Bluetooth Coupling in Hearing Aids: Effect on Audiovisual Speech Recognition and Quality Rating of Compressed Speech in Older Individuals with Sloping Hearing Loss

Hemanth Narayan Shetty[1] Shubhaganga Dhrruva Kumar[2] Srikar Vijayasarathy[1]

[1] Department of Audiology, JSS Institute of Speech and Hearing, Mysuru, Karnataka, India
[2] Department of Speech and Hearing Manipal College of Health Professions, Manipal Academy of Higher Education, Manipal

Address for correspondence Srikar Vijayasarathy, MSc, Department of Audiology, JSS Institute of Speech and Hearing, Mysuru 570004, Karnataka, India (e-mail: srkrv.y@gmail.com).

Int Arch Otorhinolaryngol 2023;27(2):e302–e308.

Abstract

Introduction Older individuals often report that they find it difficulty in enjoying watching television since they find it hard to follow the rapid intensity variations, and voice changes from scene to scene.

Objective The present study investigated the effect of coupling the hearing aid with the television via Bluetooth on audiovisual speech recognition and quality rating of compressed speech in older individuals with hearing loss.

Method Twenty participants in the age range of 60 to 75 years who had moderate to moderately severe sloping sensorineural hearing loss were bilaterally fitted with digital receiver in the canal hearing aids. The hearing aid was coupled with a television via Bluetooth using a streamer. The video recorded stimuli were presented at 65 dB SPL at normal rate, 35% compression and 45% compression conditions. Speech recognition scores and quality ratings were obtained for each condition with and without the Bluetooth streamer connected to the hearing aids.

Results Speech recognition scores were significantly better with Bluetooth coupling compared with conventional hearing aid use at 40% compressed speech rate. The quality was also rated higher in almost all parameters across speech rates when Bluetooth was used.

Conclusions The improved clarity and nullification of room reverberation offered by Bluetooth coupling can potentially compensate for the age-related temporal processing deficit contributing to ease of listening.

Keywords
- speech perception
- signal-to-noise ratio
- aging
- Bluetooth

Introduction

Older adults tend to spend quite a bit of their leisure time watching television, but subjective reports indicate poor appreciation of the quality of speech.[1] This is because tracking the speech output from the television is different from the usual speech perception. In the former, speech rate is instantaneously and continuously altered, and these swift alterations in speech rate are poorly captured by the aging

received
September 3, 2021
accepted after revision
January 26, 2022

DOI https://doi.org/10.1055/s-0042-1744170.
ISSN 1809-9777.

auditory system with a temporal processing deficit. Environmental noise and room reverberations further reduce the signal-to-noise ratio (SNR). The experience becomes worse when there is an accompanying hearing loss.[2–5]

Hearing aids are one of the best rehabilitation options to alleviate hearing loss in older adults. With recent advances in technology, satisfaction ratings are quite high.[6] However, some nagging problems remain, and the most prominent among them is the perception of speech in adverse listening situations – both in terms of intelligibility and speech quality.[6,7] With technological progress, there are increasingly more and more features and accessories that aim to enhance speech and reduce noise to deliver a more natural and clear speech. Bluetooth coupling is one such technology that aims to wirelessly transmit the signal via Bluetooth, with low acoustic and electromagnetic interference, to any Bluetooth-enabled device. The resulting signal has a high SNR, and since the direct signal is received rather than a reflected one, reverberation has little effect. The SNRs achieved through Bluetooth are even better than those provided by directional microphones[8] and could help alleviate the disordered temporal processing due to aging and hearing loss. Benefit has already been reported for cell phone use and perception from a loudspeaker in those with hearing loss on coupling the hearing aid with a Bluetooth streamer,[9] both in terms of speech perception as well as in quality rating. While there are some data on the benefit of using Bluetooth to improve perception,[9,10] there is no clarity on how much it can help alleviate deficient temporal processing. The current study is, thus, focused on assessing Bluetooth benefit (objective and subjective) in the audiovisual mode at faster speech rates to investigate if age-induced poor temporal processing can be counteracted by the better SNR and clarity offered by Bluetooth transmission in older individuals with hearing loss.

