



Original Article

Perception of Consonants in Speech-Shaped Noise among Young and Middle-Aged Adults

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OBJECTIVE: The present study was carried out to compare the consonant perception of young and middle-aged adults in quiet and noisy listening conditions.

MATERIALS and METHODS: Twenty-nine adults aged between 18 and 55 years old participated in the study, and were separated into two groups based on their age: Group I, comprising 15 young adults aged between 18 and 40 years old, and Group II, comprising 14 middle-aged adults aged between 41 and 55 years old. All the participants had normal hearing sensitivity in both ears.

RESULTS: Consonant perception was better in favorable listening conditions for both young and middle-aged adults. Comparison of the consonant identification scores of young and middle-aged adults showed significantly poorer scores among middle-aged adults in both quiet and noisy listening conditions.

CONCLUSION: The findings of the present study reveal that middle-aged adults have small but significant consonant perception difficulties compared to younger adults in quiet and noisy listening conditions.

KEYWORDS: Speech perception, aging, noise, consonant perception, speech-shaped noise

INTRODUCTION

Elderly adults frequently complain of difficulty understanding speech in less favorable listening conditions, such as in the noisy listening condition. Hence, investigations to understand the speech perception abilities of elderly adults have received considerable attention among investigators. Many investigations have demonstrated a significant difficulty among elderly adults for understanding speech in the presence of noise^[1], especially when the noise is competing speech^[2–4]. In addition to noise, other factors, such as reverberation^[5], a fast rate of speech^[6], time compression^[7,8], foreign accent^[9], and semantic information in speech^[10], also have a significant effect on speech perception among elderly adults. The poorer speech perception in elderly adults has been attributed to a general age-related decline in hearing sensitivity^[11], supra-threshold auditory processing^[12–18], and cognitive functions^[11,19,20].

In elderly adults, a deficit in temporal processing has been reported by various investigators using tasks such as gap detection^[13], gap discrimination^[15], temporal order recognition^[17], discrimination of complex tonal sequences^[1,14], and temporal fine structure processing^[18]. Further, the studies revealed a significant correlation between temporal processing and speech perception. Thus, poor speech perception in noise among elderly adults has been partly attributed to age-related auditory temporal processing deficits^[12,13,16,21]. In addition to supra-threshold auditory processing, a decline in cognitive abilities has been reported by several investigators among elderly adults^[19,20], and this decline in the cognitive functions has been found to be associated with aging^[22]. Thus, the increased difficulty of understanding speech in the presence of noise among elderly adults has been partially attributed to age-related decline in the cognitive functions.

The age-related decline in supra-threshold auditory processing and in the cognitive functions found among elderly adults happens gradually, and may have its onset in the middle-ages. Several studies have reported an abnormal auditory temporal processing among middle-aged adults, which is important for speech perception^[15,23–25]. In addition to abnormal temporal processing, the prevalence of hearing-related problems are also higher among middle-aged adults compared to younger adults^[26]. In addition, a large proportion of middle-aged adults require higher signal-to-noise ratios -SNR- to achieve criterion levels of performance during speech identification in the presence of noise^[27]. Based on these findings, it is evident that some of the supra-threshold auditory processing abilities begin to deteriorate in middle-age, which could contribute to speech perception deficits. Thus, it may not be uncommon for middle-aged adults to have speech perception difficulties. Hence, there is a need for understanding the speech perception abilities of middle-aged adults.

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Investigations to understand the speech perception abilities of middle-aged adults have received little attention to date, and there are only a handful of studies investigating speech perception in this population. For instance, Helfer and Vargo^[28] measured the speech understanding of young and middle-aged adults in the presence of speech-shaped noise and competing speech. Their results showed a significantly poorer speech understanding for middle-aged adults, especially in the presence of competing speech. Helfer and Freyman^[29] measured the speech understanding of young, middle-aged, and elderly adults in the presence of competing speech. Their results showed a significantly poorer speech understanding among middle-aged adults compared to young adults, while the speech understanding of middle-aged adults was significantly better than that of elderly adults. These above investigations reveal the presence of significant speech perception difficulties among middle-aged adults. Further, investigations studying speech perception among middle-aged adults have used words or sentences^[28–30] for measuring speech perception. However, investigating speech perception at the phoneme level provides greater understanding on the perceptual difficulties of middle-aged adults toward the perception of vowels and consonants. Hence, the present study was carried out to compare the consonant perception of young and middle-aged adults in quiet and noisy listening conditions. Vowel perception was not investigated as it is well documented in literature that it is not significantly affected even in elderly adults compared to young adults^[31].

