92	46.24	77.50	86.67	26
46	55	16.25	20	.00	50.00	56.48	82.50	93.33	29
47	61	21.25	25	10.00	37.92	46.24	77.50	86.67	27
48	50	25	30	−5.00	43.52	48.93	56.67	87.50	28
49	48	21.25	25	4.00	31.22	35.57	54.17	70.00	29
50	64	25	25	2.00	31.87	39.06	20.83	46.67	26
Mean	54.28	16.42	23.80	2.180	39.00	45.03	63.18	79.55	27
Min	41.00	5	10	−7.00	22.99	30.56	20.83	46.67	26
Max	68.00	25	35	13.00	53.22	56.48	91.67	94.17	30
Range	27.00	20	25	20.00	30.24	25.92	70.84	47.50	4

References

Akeroyd, M.A., 2008. Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. Int. J. Audiol. 47 (Suppl. 2). https://doi.org/10.1080/14992020802301142.

American National Standards Institute, 1991. Maximum Permissible Ambient Noise Levels for Audiometric Test Rooms : ANSI S3.1-1991. Acoustical Society of America through the American Institute of Physics, New York N.Y. ASA 99-1991) [revision of S3.1-1977 (R 1986)].

Atkinson, R.C., Shiffrin, R.M., 1968. Human memory: a proposed system and its control processes. In: Kenneth W. Spence, Janet Taylor Spence. Academic Press, pp. 89–195. https://doi.org/10.1016/S0079-7421(08)60422-3.

Brons, I., Houben, R., Dreschler, W.A., 2014. Effects of noise reduction on speech intelligibility, perceived listening effort, and personal preference in hearing-impaired listeners. Trends Hear 18, 233121651455392. https://doi.org/10.1177/2331216514553924.

Chen, Y., Wong, L.L.N., Chan, S.S., Yu, J., 2022. Speech perception in noise is associated with different cognitive abilities in Chinese-speaking older adults with and without hearing aids. Front. Psychol. 12, 1–10. https://doi.org/10.3389/fpsyg.2021.640300.

Degeest, S., Keppler, H., Corthals, P., 2015. The effect of age on listening effort. J. Speech Lang. Hear. Res. 58, 1592–1600. https://doi.org/10.1044/2015_JSLHR-H-14-0288.

Desjardins, J.L., Doherty, K.A., 2013. Age-related changes in listening effort for various types of masker noises. Ear Hear. 34, 261–272. https://doi.org/10.1097/AUD.0B013E31826D0BA4.

Eckert, M.A., Teubner-Rhodes, S., Vaden, K.I., 2016. Is listening in noise worth it? The neurobiology of speech recognition in challenging listening conditions. Ear Hear. 37, 101S–110S. https://doi.org/10.1097/AUD.0000000000000300.

Freyaldenhoven, M.C., Plyler, P.N., Thelin, J.W., Muenchen, R.A., 2008. Acceptance of noise growth patterns in hearing aid users. J. Speech Lang. Hear. Res. 51, 126–135. https://doi.org/10.1044/1092-4388(2008/009.

Gatehouse, S., Noble, I., 2004. The speech, spatial and qualities of hearing scale (SSQ). Int. J. Audiol. 43, 85–99. https://doi.org/10.1080/14992020400050014.