Method

Participants

The participants were tested in in a tertiary healthcare set up in an acoustically treated soundproof room. Twenty older adults with hearing loss (11 males, 9 females) in the age range of 60 to 75 years (mean = 68.6 years) participated in the study. The hearing loss ranged from bilateral moderate to moderately severe sloping sensorineural hearing loss (►**Fig. 1**). The participants had speech recognition scores ≥ 75% for monosyllables, and normal middle ear status with type 'A' tympanogram and measurable reflex thresholds. All participants had postlingual hearing loss with adequate speech and language skills and were native speakers of the Kannada, a widely spoken language in southern India. None of the participants had a history of neurological, otological, or cognitive problems. The procedures involved in the study were explained to the participants, and a signed informed consent form was obtained. The study followed the ethical guidelines for bio-behavioral research involving human subjects[11], and the institutional review board approved it (JSSISH-RC-2020–102).

Procedure

Selection of Compression Rate

The standard Kannada sentence lists, developed by Geetha et al.,[12] were used for the study. Each list consisted of 10

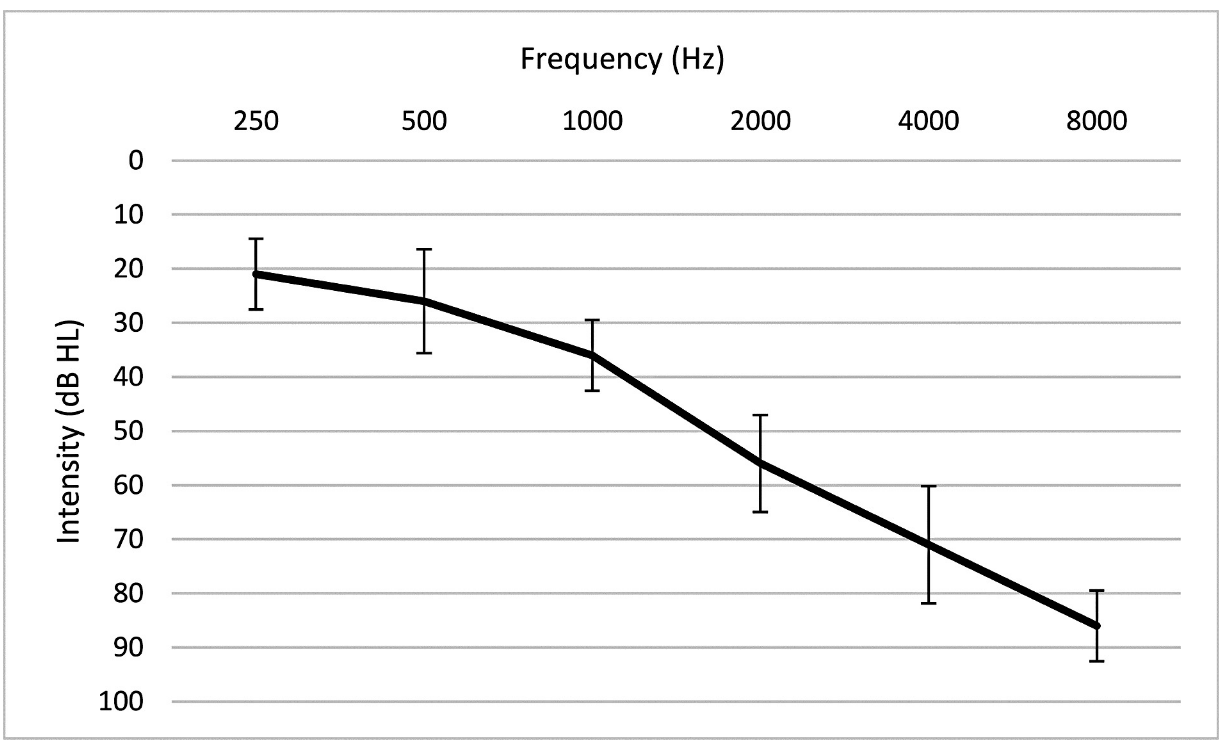

Fig. 1 Mean audiogram of the participants.

