

Central auditory functions in elderly individuals

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Elderly individuals often have more difficulty in understanding speech than younger adults, particularly in noisy environments. Three models that attempt to explain this are as follows: (a) deterioration in peripheral hearing; (b) structural changes to the central auditory system; and (c) changes in normal cognitive processes. The aim of this study was to assess the central auditory functions in an elderly population and compare them with those of an adult population.

Participants and methods

The study group included 60 elderly individuals; they were older than 60 years of age and were divided into two subgroups: the first subgroup A included 24 elderly individuals with normal peripheral hearing and the second subgroup B included 36 elderly individuals with presbycusis with a mild degree of hearing loss. The control group included 30 individuals ranging in age from 18 to 30 years. Both the study and the control group were subjected to an otological examination, immittanceometry, pure tone audiometry, speech audiometry, and central auditory processing assessment using the following selected few behavioral central auditory tests: synthetic sentence identification test with ipsilateral competing message (SSI-ICM), dichotic digits test (DDT), auditory fusion test-revised (AFT-R), and pitch pattern sequences test (PPT).

Results

There were elevated hearing thresholds at mostly all frequencies with statistically significant differences on comparing both study subgroups A and B with the control group. On using SSI-ICM, in the competition ratio (– 15 dB), there were statistically significantly low scores in subgroups A and B compared with the control group. Results of DDT showed statistically significantly low scores on comparing the results between the left ear and the right ear in both subgroups A and B. There was a statistically significant elevated gap threshold for tonal stimuli in the AFT-R test on comparing both subgroups A and B with the control group. The results of PPT showed that subgroup B obtained a statistically significantly lower score compared with the control group. There was a statistically significant negative correlation between age and the results of SSI-ICM in the competition ratio 0 dB when presented to the left ear, DDT, and PPT. There was a statistically significant positive correlation between age and the results of AFT-R when presented at 4000 Hz.

Conclusion

Age-related changes to auditory processing will occur in most adults 60 years of age and older that may or may not be concomitant with peripheral hearing loss. Aging decreases the capacity of digit recognition and also increases interaural asymmetries. Many older listeners show reduced temporal resolution even when potential influences of hearing loss are absent. Temporal ordering abilities decrease with age.

Recommendation

It is important to include central auditory tests in the audiologic assessment protocol of the elderly. The utilization of these tests in assessment of the elderly enables us to improve the quality of therapeutic-rehabilitative interventions.

Keywords:

behavioral central auditory tests, central auditory functions, elderly individuals

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Introduction

Pleis and Lethbridge-Çejku [1] reported that age-related hearing loss is one of the top three most common chronic health conditions affecting individuals 65 years of age and older.

The prevalence of self-reported hearing problems among the elderly is 30%. The prevalence increases considerably with age [2].

Dubno *et al.* [3] reported that the total auditory deficit in an elderly individual may be reflected in at least in two

components termed peripheral and central impairment. The peripheral component is reflected in the frequency-specific sensitivity loss shown by a conventional pure tone audiogram, whereas the central component is typically reflected in scores on specific speech audiometric measures of central processing ability.

The age-related changes in absolute sensitivity are the principal factor affecting older listeners' speech perception under quiet conditions. However, under less favorable listening conditions, changes in a number of speech-specific cognitive abilities can also affect higher intellectual and central functions in older individuals [4]. Putative explanatory factors include loss in audibility, cognitive decline, deficits in frequency resolution and rapid temporal processing, and related problems unique to auditory processing [5].

There was a significant influence of age ($P = 0.043$) on synthetic sentence identification test with ipsilateral competing message (SSI-ICM) results in the stimulus/competition ratio (-15 dB), with individuals between 70 and 75 years of age presenting worse results when compared with individuals who were 60–65 years of age [6].

The difficulties of older listeners are related to the well-known effects of high-frequency hearing loss on speech perception under quiet conditions and decline in temporal processing not predictable from the audiogram that accounts for reduced ability to listen under complex, noisy conditions [7].

A correlation has been found between an increasing left ear deficit on dichotic listening with increasing age [8]. Also, deficits in interhemispheric information processing may underlie some of the listening problems among senior citizens [9].

Clinically, these findings suggest that hearing aids, which have been the traditional management for improvement of speech perception in older adults, are likely to offer considerable benefit in quiet ideal listening situations because the amplification they provide can serve to compensate for age-related hearing losses. However, such devices may be less beneficial in more natural environments because they are less effective in improving speech perception difficulties that result from age-related cognitive declines [4].