MATERIALS and METHODS

Participants

Twenty-nine adults (5 males, 24 females) aged between 18 and 55 years old participated in the study, and based on their age they were categorized into two groups: Group I, comprising 15 young adults (15 females) aged between 18 and 40 years old ($M=23.66$, $SD=3.86$), and Group II, comprising 14 middle-aged adults (9 females, 5 males) aged between 41 and 55 years old ($M=46.9$, $SD=4.8$). All the participants had normal hearing sensitivity in both ears, with pure-tone thresholds of less than 15 dB HL at octave frequencies from 250 Hz to 8000 Hz. Immittance evaluation confirmed “A” type tympanogram with acoustic reflex thresholds at normal levels for all the participants, suggesting normal middle ear functioning. None of the participants had otologic or neurologic problems, exposure to hazardous noise or ototoxic medication, or difficulty understanding speech in the presence of noise. The study protocol was approved by Institutional Ethical Committee and informed consent was obtained from all the participants prior to their participation in the study.

Stimuli

Isolated non-sense syllables (consonant-vowel CV) were used to investigate the consonant perception abilities of the participants. The CV syllables were composed of 21 consonants (/p/, /t/, /k/, /t/, /s/, /ʃ/, /b/, /d/, /g/, /d/, /ʒ/, /dʒ/, /m/, /n/, /ŋ/, /r/, /l/, /j/, /v/, /ʌ/, /h/) with vowel /a/. These syllables were spoken by 12 native speakers of Kannada (6 males and 6 females), and the utterances were recorded using the Computerized Speech Lab (CSL) model 4150 version 3.2.1. The utterances were digitally recorded using a sampling rate of 44100 Hz and a 16 bit analog-to-digital converter. The recorded utterances were reviewed by two audiologists for the intelligibility, and those syllables that received a poor intelligibility judgment were replaced with new

recordings. The final stimuli set included 21 syllables spoken by 12 talkers, thus resulting in a total of 252 utterances (21 consonants * 12 talkers).

To investigate consonant perception in the presence of noise, the CV syllables were mixed with speech-spectrum-shaped noise at three different signal-to-noise ratios (SNRs), i.e., +8, 0, and –8 dB. To generate speech-spectrum-shaped noise, the CV syllables spoken by all the talkers were normalized to the same average root mean square (RMS) level, and an average spectrum was obtained using all the syllables. Using the averaged spectrum, a finite impulse response function was created, and a white noise was passed through the impulse response function to obtain speech-spectrum-shaped noise. In order to obtain the desired SNRs, the RMS amplitude of the speech-spectrum-shaped noise was adjusted with reference to the RMS amplitude of the CV syllable.

Procedure

Consonant identification was carried out in quiet and noisy listening conditions as a closed set identification task. The participants were instructed to identify the consonant in the CV syllable by clicking one of the 21 software buttons, shown on the computer screen, labeled with an individual consonant sound. The participants were allowed to hear the syllable a maximum of three times before making their decisions. After the response was obtained, the next syllable was automatically presented with an interval pause of 1.5 sec. The syllables were presented randomly across the consonants and talkers at each SNR. Consonant identification for all the conditions were completed in multiple sessions, and breaks were provided as required by the participants. Consonant perception was always investigated from the easiest condition and progressed toward the hardest conditions i.e., the quiet listening condition first, followed by the noisy listening condition. In addition, an adaptive procedure was applied for the scores. When the correct score for a certain consonant reached equal to or less than three times chance performance (3/21 or 14.28%), the consonant was not presented at lower SNRs. The responses of the participants were saved in the form of matrix called a “confusion matrix.”

Data Analysis

Confusion matrices obtained from all the participants were added separately across the conditions to obtain a combined confusion matrix. The combined matrices were subjected to information transfer analysis (SINFA)^[32], using the feature information xfer (FIX) software. The features of the consonants, such as place of articulation, manner of articulation, and voicing, were used for the information transfer analysis. The values for the place of articulation were bilabial, alveolar, palatal, dental, retroflex, glottal, and velar; whereas for the manner of articulation the values used were stop, affricate, fricative, glide, liquid, and nasal. Voicing had two values: voiced and voiceless. The mean consonant identification score was also obtained for each participant across the conditions, and the percent correct identification score was transformed into rationalized arcsine units (RAU). The transformed RAU data was subjected to repeated measure ANOVA to investigate the effects of the group and listening conditions on consonant identification. All the statistical analyses were performed using Statistical Package for the Social Sciences (SPSS Inc.; Chicago, IL, USA) software version 16.0.