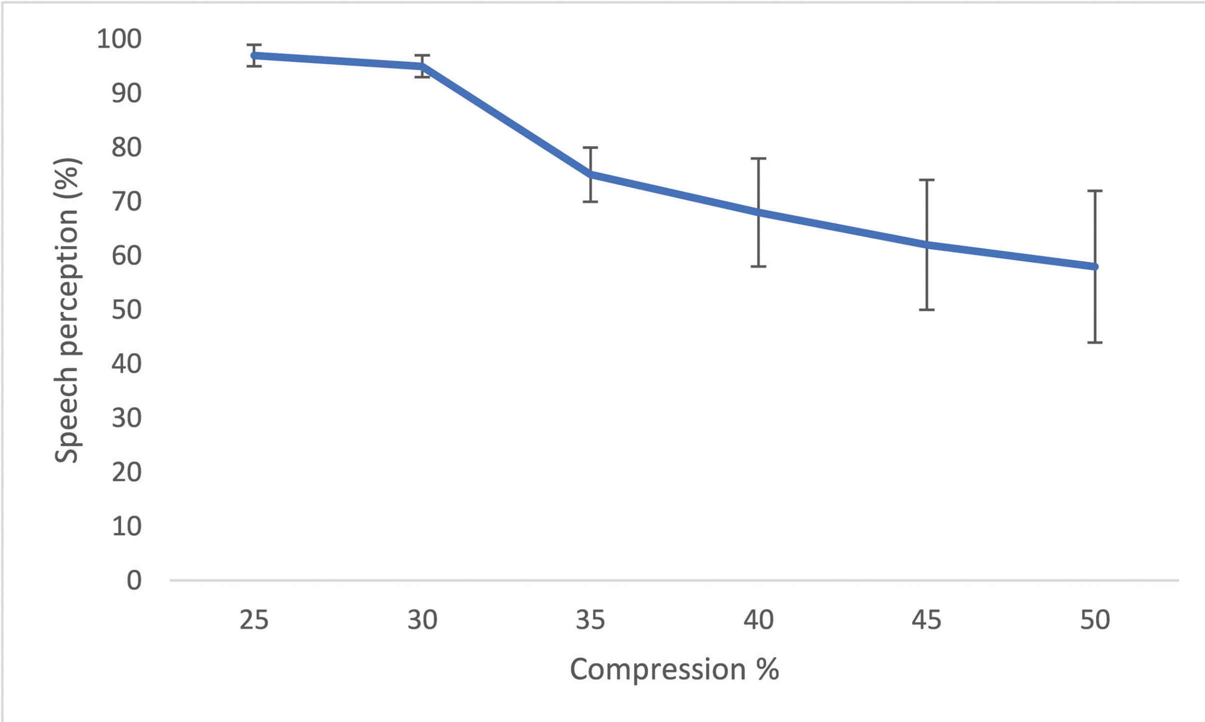

Fig. 2 Mean sentence recognition scores across different rates of compression. Footnote: Error bars represent one standard deviation.

sentences, and each sentence consisted of 4 keywords so that a maximum score of 40 could be achieved. The sentences were subjected to compression of 25 to 50% in steps of 5% using the Adobe Audition software ,version 1.5 (Adobe Inc., San Jose, CA, USA), and the method of constant stimuli was used to determine rates corresponding to a 60 to 70% score on the mean psychometric function of 10 subjects with normal hearing sensitivity (►**Fig. 2**). The detailed procedure of compressing the sentence at each rate is explained elsewhere.[13] The two compression rates selected for the study were 35% and 40%. The average rate of speech was 10 syllables/sec and 12 syllables/sec for 35% and 40% compression, respectively.