This work will focus mainly on studying central auditory functions in elderly individuals that may affect their performance and behavior in different life situations.

Participants and methods

The control group included 30 normal-hearing adults of both sexes; their ages ranged from 18 to 30 years and all were volunteers from among medical students and relatives of the patients who attended the audiology unit for examination and proved to have normal hearing sensitivity. The study group included a group of 60 patients; they were older than 60 years of age with normal

peripheral hearing or with presbycusis with a mild degree of hearing loss. Participants selected were in good general health and all of them were right handed.

Exclusion criteria

- (1) Evidence of systemic illness.
- (2) Evidence of neurological or psychiatric illness.
- (3) Evidence of active middle ear disease.

Each participant was subjected to assessment of detailed history including history of neurological disorder and history of systemic diseases including hypertension, diabetes, or heart disease.

Otoscope examination, neurological examination, a basic audiological evaluation using a dual channel clinical audiometer (Madsen OB 822, GN Otometrics, Copenhagen, Denmark), and immittance measurement using (Impedance Audiometer Interacoustic AZ 26, Denmark) were performed. Selected central auditory test, using Panasonic Stereo CD player SA-AK 240 (Malaysia), and test materials for the selected central auditory test were used to evaluate different aspects and different functions, which were as follows.

Synthetic sentence identification test with ipsilateral competing message

The participant was seated comfortably in a sound-treated room and the recorded test materials were delivered through earphones. The test material included 10 synthetic sentences. The sentences were recorded with background speech noise at two message-to-competition ratios: 0 and -15 dB. The 10 sentences were presented monaurally at 50 dB SL [speech reception threshold (SRT)]. Each participant was instructed to hear one sentence at a time and was asked to identify each sentence heard by choosing it from the card in front of him/her (or repeat it). Scoring was performed by counting the number of correctly identified sentences, and the percent total scores were calculated for each ear separately and for each message-to-competition ratios.

Dichotic digits test

This test assesses binaural integration skills. In a sound-treated room, the participant was seated comfortably and the recorded test materials were delivered through earphones. The test consisted of 20 stimulus presentations or 80 total digits (40/ear). The test items were presented simultaneously at 50 dB SL (SRT) in both ears. The patient was instructed as follows: 'You will be hearing two numbers in each of your ears. Listen carefully in both ears and repeat all the numbers you hear. The order doesn't matter; the first few items will be for practice'.

The first three sets of digits in the test were for practice and were not included in the scoring. Scoring was performed by counting the number of correctly identified digits repeated and multiplying it by 2.5.

Auditory fusion test-revised

This test is designed to measure temporal resolution. The patient was seated in a sound-treated room and the recorded test materials were delivered through a loud speaker. Subtest 2: standard test includes interpulse intervals (IPIs) that range from 0 to 40 ms in ascending and descending IPI; for example, the test sequence at a given frequency begins with 0 ms IPI and proceeds to a maximum of 40 ms IPI, which is repeated, and then the intervals decrease to 0 ms. The signals were presented at 50 dB SL and the patient was instructed to report whether the stimulus pairs are heard as one or two tones.

The method of evaluation was through determination of the auditory fusion threshold (AFT). The interval at which the tone pairs are perceived as two (when the IPI is increasing) was averaged with the interval at which the tone pairs were perceived as one (when the IPI is decreasing), and this average is called the AFT. The AFT was measured in milliseconds.

Pitch pattern sequence test

These tests are designed to test temporal ordering ability. The test items are sequences of three tone bursts. In each of the sequences, two tone bursts are of the same frequency, whereas the third tone is of a different frequency. Only two different frequencies used in this test: one is a high-frequency sound and the other is a low-frequency sound. The individual therefore hears patterns, such as high-high-low or low-high-low. The participant was seated comfortably in a sound-treated room and the recorded test materials were delivered through ear-phones; 30 sequences were presented monaurally at 50 dB SL (ref. SRT). An individual was asked to describe verbally each sequence heard. Scoring was performed in percent correct for each ear.

Statistical analysis

A data entry file, using the Excel 2003 program, was prepared. Data were analyzed using SPSS (version 16; SPSS Inc., Chicago, Illinois, USA). The frequencies, percentages, the mean, and SD were computed. An independent-samples *t*-test was used as the test of significance to compare quantitative data between two groups. The 5% level was chosen as the level of significance and a 95% confidence interval. A paired *t*-test was used as the test of significance to compare quantitative data between right and left ears. The correlation between variables was assessed using regression analysis (Pearson's correlation test). A *P*-value of more than 0.05 was considered nonsignificant, less than 0.05 was considered significant, and less than 0.001 was considered highly significant.