RESULTS

Consonant Perception

Figure 1 shows the mean consonant identification scores for the young and middle-aged adults across the quiet and noisy listening conditions. It can be observed that the mean consonant identification scores are better for young adults compared to middle-aged adults across the listening conditions (quiet and noisy). Further, the mean consonant identification score was the highest in the quiet listening condition for both the young and middle-aged adults, while it decreased with SNRs in the noisy listening condition. Comparison of the mean consonant identification scores across the SNRs shows a reduction in the scores with SNR for both young and middle-aged adults. To investigate if the mean difference for the identification scores, between groups and listening conditions, are significantly different, a repeated measure ANOVA was carried out with the groups as a between subject factor, and for listening conditions as a within subject factor. The results showed a significant effect of the listening conditions ($F(3,81)=1596.3$, $p<0.001$) and groups ($F(1,27)=6.94$, $p=0.014$) on the mean consonant identification scores, while there was no significant interaction between the groups and listening conditions ($F(3,81)=1.074$, $p=0.365$). A pairwise comparison of the consonant identification scores across the listening conditions revealed a significant difference between the mean consonant identification scores across all the conditions ($p<0.001$).

Information Transfer

Figure 2 shows the transfer of information for the consonant features, i.e., place of articulation, manner of articulation, and voicing across the listening conditions for both young and middle-aged adults. It can be seen that the transfer of information for all the consonant features is best in the quiet listening condition, while it decreased with SNRs in the noisy listening condition for both young and middle-aged adults. In addition, it can also be noted that the information transfer is highest for the manner of articulation and least for the place of articulation across the listening conditions for both young and middle-aged adults. Further, comparison of the transfer of consonant information across the groups shows better information transfer among young adults compared to middle-aged adults.

Figure 3 shows the identification scores for individual consonants across the listening conditions for both young and middle-aged adults. It can be observed that there is a general reduction in the identification score for each consonant with SNRs for both groups. At 8 dB SNR, the identification score of most of the consonants are similar to in the quiet listening condition, while the perception of the consonants (/ɲ/, /m/, /d/, /d/, /b/) are slightly more affected for both groups. At 0 dB SNR, the identification score of all the consonants decreases rapidly for both groups, except for the fricatives (/s/, /ʃ/), affricates (/tʃ/, /dʒ/), and semivowel (/j/). Further, at -8 dB SNR, the identification score of most of the consonants are below chance level, except for the fricatives (/s/, /ʃ/) and affricates (/tʃ/, /dʒ/). Based on the results of the present study, and similar to the findings of earlier investigations, the consonants could be grouped into three sets. One set of consonants were difficult to perceive and were greatly affected by noise. This set contains the consonants /ɲ/, /m/, /d/, /d/, and /b/, and was labeled as C1. In contrast, the consonants (/p/, /t/, /k/, /t/, /g/, /n/, /r/, /l/, /v/, /l/, /h/) were moderately affected by noise in both

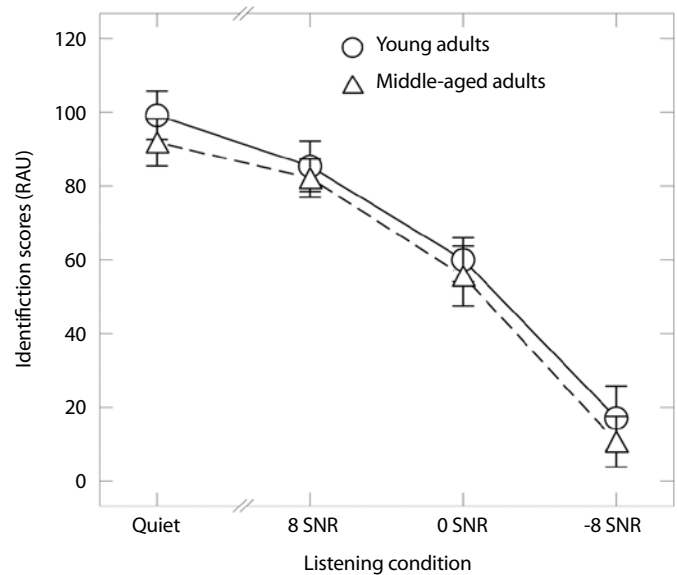


Figure 1. Mean consonant identification scores in rationalized arcsine units (RAU) and standard deviation (error bars) for young and middle-aged adults across the listening conditions

