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Effects of ageing on speed and temporal resolution of speech stimuli in older adults

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Abstract

Background: According to previous studies, most of the speech recognition disorders in older adults are the results of deficits in audibility and auditory temporal resolution. In this paper, the effect of ageing on time-compressed speech and auditory temporal resolution by word recognition in continuous and interrupted noise was studied.

Methods: A time-compressed speech test (TCST) was conducted on 30 young and 32 older adults with normal hearing thresholds. Lists of monosyllabic words were used at three time compression ratios. Auditory temporal resolution was determined by measuring the monosyllabic word recognition score (WRS), in the presence of continuous and interrupted noise, at three signal-to-noise ratios (S/Ns).

Results: There was a significant difference in TCST scores at the three compression ratios within and between young and older adult groups ($p< 0.001$). Similar results were obtained in WRSs at the three S/Ns in the presence of interrupted and continuous noise ($p< 0.001$), and in the degree of auditory temporal resolution ($p=0.007$). A significant correlation was found between the level of test difficulty of TCST with WRSs in both young ($r = 0.549$, $P=0.002$) and older adults ($r= 0.531$, $P=0.003$).

Conclusion: Our results showed that ageing remarkably affects the processing of fast speech stimuli and temporal resolving ability. These results are more supportive of the effect of ageing on speech perception than on loss of hearing.

Keywords: Ageing, Time-compressed speech, Word recognition score, Auditory temporal resolution, Interrupted noise, Continuous noise.

Introduction

Age-related hearing loss or presbycusis is the most common sensory deficit among older adults, and is also considered to be one of the most severe social and health problems older individuals' experience (1). With increasing age, the prevalence of hearing loss is significantly accelerated. As a whole, nearly 10% of society has some degree of hearing loss, which causes communication challenges; this estimate increases to 40% at ages above 65 years (2). Shift in the hearing threshold and decreased speech perception are the two main clinical signs of presbycusis. In some investigations, decreased speech perception has been attributed to changes in the hearing threshold resulting from presbycusis (3), while in others, reasons other than hearing threshold alteration have been mentioned (1).

Research attempting to confirm the effect

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of ageing on speech recognition in the presence of noise are complex, and results hinge on the number of variants present in the stimulus, such as speech audibility, type of speech signal (word vs. sentence), type of background noise (steady, fluctuating, speech) and signal-to-noise ratio (S/N), in addition to subject-specific variants (1) . Most studies on the effects of ageing on the recognition of speech and other complex sounds have cited a non-peripheral origin and defects in auditory temporal processing in older adults (4,5). Currently, it is accepted that presbycusis influences temporal and spectral resolution of the auditory system, while it is also believed that defects in temporal resolution of stimuli in individuals with presbycusis result from the effects of ageing on auditory synchronization (6), and that it is independent of the degree of peripheral hearing loss (1).

Temporal resolution is defined as the ability to perceive stimulus alteration across time, e.g. the ability to detect a small time gap between two sounds (7). Good temporal resolution is necessary for speech perception because it provides a measure of information about vowels, consonants, syllables and phrase boundaries (1). Temporal resolution can be measured in several ways such as temporal modulation transfer function, gap detection threshold (8), forward/backward masking, time-compressed speech test (TCST) (1) and calculation of difference between the monosyllabic word recognition score (WRS) in the presence of interrupted or continuous noise (6). For the gap detection test, which is the most commonly used test in this study area, the subject must detect the gaps or fluctuating silent periods in the stimulus, and the threshold is considered as the shortest silent period that the subject can identify (8).