Results

This study included 90 individuals of both sexes. They were classified into two groups: control group and study group. The control group included 30 normal-hearing adult participants; their ages ranged from 18 to 30 years.

The study group included 60 patients; they were older than 60 years of age and divided into the following two subgroups:

The first subgroup (A) included 24 elderly individuals with normal peripheral hearing.

The second subgroup (B) included 36 elderly individuals with presbycusis with a mild degree of hearing loss.

Basic audiological evaluation

Pure tone audiometry

There was a statistically significant elevated hearing threshold at almost all frequencies on comparing both subgroup A and subgroup B with the control group. Also, there was a statistically significantly elevated hearing threshold on comparing subgroup B with subgroup A (Table 1).

Results of the mean of speech discrimination score

Although Subgroup B had a lower score compared with either the score of subgroup A or the control group, the speech discrimination score (SDS) for the control and both subgroups A and B were excellent; this indicates that the use of SDS in that ideal situation does not suggest central auditory system (CAS) dysfunction.

Results of central auditory tests

Synthetic sentence identification test with ipsilateral competing message

In terms of the competition ratio (0 dB), subgroup B obtained statistically significant low scores compared with either subgroup A or the control group for both the right and the left ear.

In terms of the competition ratio (-15 dB), subgroups A and B obtained statistically significant low scores when compared with the control group for both the right and the left ear (Table 2 and Fig. 1).

This indicates a reduction in brainstem efficacy and the presence of a communication disorder in the elderly population.

Dichotic digits test

On comparing the mean scores of the right ear, subgroup B obtained statistically significantly low scores compared with the control group.

On comparing the mean scores of the left ear, both subgroups A and B obtained statistically significantly low scores compared with the control group; also, there was a statistically significant difference between subgroups B and A.

On comparing the mean scores of the right ear with that of the left ear, It was clear that the identification of the correct items was worse in the left ear compared with that in the right ear in both subgroups A and B. However, there was no statistically significant difference between the right and the left ears in the control group (Table 3).

Table 1 Comparison between the mean (X) and SD of pure tone audiometric thresholds between study subgroups A, B, and the control group

Frequencies (Hz)	Ear	Mean ± SD			P-value A vs. B	P-value A vs. control	P-value B vs. control
		Subgroup A	Subgroup B	Control			
250	Rt	14.8 ± 6.2	18.5 ± 6.7	14.7 ± 4.5	0.021*	0.939	0.011*
	Lt	15.8 ± 5.3	17.5 ± 8.0	14.0 ± 5.6	0.340	0.313	0.034*
500	Rt	17.7 ± 4.9	19.7 ± 6.0	13.5 ± 4.4	0.145	0.004*	0.000*
	Lt	15.6 ± 4.5	17.9 ± 5.8	12.3 ± 4.9	0.096	0.022*	0.000*
1000	Rt	17.7 ± 5.3	24.2 ± 7.2	12.8 ± 4.1	0.000*	0.003*	0.000*
	Lt	15.0 ± 5.9	22.4 ± 7.9	12.0 ± 4.3	0.000*	0.088	0.000*
2000	Rt	18.3 ± 4.8	30.1 ± 11.0	12.2 ± 4.5	0.000*	0.005*	0.000*
	Lt	16.5 ± 5.2	29.3 ± 11.3	12.0 ± 4.3	0.000*	0.046*	0.000*
4000	Rt	22.0 ± 4.4	42.6 ± 10.4	13.8 ± 5.4	0.000*	0.000*	0.000*
	Lt	19.4 ± 5.0	46.7 ± 12.1	14.0 ± 5.6	0.000*	0.027*	0.000*
8000	Rt	22.9 ± 3.6	49.9 ± 14.9	12.7 ± 4.9	0.000*	0.000*	0.000*
	Lt	20.0 ± 5.9	56.8 ± 16.3	12.2 ± 4.5	0.000*	0.011*	0.000*

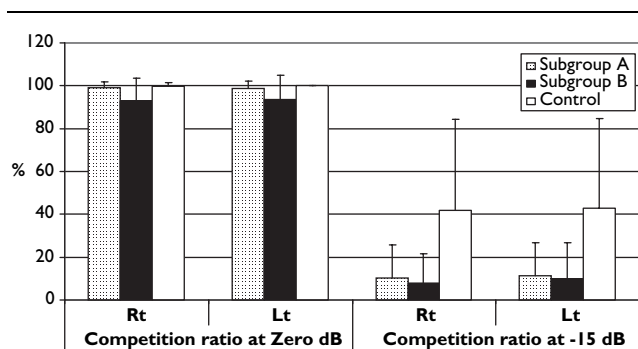
*Significant.