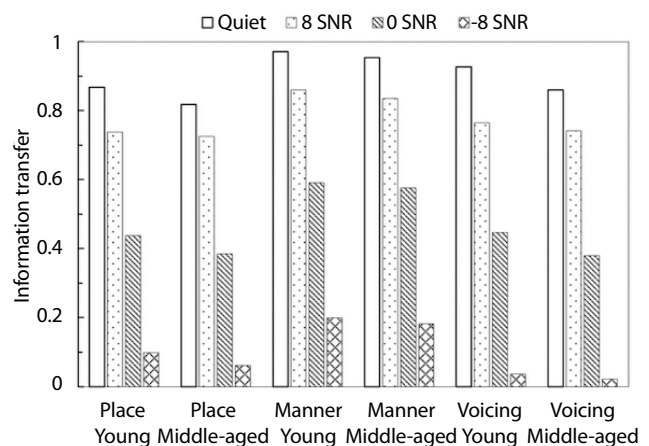


Figure 2. Mean information transfer for various features of the consonants (place, manner, and voicing) in quiet and noisy listening conditions for young and middle-aged adults

group, and had relatively high identification scores at 0 dB SNR, and were labeled as C2. The remaining consonants (/s/, /ʃ/, /tʃ/, /dʒ/), labeled as C3, were resistant to the effects of noise, and could be identified accurately at -8 dB SNR.

DISCUSSION

The present study was carried out to compare consonant perception of young and middle-aged adults in quiet and noisy listening conditions. The results showed consonant perception to be better in favorable listening conditions for both young and middle-aged adults. This finding was expected based on the findings of various investigations reported in literature [33-35]. In the presence of noise, the consonant identification scores decreased with SNRs for both young and middle-aged adults, this reduction could be attributed to the masking effects of noise on the speech syllables. Comparison of the consonant identification scores of young and middle-aged adults showed significantly poorer scores for middle-aged adults in both quiet and noisy listening conditions.