Temporal compression is a method for simulating an increase in speech speed. TCST, the most popular monaural test for assessing the function of the central auditory system, is a type of speech test with low redundancy that measures auditory closure. Auditory closure is defined as the ability to recognize the whole word when some parts of the stimulus are omitted (6). TCST is usually stated as the percentage of time reduction, i.e. 30% speech compression indicates that 30% of the signal has been removed in small sections (7). Previous studies have shown a remarkable deficit in perception of fast spoken signals among elderly people and in those with central auditory processing disorders (1). In a study by Gordon-Salant and Fitzgibbon (7) aimed at comparing the perception of uniformly compressed speech with that of selectively compressed speech (special acoustic cues), older individuals showed poorer performance than young individuals in all except one section of the test. In another study by these authors, in which the effect of the location of time compression along the sentence investigated, performance was comparable between young and older adults with regard to the status of the stimulus without compression. However, in different types of compression, older adults showed poorer performance than young individuals; older adults were challenged even when only a single phrase along the sentence was compressed. The longer the compression time along the sentence, the poorer the performance by older individuals. In these studies, the poor perception of compressed speech of the elderly people was attributed to at least two reasons: 1) a defect in processing fast information followed by a general speed decrement and 2) weakness in processing consonants that have been excessively compressed (7).

In 1994, Philips et al. introduced a novel method of assessing temporal resolution (9). In this method, word recognition is assessed as a function of S/N in the presence of interrupted and continuous wide-band noise. Since the noise varies in temporal continuity, while having the same spectral structure, the difference in word recognition is considered as the subject’s ability to use temporal structures in interrupted noise. In another study by these authors in 1996 involving young adults and two groups of aged people (one with normal hearing and one with presbycusis), older adults performed markedly less well than young adults (1).

Behavioural studies have confirmed a decrement in the ability to process auditory stimuli with increasing age, and in particular, reveal that older adults have greater weakness in perception of supra segmental elements, as well as a decrement in the speed of speech processing. These deficits challenge verbal communication even in individuals with normal hearing thresholds. On the other hand, as the elderly population is likely to increase in the decades to come, precise studies on the effects of ageing on the processing of auditory stimuli, especially speech would assist in providing this group with more accurate and helpful consultation and treatment services.

In this study, the effect of two types of distortion, i.e. temporal compression of speech, and the effect of interrupted and continuous noise on speech recognition in Persian-speaking older adults were compared to that of young adults with normal hearing. Subjects with normal hearing were selected in order to control the effect of hearing loss and to study the effect of ageing on speech perception.

Methods

The present study was performed on 30 young adults (16 men and 14 women) aged from 18 to 30 years old with a mean age of 22.48 (SD= 2.18) years, and 32 older adults (18 men and 14 women) aged from 65 to 80 years old with a mean age of 71.28 (SD= 6.64) years. All individuals had normal hearing thresholds and were recruited from the rehabilitation school of the Iran University of Medical Science, from July to November 2011. This study was approved by ethics committee of Iran University of Medical Sciences.

Our study was conducted on right-handed older adults with diploma or higher degree level, monolingual with good competency in Persian as their native language, no history of ear diseases, head trauma or accident, head surgery, depression, epilepsy or neurological drug intake. These individuals were ≥65 years old and selected among members of three cultural centres in Tehran. Auditory screening was performed at four octave band frequencies, viz. 500, 1000, 2000 and 4000 Hz in 20 dB HL, in both ears in a quiet location. If these individuals successfully passed the Persian version of the mini-mental state examination (MMSE) test (10), they were referred to the rehabilitation faculty for further studies. These criteria were also used for selection of the subjects in the control group, except for the age criterion.

To ensure normal hearing thresholds in all individuals, pure-tone audiometry was accomplished in a double-walled, sound-treated audiometric booth, using a two channel-calibrated clinical audiometer (Madsen OB-822) and a supra-aural headphone (Telephonics TDH-39P). Pure-tone thresholds were obtained at six octave band frequencies from 250 to 8000 Hz, with the Hughson-Westlake method, using a 10 dB up and 5 dB down regimen (11). Additionally, the contra lateral acoustic reflex at four frequencies of 500, 1000, 2000 and 4000 Hz were measured using an AZ229 Interacoustics tympanometer. In this phase, individuals were included in the study with hearing thresholds of ≤20 dB HL in both ears at all frequencies (pure-tone average in young adults was 5.78 dB and in older adults was14.62 dB HL), and if their contra lateral acoustic reflexes were obtained at least three frequencies, viz. 500, 1000 and 2000 Hz. In total, of 476 older adults who were initially screened, 51 passed the primary auditory screening, of which 32 individuals met the criteria for pure-tone audiometry and contra lateral acoustic reflexes.