Table 2 Descriptive measures of the synthetic sentence identification test with ipsilateral competitive message at 0 and -15 stimulus/competition ratio in study subgroups A, B, and the control group in both the right (Rt) and the left (Lt) ear

Competition ratios	Ear	Mean ± SD			P-value A vs. B	P-value A vs. control	P-value B vs. control
		Subgroup A	Subgroup B	Control			
0 dB	Rt	99.2 ± 2.8	93.1 ± 10.6	99.7 ± 1.8	0.001*	0.794	0.000*
	Lt	98.8 ± 3.4	93.6 ± 11.3	100.0 ± 0.0	0.009*	0.536	0.001*
P-value Rt vs. Lt		0.664	0.701	0.326			
-15 dB	Rt	10.4 ± 15.5	7.8 ± 13.8	41.7 ± 42.8	0.716	0.000*	0.000*
	Lt	11.3 ± 15.4	10.0 ± 16.7	43.0 ± 41.5	0.863	0.000*	0.000*
P-value Rt vs. Lt		0.539	0.332	0.293			

*Significant.

Figure 1



Histogram showing synthetic sentence identification test with ipsilateral competing message of right and left ears of the study subgroups A, B, and the control group.

This indicates that hemispheric asymmetries and right ear advantages (REA) were greater in the elderly. Table 4 is graphically represented in Fig. 2.

Auditory fusion test-revised

There was a statistically significant elevated gap threshold at all tonal frequencies in subgroup A when compared with the control group, at 2000 and 4000 Hz in subgroup B when compared with the control group, and only at 500 Hz in subgroup A compared with subgroup B (Table 4).

This result suggests that gap thresholds for the older listeners were generally observed to be larger than those of the younger listeners. Thus, they perform poorly in understanding of speech under noisy and reverberant

listening conditions, and this was attributed to the poor resolution performance of the older listeners.

Pitch pattern sequences test

There is was statistically significant low score in subgroup B in comparison with the control group for both right and left ears. This means that temporal ordering abilities are decreased with age; hence, older listeners experience difficulty in discrimination and recognition tasks that require temporal order judgments such as those found in speech or music.

The correlation between age and the result of each of the central tests in the study group

The study group was classified according to age into two subgroups:

The first subgroup included individuals who ranged in age from 60 years to younger than 65 years.

The second subgroup included individuals who were 65 years of age and older.

There were statistically significant negative correlations between age and the results of dichotic digits test (DDT), pitch pattern sequences test (PPT), and SSI-ICM. This means that the scores of these tests were decreasing with increasing age. These correlations are shown in the Figs 3–5.

There was a statistically significant positive correlation between age and AFT-revised (AFT-R) when presented at 4000 Hz; this means that the gap threshold is increased with increasing age. This correlation is shown in Fig. 6.

Table 3 Comparison between the mean (X) and SD of dichotic digits test between study subgroups A, B, and the control group in both the right (Rt) and the left (Lt) ear

Ear	Mean ± SD			P-value A vs. B	P-value A vs. control	P-value B vs. control
	Subgroup A	Subgroup B	Control			
Rt	86.3 ± 10.1	81.8 ± 15.9	91.8 ± 11.7	0.205	0.127	0.003*
Lt	68.1 ± 18.0	55.7 ± 25.5	89.6 ± 16.9	0.028*	0.014*	0.000*
P-value Rt vs. Lt	0.000*	0.000*	0.562			

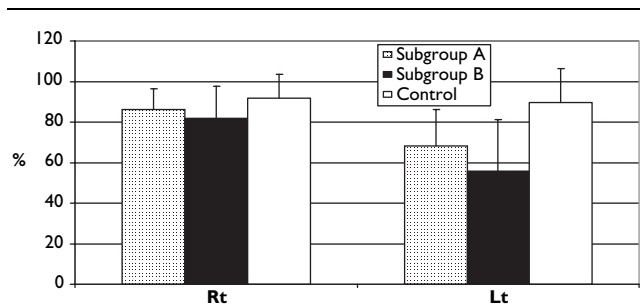
*Significant.