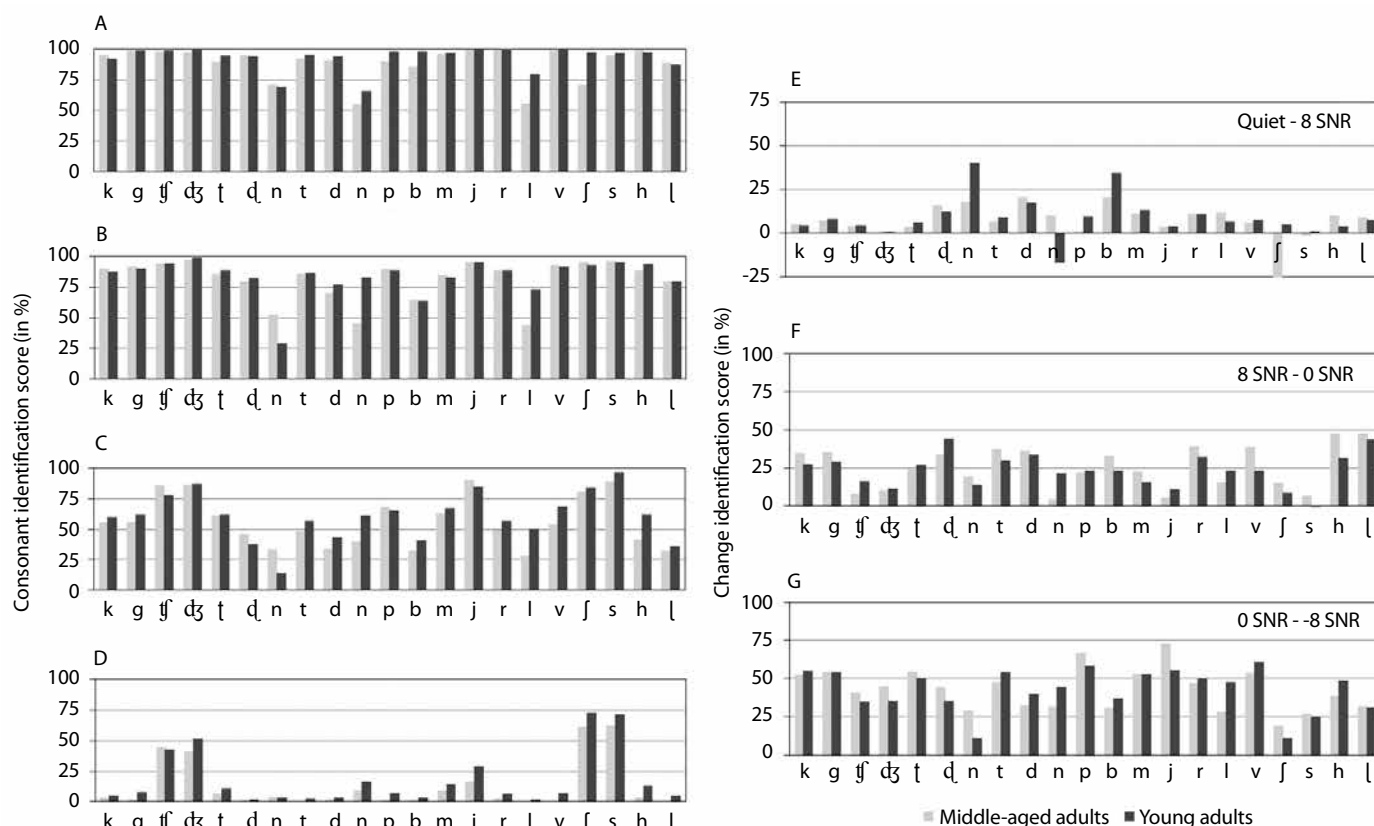


Figure 3. Left panels show the mean consonant identification scores for individual consonants in quiet and noisy listening conditions for young and middle-aged adults. Panels A, B, C, and D show the mean scores for individual consonants in quiet and noisy listening conditions at 8, 0, and -8 dB SNR, respectively. The right panels show the changes in consonant identification scores for individual consonants across the listening conditions. Panel E shows the change in consonant identification scores between the quiet listening condition and 8 dB SNR, while panel F shows the difference in scores between 8 and 0 dB SNR, and panel G shows the change in scores between 0 and -8 dB SNR.

This finding shows the presence of a small but significant consonant perception difficulty among middle-aged adults in quiet and noisy listening conditions. In line with the findings of the present study, poorer consonant perception has been reported in the literature among middle-aged adults in quiet [33, 34, 36], noisy [34], and spectrally degraded [36] conditions. Further, in addition to poor consonant perception, poorer speech perception has been reported in the presence of noise [30, 37], competing speech [28–30], reverberation [5], interrupted speech [37, 38], time-compressed speech [7], and music [30]. The slight consonant perception difficulty noted in the present study among middle-aged adults may not have any significance for understanding speech in simple listening conditions, such as in the quiet listening condition or in the presence of steady noises, whereas in challenging listening conditions, such as understanding speech in the presence of multi-talker babble or competing speech, it may have a significant effect on speech perception.

Comparison of the transfer of consonantal information across the groups showed the manner of articulation to be transmitted better than the place of articulation and voicing, while transfer of the place of articulation was greatly affected. Further, the results showed a reduction in the amount of transfer of consonantal information with SNRs for both young and middle-aged adults. The above results in the present study are in line with the reports of earlier investigations [39]. The reduction in the transfer of consonantal information could be attributed to the masking effects of noise on speech, which leads to poorer consonant perception. The addition of noise to speech results

in masking of consonantal cues, which are important for the accurate identification of consonants, which leads to confusion in the perceived consonants and a decrease in the transfer of information. Comparison of the identification scores of individual consonants across quiet and noisy listening conditions showed fricatives and affricates to be the least affected by noise, similar to the findings of earlier investigations [35, 40]. Better identification score for the above consonants in the presence of noise may be attributed to the higher SNRs for speech stimuli at high frequencies. In addition, the findings of the present study show that the consonant perception difficulties of middle-aged adults are similar to young adults. Middle-aged adults had greater difficulty for perceiving C1 consonants, while perception of the C3 consonants were least affected, similar to young adults. These results are similar to the findings of earlier investigations [33, 34] that also reported similar consonant perception difficulties across the ages.

The poorer consonant perception among middle-aged adults may be a consequence of poorer auditory and cognitive processing. Several investigations measuring the auditory processing abilities of middle-aged adults have consistently shown poorer temporal processing among middle-aged adults, which could be attributed to aging [23, 28]. In addition, working memory capacity is also found to be poorer among middle-aged adults compared to young adults [20, 41]. Thus, the poorer consonant perception among middle-aged adults may be attributed to both age-related changes in temporal processing and in the cognitive functions. These changes may lead to subtle

problems while processing speech, resulting in poorer speech perception. However, the present study did not measure the auditory and cognitive processing abilities of the participants, hence we do not know the effects of these on consonant perception.

To conclude, the result of the present study showed slight but significantly poorer consonant recognition scores among middle-aged adults compared to young adults. This slight difficulty may not have any significant effects on speech perception in simple listening conditions, such as in the quiet listening condition or in the presence of steady noises. However, in challenging listening conditions, such as understanding speech in the presence of multi-talker babble or competing speech, it may have significant effects on speech perception. Further, the pattern of consonant perception difficulty was similar for both young and middle-aged adults.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Kasturba Medical College, Mangalore.

Informed Consent: Written informed consent was obtained from patients who participated in this study.

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