In TCST, each subject was instructed as below: “This simple test was designed to assess the ability to recognize normal and compressed words. Each stimulus presentation, was heard carefully and wrote in the response from what was given.” The TCST was executed in right ear at a 30 dB sensation level, at three time compressions of 0% (no compression), 40% and 60%. Each phonetically balanced list was composed of 50 meaningful monosyllabic CVC and CVCC words, recorded by a trained male presenter speaking in standard Persian (12). These words were compressed temporally with Cool Edit Pro 2.1 Software. Subjects were allowed 4-silent periods to write their answers. This time was enough for all people. Moreover, in order to preserve the subjects' attention during the test, a 2-min break was provided before the presentation of each list.

To measure the auditory temporal resolution, subjects were instructed as below: "this test was aimed at assessing your ability to discriminate words in the presence of interrupted and continuous noise. At each stimulus the presentation was heard carefully and wrote whatever the response form concept."

Four 50-word meaningful monosyllabic lists, different from those used in the TCST, along with interrupted and continuous wide-band noise, were employed to test auditory temporal resolution. The competing continuous and interrupted broadband noise has been described in detail elsewhere (9, 13-15). Briefly, both types of noise with equal long-term effect and average spectra in the frequency range of 100 to 8000 Hz, were normalized to have equal power, and differed only in their temporal structure. The interrupted wide-band noise consisted of noise bursts and silent periods with varying duration of 5 to 95ms.The noise duty cycle was 0.50. Moreover, the temporal structure of the interrupted wide-band noise resembled the acoustic units of speech. In this study, the test stimuli was presented to right ears via an audiometer at 30 dB sensation level, at three S/Ns of −10, 0, +10dB. Interrupted and continuous noises were presented alternately among subjects, while the four lists of words and S/Ns selected randomly. The improvement in WRS in the presence of interrupted noise in comparison with continuous noise at each S/N was attributed to the subject's ability to take advantage of temporal structures present in interrupted noise. Degrees of release from masking (i.e. the difference in WRS in the presence of continuous noise vs. interrupted noise, (in percentage) were interpreted as the subjects' temporal resolution ability (9, 13-15). In both TCST and test of temporal resolution of speech, the score of each presentation in percentage was determined by multiplying the number of correct responses in number 2.

Statistical analysis

Statistical analysis was performed with SPSS.17 (Chicago, IL, USA) software, using a significance level of $\alpha<0.05$. The Kolmogorov-Smirnov test was used to verify the normal distribution of numerical data. A repeated measures multi variance test was conducted to compare the mean of word recognition scores within and between groups of young and older adults. Independent t-tests were used to compare the scores of the two sexes. The Pearson correlation coefficient test was utilized to determine the relation between the TCST and the temporal resolution test.

Results

The Kolmogorov-Smirnov test indicated that data were normally distributed among all TCST and temporal resolution test scores ($p>0.066$). The mean WRS in a quiet location was 98.28% (SD= 3.39%)for young adults and 85.38% (SD= 12.86%)for the older individuals.

Using a repeated measures test, there was a significant difference in the TCST scores at the three time compression ratios of 0, 40 and 60%, within each group ($p< 0.001$). Moreover, in between-group analysis, a significant difference was shown between young and older adults at the three compression ratios ($p< 0.001$). In Fig. 1, the TCST scores of the two test groups at the three compression ratios of 0, 40 and 60% were compared.

In the within group analysis of WRSs by repeated measures test, a significant difference was shown at the three S/Ns in the presence of interrupted and continuous noise, in each group separately ($p< 0.001$).

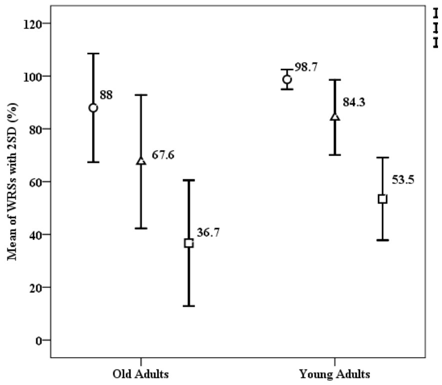

Fig.1. Comparison of TCST scores between young and older adults at three compression ratios of 0% (○), 40% (△) and 60% (□).