Table 4 Comparison between the mean (X) and SD of auditory fusion test-revised between study subgroups A, B, and the control group

Frequencies (Hz)	Mean ± SD			P-value A vs. B	P-value A vs. control ^a	P-value B vs. control
	Subgroup A	Subgroup B	Control			
500	21.4 ± 5.9	16.7 ± 5.1	14.3 ± 4.7	0.002*	0.000*	0.064
1000	16.6 ± 4.8	15.0 ± 5.5	12.6 ± 4.6	0.242	0.005*	0.054
2000	16.3 ± 5.0	15.5 ± 4.5	12.3 ± 4.2	0.524	0.002*	0.006*
4000	15.9 ± 4.7	15.6 ± 4.6	12.7 ± 4.3	0.751	0.010*	0.12.0*

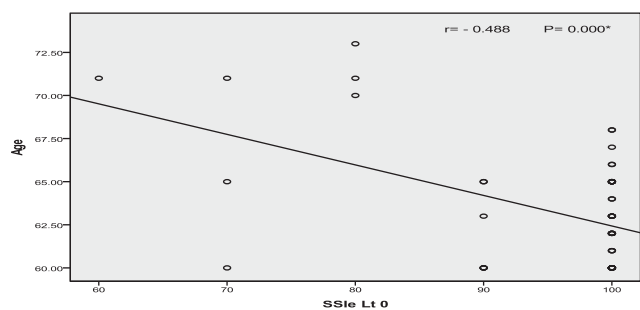
*Significant.

Figure 2



Histogram showing dichotic digits test (DDT) of right and left ears of the study subgroups A, B, and the control group.

Figure 3

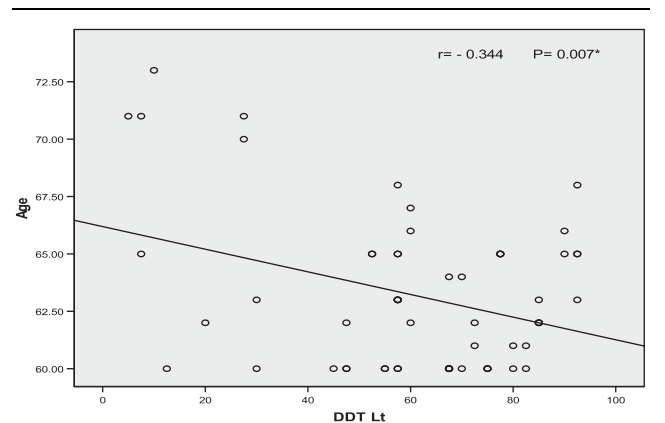


Correlation between age and result of showing synthetic sentence identification test with ipsilateral competing message (SSI-ICM) at message competition ratio 0 dB at the left ear.

Discussion

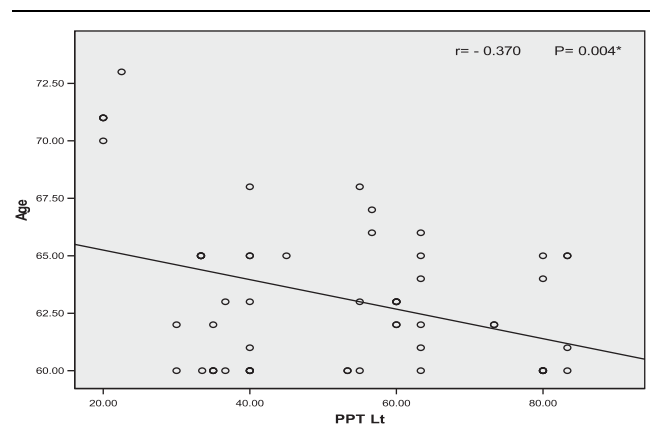
Hearing loss in older adults is a major problem that affects communication and quality of life; yet, few epidemiological studies have been carried out to evaluate the magnitude of the problem, identify modifiable factors contributing to the risk of hearing impairment, or test potential prevention strategies [10].

Figure 4



Correlation between age and result of dichotic digits test (DDT) on the left ear.