Geetha, C., Shivaraju, K., Kumar, S., Manjula, P., Pavan, M., 2014. Development and standardisation of the sentence identification test in the Kannada language. J. Hear. Sci. 4, 18–26.
Gorfein, D., MacLeod, C., 2007. Inhibition in Cognition. American Psychological Association, Washington, DC.
Gosselin, P.A., Gagné, J.P., 2011. Older adults expend more listening effort than young adults recognizing speech in noise. J. Speech Lang. Hear. Res. 54, 944–958. https://doi.org/10.1044/1092-4388(2010/10-0069.
Griffin, J.W., John, S.E., Adams, J.W., Bussell, C.A., Saurman, J.L., Gavett, B.E., 2017. The effects of age on the learning and forgetting of primacy, middle, and recency components of a multi-trial word list. J. Clin. Exp. Neuropsychol. 39, 900–912. https://doi.org/10.1080/13803395.2017.1278746.
Gustafson, S., McCreery, R., Hoover, B., Kopun, J.G., Stelmachowicz, P., 2014. Listening effort and perceived clarity for normal-hearing children with the use of digital noise reduction. Ear Hear. 35, 183–194. https://doi.org/10.1097/01.aud.0000440715.85844.b8.
Hornsby, B.W.Y., Naylor, G., Bess, F.H., 2016. A taxonomy of fatigue concepts and their relation to hearing loss. Ear Hear. 37, 136S–144S. https://doi.org/10.1097/AUD.0000000000000289.
International Organization for Standardization. ISO, 2017. ISO 7029:2017 Acoustics - Statistical distribution of hearing thresholds related to age and gender. https://www.iso.org/standard/42916.html.
Kahneman, D., 1973. Attention and Effort. Prentice-Hall, Englewood Cliffs, NJ.
Kathleen Pichora-Fuller, M., Singh, G., 2006. Effects of age on auditory and cognitive processing: implications for hearing aid fitting and audiologic rehabilitation. Trends Amplif 10 (1), 29–59. https://doi.org/10.1177/108471380601000103.
Kwak, C., Han, W., 2021. Age-related difficulty of listening effort in elderly. Int. J. Environ. Res. Publ. Health 18. https://doi.org/10.3390/ijerph18168845.
Lunner, T., Rudner, M., Rosenbom, T., Ågren, J., Ng, E.H.N., 2016. Using speech recall in hearing aid fitting and outcome evaluation under ecological test conditions. Ear Hear. 37, 145S–154S. https://doi.org/10.1097/AUD.0000000000000294.
McCoy, S.L., Tun, P.A., Cox, L.C., Colangelo, M., Stewart, R.A., Wingfield, A., 2005. Hearing loss and perceptual effort: downstream effects on older adults' memory for speech. Q. J. Exp. Psychol. 58, 22–33. https://doi.org/10.1080/02724980443000151.
Murdock, B.B., 1962. The serial position effect of free recall. J. Exp. Psychol. 64, 482–488. https://doi.org/10.1037/h0045106.
Nabelek, A.K., Freyaldenhoven, M.C., Tampas, J.W., Burchfield, S., Muenchen, R.A., 2006. Acceptable noise level as a predictor of hearing aid use. J. Am. Acad. Audiol. 17, 626–639. https://doi.org/10.3766/JAAA.17.9.2.
Nabelek, A.K., Tucker, F.M., Letowski, T.R., 1991. Toleration of background noises. J. Speech Hear. Res. 34, 679–685. https://doi.org/10.1044/JSHR.3403.679.
Nasreddine, Z.S., Phillips, N.A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J.L., Chertkow, H., 2005. The Montreal Cognitive assessment, MoCA: a brief screening tool for mild cognitive impairment. J. Am. Geriatr. Soc. 53, 695–699. https://doi.org/10.1111/J.1532-5415.2005.53221.X.
Neher, T., Grimm, G., Hohmann, V., 2014. Perceptual consequences of different signal changes due to binaural noise reduction. Ear Hear. 35, e213–e227. https://doi.org/10.1097/AUD.0000000000000054.
Peelle, J.E., 2018. Listening effort: how the cognitive consequences of acoustic challenge are reflected in brain and behavior. Ear Hear. 39, 204–214. https://doi.org/10.1097/AUD.0000000000000494.