Stimulus Preparation

Lists from the Kannada sentence bank[12] were used in this part of the study too. The sentences were recorded in an acoustically treated recording room by an adult female and male speaker who were native speakers of Kannada. Each speaker was first asked to speak naturally at a normal rate. Another recording was made with the speakers being asked to match the rate of sentences electronically time-compressed at 35% and 40%. The video recorded with the camera Nikon D500 (Nikon Corp., Minato City, Tokyo, Japan) and the audio recorded in Adobe Audition were synched using the Adobe Premiere Pro software (Adobe Inc.). The synched audio-video recordings were sliced into individual sentences and saved separately. The recorded speech was verified to have the same rate as that of the compressed speech. The prepared sentence materials consisted of both male and female speakers (mixed randomly), and were either presented unmodified (0% compression), or presented with time compression (35% and 45% compression).

Hearing Aid Fitting and Stimulus Presentation

The participants were bilaterally fitted with the Starkey Livio series receiver-in-canal support (Starkey Hearing Technologies, Eden Prairie, MN, USA) programmed using the NAL-NL2 fitting formula. It was ensured that the directional microphone and noise reduction circuitry were activated. The accompanying 'TV streamer' was connected to the TV and paired with the fitted hearing aids. Each participant was seated one meter away from the television set. A practice session was first performed with a compression of 10% to familiarize the subjects with the procedure. A total of six lists of recorded video clippings were used for the test session. Two lists each were presented at three conditions: normal, 35%, and 40% compression conditions. The sentences were presented through the television set at 65 dB SPL, and the order of conditions was randomized to prevent the order effect. The participants were asked to repeat back the sentence heard in verbatim. The responses were scored online (as and when the participant responded) but were recorded for offline verification.

Subjective Quality Rating

Each participant was asked to rate the quality of speech on a 10-point scale in terms of clarity, pleasantness, ease of understanding, and overall impression[14] to assess the quality of speech with and without the streamer. The quality ratings were obtained immediately after listening to each condition, but the participants were blinded to the condition being presented to avoid bias in ratings. The participants were provided with the description of each dimension (►**Table 1**), and adequate explanation on each dimension was provided whenever the participants required clarifications before rating.

Table 1 Description of measures for quality rating

Terms	Description
Clarity	How clear, understandable, bright, and distinct the sound is.
Pleasantness	How agreeable, comfortable, and pleasant the sound is.
Ease of understanding	How easily they can understand speech
Overall impression	Considering everything they have heard, what do they think about the speech delivered to their ears?

Statistical Analysis

The data was subjected to statistical analysis using the SPSS Statistics for Windows, Version 17.0 software (). The Shapiro-Wilk analysis indicated a Gaussian distribution of all variables ($p > 0.05$). Inferential analysis was done using repeated measures analysis of variance (R-ANOVA) and posthoc *t*-tests with correction for multiple comparisons.

Results

Speech Recognition

Speech recognition was quantified as the number of keywords correctly repeated back rather than the typical percentage conversion to retain the natural distribution of data. Two-way repeated measures ANOVA was used (►**Fig. 3**) to