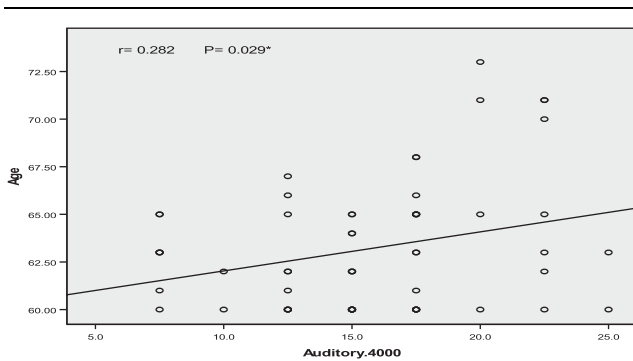
Figure 5



Correlation between age and result of pitch pattern sequences test (PPT) when presented on the left ear.

Three models have been used in an attempt to explain age-related decline in the ability to understand speech. These models were (a) deterioration in peripheral

Figure 6



Correlation between age and result of auditory fusion test-revised when presented at 4000 Hz.

hearing; (b) structural changes to the CAS, which consists of the brainstem and forebrain [11,12]; and (c) changes in normal cognitive processes. Whereas it is quite possible that all three models are equally important in assessment of age-related changes to understanding speech, we will focus on the second model, that is, the structural changes to the CAS, and the likely central auditory processing abnormality arising from this.

The ability to detect the presence of sounds is only one part of the processing that occurs within the auditory system [13].

There are many individuals who have no trouble detecting the presence of sound, but who have other types of auditory difficulties (e.g. difficulties understanding conversations in noisy environments, problems following complex directions) that can affect their ability to communicate effectively. Often, these individuals are not recognized as having hearing difficulties because they do not have trouble detecting the presence of sounds or recognizing speech in ideal listening situations [14].

Auditory processing assessment information is important to identify functional deficits that could be associated with difficulties in speech understanding [15], in audiologic rehabilitation/training [16], and to monitor the results of treatment interventions [17].

In the present study, we included two groups: the control group, which included 30 individuals ranging in age from 18 to 30 years, and the study group, which included individuals who were older than 60 years of age. The study group was further subdivided into two subgroups: subgroup A with normal hearing (24 individuals) and subgroup B with presbycusis (36 individuals).

Basic audiological evaluation

Pure tone audiometry

All participants in the control group and subgroup A had normal hearing sensitivity at all frequencies; in contrast, participants in subgroup B had normal hearing sensitivity up to 1000 Hz with elevated threshold at higher frequencies (presbycusis with a mild degree of hearing loss) (Table 1). This is in agreement with recent studies

that concluded that pure tone hearing sensitivity tends to decline with increasing age, with the greatest loss in the frequencies above 1000 Hz. Further, the hearing loss tends to be bilateral, symmetrical, and sensory-neural in origin [18].

Speech audiometry

The mean SDS for the control and both subgroups A and B were excellent; this indicates that the use of SDS in ideal situations does not suggest evaluation of CAS, underestimates hearing problems in noise, and also may not necessarily correlate with good functional performance. Previous studies have suggested that an audiologic evaluation should include some measures of the ability of an individual to understand speech in a background of competing speech noise [19].

Central auditory processing tests

It is well known that the effect of aging on the auditory system is not necessarily shown by the classical high-frequency loss in pure tone audiometry. Thus, the purpose of this assessment was to investigate whether or not central tests undergo an analogous alteration as a consequence of aging.

Synthetic sentence identification test with ipsilateral competing message

In terms of the competition ratio (-15 dB), there were statistically significantly low scores in subgroup A and subgroup B compared with the control group, but on comparing subgroup A with subgroup B group, no statistically significant difference was present in both the right and the left ear (Table 2).

The presence of statistically significantly low scores in subgroup A in comparison with the control group could suggest a slow and progressive involvement of the brainstem auditory pathways with aging. However, the significant influence of hearing loss on subgroup B prevents definitive conclusions in these respects and stresses that this test must be used carefully in individuals with presbycusis.

This is in agreement with other researchers who proved that in patients older than 65 years of age, the maximum SSI-ICM score decreases markedly and the SSI-ICM function usually decreases below the phonetically balanced words function. This is in agreement with the result of the present work [20].

This test helps us to identify communicative disorders and, consequently, rehabilitative problems.

Dichotic digits test

DDT will be helpful in the assessment of individuals who have difficulty hearing in background noise or when more than one individual is speaking.

In the present study, the mean scores of DDT in the right ear were 86.25, 81.81, 91.82% in subgroups A, B, and the control group, respectively. However, the scores obtained for the left ear were 68.13, 55.69, and 89.58% (Table 3).