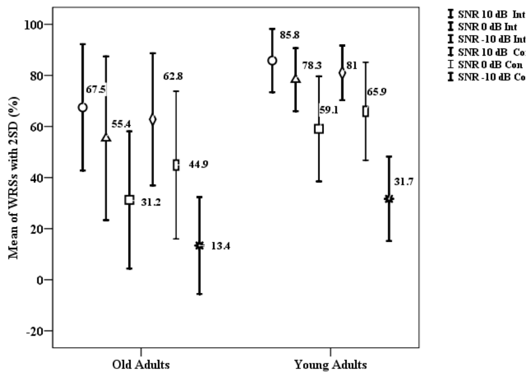

Fig.2. Mean of WRSs at three S/Ns in the presence of interrupted and continuous noise in young and older adults. (○: SNR 10 dB Int, △:SNR 0 dB Int, □: SNR -10 dB Int, ◊: SNR 10 d Con,▯: SNR 0 dB Con, ❋: SNR -10 dB Con).

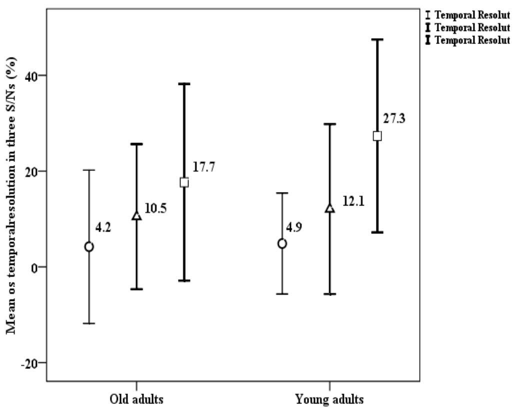

Fig.3. Mean of difference between interrupted and continuous noises at three S/Ns in young and older adults. (○: S/N 10 dB, △: S/N 0 dB, □: S/N -10 dB).

The WRSs obtained in the presence of continuous noise were lower than those measured in the presence of interrupted noise at all S/Ns. In the between-group analysis, the difference in WRS obtained in the presence of interrupted and continuous noise at different S/Ns between young and older adults was also significant ($p< 0.001$). Fig. 2 shows a comparison of the WRSs of the two test groups at the three S/Ns in the presence of interrupted and continuous noise.

The degree of auditory temporal resolution attained was assessed by determining the difference in WRS between interrupted and continuous noise at each S/N. As shown in Fig. 3, the amount of difference at −10dB S/N was higher than at the other two S/Ns in both groups, and it was lower in older adults than that of young adults at each S/N. A significant difference in auditory temporal resolution was found both in the within-group ($p=0.007$) and between-group ($p=0.002$) with the analysis of temporal resolution in young and older adults, using the repeated measures test.

No significant difference was found between the two sexes in the TCST scores at the three time compression ratios of 0, 40 and 60% ($p=0.136$), or in the WRSs ($p=0.390$), or in the degree of auditory temporal resolution ($p=0.130$) in both young and older adults.

The Pearson correlation coefficient test was used to determine the relation between the TCST and WRS results. In young adults, the best positive and most significant correlation was found between the WRS at a S/N of 0dB in the presence of continuous noise and the TCST at a compression ratio of 60% ($\alpha=0.01$, $p=0.002$, $r=0.549$). In older adults, the best positive and most significant correlation was found between the WRS at a S/N of 0dB in the presence of interrupted noise and the TCST at a compression ratio of 40% ($\alpha=0.01$, $p=0.003$, $r=0.531$).