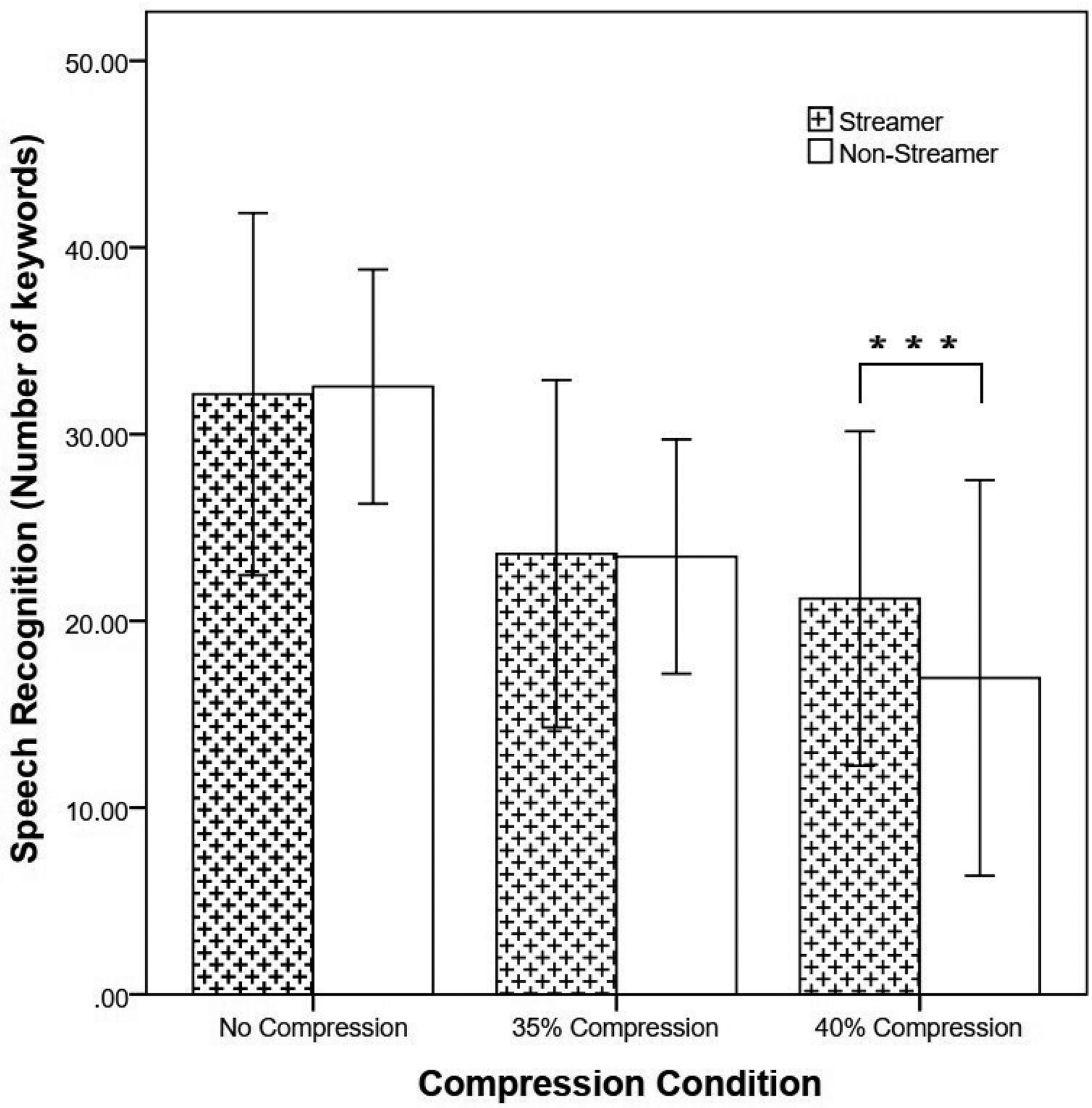

Fig. 3 Mean and standard deviation of speech recognition scores for different rates of speech with and without Bluetooth. Footnote: ***: $p < 0.001$.