It is clear that the identification of the correct items in the left ear was worse than that in the right ear mainly in subgroups A and B. Thus, the REA was observed in the elderly participants. This indicates that elderly participants showed greater hemispheric asymmetries and lower accuracy in the scores obtained in the test. This confirms that the ability of the auditory system to cope with binaural information is better in middle age. The elderly participants tended to report the information presented to only one ear, mainly the right ear.

Thus, fitting of a monaural hearing aid is better than binaural fitting in cases of symmetric hearing loss and deficit in dichotic listening, and DDT should be included in assessments of symmetric hearing loss as suggested by a previous study [21].

The results of this work are consistent with other studies such as those of Zenker *et al.* [22] and Strouse *et al.* [23], and also in agreement with the study of Jerger *et al.* [8], which showed a correlation between an increasing left ear deficit on dichotic listening with increasing age.

Auditory fusion test-revised

In this study, there was a statistically significant elevated gap threshold in subgroup A when compared with the control group for all tonal stimuli. Also, there was a statistically significant elevated gap threshold of subgroup B when compared with the control group for tonal stimuli presented at 2000 and 4000 Hz (Table 4).

On comparing subgroup A with subgroup B, there were statistically significant differences at only 500 Hz.

This result suggests that younger adults can better detect short gaps between all frequency stimulus pairs than older individuals.

Obviously, the results of this test did not differ significantly in elderly individuals whether they had hearing loss or not, and in general, the results in older participants were worse than the results in adult participants. This is agreement with the result of Robert and Keith [24], who proved that the AFT-R is unaffected by peripheral hearing loss.

These results are also in agreement with other researches carried out to compare the function of temporal resolution between different age groups. In this approach, 400-ms tone bursts were used to compare gap thresholds in younger and older listeners with relatively normal hearing. Gap thresholds collected from the older listeners were generally observed to be larger than those of the younger listeners, but most of the age-related differences were attributed to the poor resolution performance of a few older listeners [25].

Subsequent measurements of gap resolution performed by Schneider *et al.* [26] and Strouse *et al.* [27] showed that many older listeners with normal hearing do show elevated gap thresholds. Other studies found that there are significant age-related differences in gap thresholds [28].

Snell [29] focused on age effects in temporal resolution on comparing temporal gap thresholds in groups of

younger (17–40 years old) and older (64–77 years old) listeners with normal hearing and closely matched audiometric thresholds. He observed reduced gap-resolution abilities in about one-third of the older listeners.

However, Museik *et al.* [30] argued that the effect of ageing on temporal resolution ability remains unclear: 'older subjects may present with increased gap detection thresholds in comparison with younger control subjects'; but only limited normative data are available for this age group.

However, several of the reports have found considerable variability in the performance measures collected from older listeners and point to observations showing that the resolution performance of some older listeners is quite similar to that of younger listeners [31]; this is not in agreement with the result of this work.

This test enables assessment of older listeners who perform poorly in tasks of speech understanding under noisy and reverberant listening conditions, which can be attributed to deficits in temporal resolution [32].

Pitch pattern sequences test

Listener sensitivity to the order of sounds in a sequence is considered a basic aspect of auditory processing and one that is essential to understanding a number of complex stimulus patterns, such as those found in speech or music [31].

In this work, it was found that there were lower scores in subgroups A and B in comparison with the control group but reached a statistically significant value in subgroup B in comparison with the control group (Table 5). This means that temporal ordering abilities decrease with age; there is some evidence in the research literature indicating that older listeners do experience difficulty in discrimination and recognition tasks that require temporal order judgments [11,33]. This is in agreement with the results of the present work. Similarly, Fitzgibbons and Gordon-Salant [34] used contiguous three-tone stimulus sequences and compared the performance of younger and older listeners on the ordering tasks and they found significantly reduced ordering abilities among the older listeners.

Obviously, in this study, the peripheral hearing loss (presbycusis) reduces the ability of the elderly in temporal order perception. This result is not in agreement with those reported by Sanchez *et al.* [6], who found that hearing loss and age did not influence the result. This difference may be because of the inclusion of participants with normal hearing in their study. However, a previous study proved that the frequency pattern test may be used with mild, relatively flat hearing losses; however, because there is a frequency or spectral element involved in this test, it may not be completely resistant to hearing loss [35].