Discussion

Older individuals experience difficulties in speech perception, which may even be observed in persons without remarkable hearing loss (16). In older adults, these difficulties are often observed in adverse listening conditions and challenging environments, such as high-level background noise or with fast-spoken speech (1). In this study, as the compression ratios changed, a marked decrease was seen in the WRS of young and older adults with normal hearing thresholds. Moreover, a meaningful difference was found between the two test groups in the WRS at each compression ratio. In a study by Beasley et al. (1,7), in which the effect of temporal compression on speech perception in adults with normal hearing was surveyed, a significant decrement in WRS at a compression ratio of 70% was reported. These authors also considered that the redundancy in the higher cerebral structures and in the information contained in the speech signal reduces the negative effect of speed increments in the speech stimulus; at higher compression ratios, greater stimulus intensity is required to improve speech perception.

In daily conversation, 200 to 275 words are spoken per minute (WPM). In a study by Wingfield et al (17), when increasing the number of spoken WPM to 420 words, the function of older individuals was reduced, but no marked effects were seen on younger subjects. This study indicated that ageing had a greater influence on recognition of speech signals with content information or low redundancy (such as phrases or words) than on daily conversation (1). In the studies by Fitzgibbons and Gordon-Salant on compressed speech (7) and the effect of the location of speech compression throughout the sentence (8), older individuals rated worse than young individuals. Another study by these authors on factors that have considerable effects on speech recognition ability in young and older adults with normal hearing thresholds, the effect of age and hearing loss on WRS was independent of each other. This study concluded that apart from loss of hearing thresholds, age-related factors had a negative effect on speech recognition function in older people (17); these findings were congruent with our results.

In this study, measuring WRS at various S/Ns in the presence of continuous and interrupted noise revealed markedly poorer performance by older than young adults. Moreover, both groups performed better in the presence of interrupted rather than continuous noise. The difference between WRS in the presence of continuous and interrupted noise, which can be interpreted as temporal resolution (13-15) were 9.4, 12.1 and 27.3% in young adults, and 4.21, 10.28 and 17.66% in older adults, at S/Ns of 10, 0, −10 dB, respectively. The greater the decrease in S/N, the more challenging communication conditions became. Accordingly, the decrement in scores in the presence of continuous noise led to an improvement in the degree of temporal resolution. In other words, the degree of temporal resolution improved as the S/N was decreased. Additionally, the degree of temporal resolution in young adults was higher at each S/N than that in older adults; this difference was very marked at −10 dB S/N. Since continuous and interrupted noise vary in temporal continuity while having a similar spectral structure, the difference between the degrees of temporal resolution in young vs. older adults can likely be interpreted as a reduced ability in older adults to take advantage of the temporal structures present in interrupted noise, i.e. improvement in signal redundancy and release from masking. In a similar study by Stuart and Philips (9), performance in the presence of interrupted vs. continuous noise was assessed. In their study, the WRS of young adults was found to be markedly higher than that of older adults with normal hearing and those with hearing loss, in the presence of each type of noise and at each S/N.

The effect of ageing on release from masking in the presence of fluctuating or modulated noise in comparison to a situation with a steady noise has been the focus of several studies in recent years. Some researchers have shown that young adults with normal hearing have better speech perception than older individuals with normal hearing and those with hearing loss in the presence of temporally modulated rather than steady noise. This indicates that young adults can benefit from noise reduction when S/N improves (17). Although the benefit of transient noise reduction in comparison with steady noise has been proven in older adults, it seems that this effect is greater in young adults (4, 17). According to some studies, the weaker performance of older adults is suggestive of the influence of hearing loss in intervals of release from masking, rather than the effect of ageing.The study by Stuart and Philips as well as our own results do not support this concept. Despite normal hearing thresholds in older individuals in these two studies, there was still a remarkable difference in their performance compared to that of young adults; this indicates an effect of ageing on the results. Generally, the results in this field are suggestive of older adults' reduced capacity to benefit from temporal fluctuations in noise, relative to young adults with normal hearing. This would to some extent explain the challenge that older individuals experience when faced with multiple speakers (17).