Picou, E.M., Ricketts, T.A., 2014. The effect of changing the secondary task in dual-task paradigms for measuring listening effort. Ear Hear. 35, 611–622. https://doi.org/10.1097/AUD.0000000000000055.
Plyler, P.N., Alworth, L.N., Rossini, T.P., Mapes, K.E., 2011. Effects of speech signal content and speaker gender on acceptance of noise in listeners with normal hearing. Int. J. 50, 243–248. https://doi.org/10.3109/14992027.2010.545082.
Rönnberg, J., 2003. Cognition in the hearing impaired and deaf as a bridge between signal and dialogue: a framework and a model. Int. J. Audiol. 42 (Suppl. 1). https://doi.org/10.3109/14992020309074626.
Rönnberg, J., Lunner, T., Zekveld, A., Sörqvist, P., Danielsson, H., Lyxell, B., Dahlström, Ö., Signoret, C., Stenfelt, S., Pichora-Fuller, M.K., Rudner, M., 2013. The Ease of Language Understanding (ELU) model: theoretical, empirical, and clinical advances. Front. Syst. Neurosci. 7. https://doi.org/10.3389/fnsys.2013.00031.
Rudner, M., Lunner, T., Behrens, T., Thorén, E.S., Rönnberg, J., 2012. Working memory capacity may influence perceived effort during aided speech recognition in noise. J. Am. Acad. Audiol. 23, 577–589. https://doi.org/10.3766/jaaa.23.7.7.
Rudner, M., Rönnberg, J., Lunner, T., 2011. Working memory supports listening in noise for persons with hearing impairment. J. Am. Acad. Audiol. 22, 156–167. https://doi.org/10.3766/JAAA.22.3.4.
Sarampalis, A., Kalluri, S., Edwards, B., Hafter, E., 2009. Objective measures of listening effort: effects of background noise and noise reduction. J. Speech Lang. Hear. Res. 52, 1230–1240. https://doi.org/10.1044/1092-4388(2009/08-0111.
Schneider, B.A., Daneman, M., Pichora-Fuller, M.K., 2002. Listening in aging adults: from discourse comprehension to psychoacoustics. Can. J. Exp. Psychol. 56, 139–152. https://doi.org/10.1037/H0087392.
Shetty, H.N., Kumar, U.A., 2018. Development of Some Auditory Related Cognitive Tests: Assessment of Cognitive Reserve in Older Adults.
Shetty, H.N., Raju, S., Kumar, Y., Singh, S.S., 2022. Listening effort in individuals with noise-induced hearing loss. Hear. Bal. Commun. 20, 263–271. https://doi.org/10.1080/21695717.2022.2102733.
Singh-Manoux, A., Kivimaki, M., Glymour, M.M., Elbaz, A., Berr, C., Ebmeier, K.P., Ferrie, J.E., Dugravot, A., 2012. Timing of onset of cognitive decline: results from Whitehall II prospective cohort study. BMJ 344. https://doi.org/10.1136/BMJ.D7622.
Tun, P.A., Benichov, J., Wingfield, A., 2009. Effortful processing of spoken sentences in younger and older adults: effects of age and hearing. In: Cognitive Aging Conference. Atlanta, GA.
Unsworth, N., Spillers, G.J., Brewer, G.A., 2010. The contributions of primary and secondary memory to working memory capacity: an individual differences analysis of immediate free recall. J. Exp. Psychol. Learn. Mem. Cogn. 36, 240–247. https://doi.org/10.1037/a0017739.
Vaughan, N., Storzbach, D., Furukawa, I., 2006. Sequencing versus nonsequencing working memory in understanding of rapid speech by older listeners. J. Am. Acad. Audiol. 17, 506–518. https://doi.org/10.3766/JAAA.17.7.6.
Ward, K.M., Shen, J., Souza, P.E., Grieco-Calub, T.M., 2017. Age-related differences in listening effort during degraded speech recognition. Ear Hear. 38, 74. https://doi.org/10.1097/AUD.0000000000000355.
Wingfield, A., Tun, P.A., 2001. Spoken language comprehension in older adults: interactions between sensory and cognitive change in normal aging. Semin. Hear. 22, 287–301. https://doi.org/10.1055/S-2001-15632/ID/64.