In this study, there was no statistically significant difference between right and left ears for both subgroups A, B, and the control group; this is in agreement with the result of Maura *et al.* [6] as they found that there was no

Table 5 Comparison between the mean (X) and SD of pitch pattern sequences test between study subgroups A, B, and the control group in both the right (Rt) and the left (Lt) ear

Ear	Mean \pm SD			P-value A vs. B	P-value A vs. control	P-value B vs. control
	Subgroup A	Subgroup B	Control			
Rt	53.1 \pm 18.6	48.8 \pm 17.3	62.7 \pm 20.8	0.386	0.069	0.004*
Lt	56.7 \pm 17.0	48.6 \pm 20.4	62.0 \pm 20.3	0.119	0.332	0.007*
P-value Rt vs. Lt	0.073	0.931	0.564			

*Significant.

significant difference between the ears. The mean scores obtained were 66.8 and 67.9% in the right and left ear, respectively, in their study.

Correlation between selected central tests and age

In this study, there were statistically significant negative correlation affection of age on:

- (1) *SSI-ICM at competition ratio 0 dB when presented on left ear*: the scores of the result decrease with increasing age, which indicates a reduction in brainstem efficacy, considering that this test is sensitive enough to detect the involvement of this region of the auditory system [36–38]. This is in agreement with the result of a previous study [6], which proved that individuals ranging in age between 71 and 75 years presented a higher number of errors when compared with those in the range of 60 and 65 years. There was a trend toward a larger number of errors in individuals in the age range of 66–70 years in comparison with individuals between 60 and 65 years. These findings could suggest a slow and progressive involvement of the brainstem auditory pathways with aging. This also in consistent with proved that in patients older than 65 years of age, the maximum SSI-ICM score decreases considerably and the SSI-ICM function usually falls below the PB function [20]. This seems to be in agreement with the result of the present work.
- (2) *DDT on left ear*: the scores of the results decrease with increasing age; this is consistent with the physiological–anatomical observation that attributes much of the REA in aging to cortical impairment and a deterioration of the fibers in the corpus callosum [39,40]. This is also in agreement with other studies that noted increased left ear disadvantages among elderly listeners [41,42]. The results of this work are consistent with other studies such as those of Zenker and colleagues [22,34] and with the study of Jerger et al. [8], which showed a correlation between an increasing left ear deficit on dichotic listening with increasing age. This is not in agreement with some reports that showed no effect of age on dichotic listening tests [43,44].
- (3) *PPT*: the scores of the result decrease with increasing age; which means that temporal ordering abilities decreased with aging. The ability to probably recognize, identify, and sequence auditory patterns involves several perceptual and cognitive processes [45]. These

processes are not restricted to one hemisphere alone, but rather require integration of information from both hemispheres across the corpus callosum [46].

In this study there were statistically significant positive correlation affection of age on:

AFT-R: when presented at 4000 Hz, there were elevated gap threshold with increasing age; this is in agreement with other researches carried out to detect temporal resolution in elderly individuals [26,47]. Others [48] reported that there are elevated gap-detection thresholds even when elderly individuals had clinically normal hearing sensitivity.

Conclusion

- (1) Age-related changes to central auditory processing will occur in most adults 60 years of age and older that may or may not be concomitant with peripheral hearing loss.
- (2) Aging decreased the capacity of digit recognition and also increased interaural asymmetries. Many older listeners show diminished temporal resolution even when potential influences of hearing loss are absent. Temporal ordering abilities are decreased with aging. Binaural hearing aids may not be the best intervention strategy for some elderly individuals.
- (3) Assessment of the peripheral auditory system must certainly be a starting point for assessment of central auditory nervous system, although it is a poor predictor of performance in a complex listening situation.

Recommendation

Central auditory tests should be used in the audiologic assessment protocol of an elderly population.

The utilization of these tests in assessment of the elderly enables us to detect any communication disorder as soon as possible.

Thus, an appropriate rehabilitation program can be initiated on an individual basis.

The recommendations for older listeners who perform poorly in understanding speech in noisy and reverberant listening conditions:

- (1) Slower rate of speech presented.
- (2) Use of smaller language units.

- (3) Frequent repetition.
- (4) Deliberate pauses that provide time for auditory comprehension.
- (5) The provision of visual clues should also aid auditory comprehension.
- (6) Perceptual training and computer-assisted remediation such as listening and auditory communication enhancement addresses listening in noise and aural rehabilitation individualized auditory training addresses dichotic listening skills may be helpful.

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Conflicts of interest

There are no conflicts of interest.

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