In the current study on temporal resolution, monosyllabic words were used as speech stimuli in the presence of continuous and interrupted noise, which in comparison with tonal stimuli, provided a more realistic situation, in order to better assess the difficulties encountered daily in speech perception. In many previous studies, a gap detection test using tonal stimuli was employed to evaluate temporal resolution. Poorer function in older adults in detection of short temporal gaps among sequential tones or in noise bursts were reported in several similar studies. Moreover, the thresholds of gap detection in older individuals were found to be twice that of young adults (7, 17).

Sex had no effect on the results of the current study. The effects of sex on the results of the speech recognition test were limited to a few studies. For instance, in a cohort study with an age range of 48 to 92 years, the effect of age on the speech recognition score in the presence of a competing message was seen in both sexes. However, males performed less well than females in all age groups and hearing loss categories (1). In a study by Schmitt et al (17) to assess auditory perception of time-compressed speech in 28 individuals aged from 75 to 84years, presentation of some compressed questions at four compression ratios or with different speeds revealed no significant difference between the two sexes. Generally, sex is a demographic variable for which unequal influence has been reported in behavioural and psychoneurological studies.

In the current study, two types of distorted auditory stimuli were used to assess the auditory function of older individuals with normal hearing thresholds. To increase the level of difficulty, in one test, WRS was performed in the presence of continuous and interrupted noise at three S/Ns of −10, 0 and 10 dB, and in the other test, WRS was assessed at three time compression ratios of 0, 40 and 60%. Statistical analysis on data from the young adult group indicated that the highest level of significance and best correlation coefficient were found between WRS at an S/N of 0dB in the presence of continuous noise and TCST at a compression ratio of 60%. In contrast, in older adults, the highest level of significance and best correlation coefficient were seen between WRS at S/N of 0dB, in the presence of interrupted noise and a TCST at a compression ratio of 40%. We conclude from these findings that a close relation existed between these two types of stimulus redundancy decrements in older adults, and that the WRS at S/N of 0dB, in the presence of interrupted noise, and TCST at a compression ratio of 40%, in older adults, and the results of WRS at S/N of 0 dB in the presence of continuous noise and TCST at compression ratio of 60%, in young individuals, were comparable. This indicates that there was a remarkable relation between more difficult levels and less difficult levels of speech stimulus distortion in young and older adults, respectively. Given that both groups demonstrated normal hearing thresholds and that similar test conditions were used, it can be concluded that indicates an effect of age on the function of the auditory system.

Finally, it should be noted that, although in some studies the reduction in speech perception is attributed to hearing loss and hearing threshold changes as a consequence of presbycusis (3), in some others, reasons for the reduction in speech perception beyond hearing threshold changes have been demonstrated (1). Some older adults complained that when speech was spoken softly, it can be heard and understood; however, when speech was compressed or temporally altered, then it was difficult to understand. This finding has also been confirmed by many researchers (17). The difficulties in perception of fast spoken speech and detection of temporal gaps experienced by older adults are suggestive of a slower processing within the auditory system in older adults, as a consequence of ageing. Moreover, as is reflected by our study, although speech perception among aged people is affected by hearing loss, some cognitive functions, such as attention and memory, which decrease with age, also influence speech perception. For instance, in comparison to young adults, older adults show poorer word recall at unfavourable S/Ns (18). In other words, despite the bottom-up factors that have been reported to affect speech perception (including splitting speech stimuli into its basic elements in order to recognize phonemes), cognitive defects in older adults, or top-down elements, also influence speech perception.

Conclusions

This study revealed poorer temporal processing of speech among older than young adults. Accordingly, it seems that this result is not necessarily only attributable to hearing loss, as at least some aspects of speech perception difficulties in older adults are derived from ageing and its effects on the function of the nervous system. These findings can facilitate design of hearing prostheses and assistive communication devices for older adults, with and without hearing loss, and are also valuable for studies that focus on age-related neuroplasticity. In summary, temporal processing of auditory stimuli and speech in particular, is an interesting and wide field of ongoing research, which yields invaluable information about ambiguities in the auditory system and human brain, thanks to advances in research methods and instrumentation. Moreover, it is important that the findings of such investigations should be implemented in clinical practice in the field of consultation and rehabilitation of communication difficulties in aged people.

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