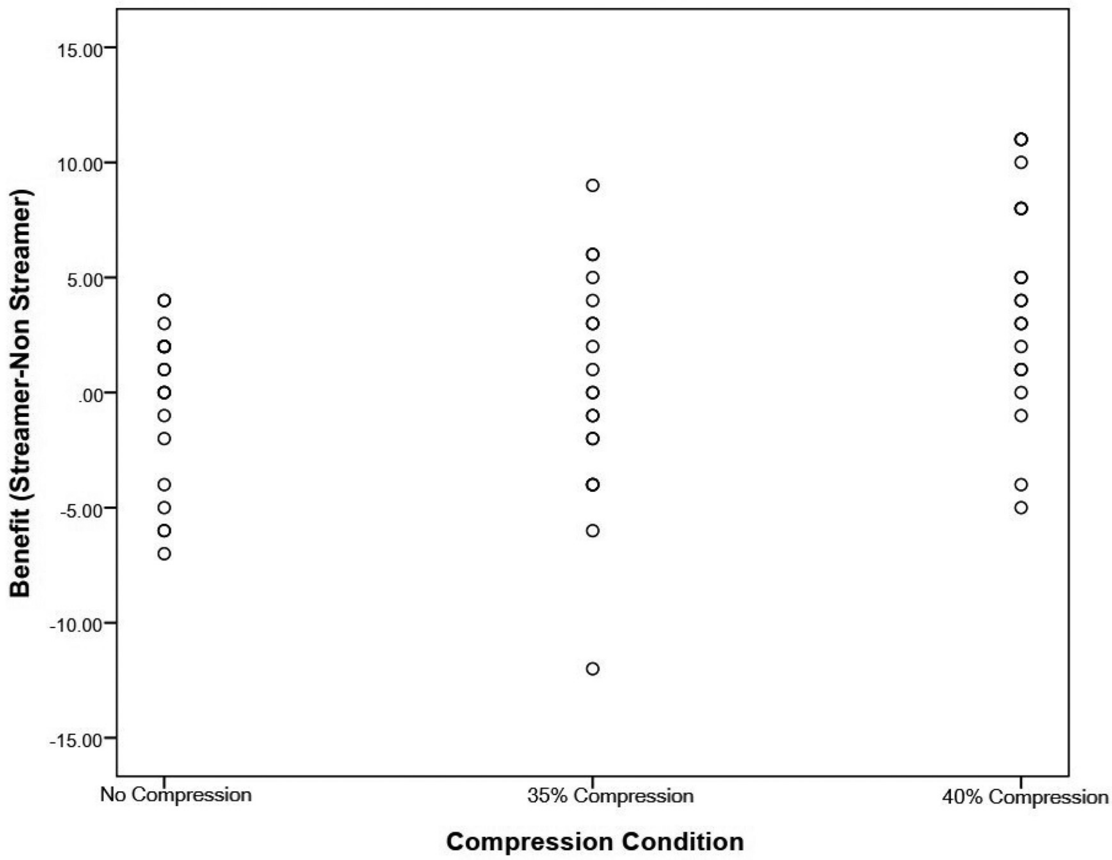

Fig. 4 Benefit obtained with the streamer at different rates of speech.

analyze the main effect of rate, Bluetooth use, and their interaction. There was a significant main effect of rate ($F_{(2, 18)} = 76.469$, $p < 0.01$), with the scores being better at normal rate (vs 35% compression: $t_{(1,39)} = 13.9$, $p < 0.01$; vs 40% compression: $t_{(1,39)} = 12.1$, $p < 0.01$), and better performance at 35% compared with 40% compression ($t_{(1,39)} = 4.3$, $p < 0.01$). Although the recognition score was better on average with Bluetooth, it failed to reach significance ($F_{(1, 19)} = 3.112$, $p = 0.094$). The interaction between the rate and condition, however, was statistically significant ($F_{(2, 18)} = 11.449$, $p < 0.001$), and a dependent *t*-test was performed to analyze the differences across all conditions. Bluetooth coupling did not significantly improve speech recognition at normal rate ($t_{(1, 19)} = -0.518$, $p = 0.611$) and at 35% compression conditions ($t_{(1,19)} = 0.137$, $p = 0.892$). However, in the 40% compression condition, speech recognition with the streamer was superior to that of just conventional hearing aid ($t_{(1,19)} = 3.942$, $p = 0.001$). A trend of increased benefit could be noted as the rate became faster (►**Fig. 4**).

Quality Rating

It was observed that the rating was higher for Bluetooth use at all rates, more so at higher compression conditions (►**Fig. 5**). Dependent *t*-tests were performed to investigate differences in quality perception at each rate with and without the streamer (►**Table 2**). Except for the 'clarity

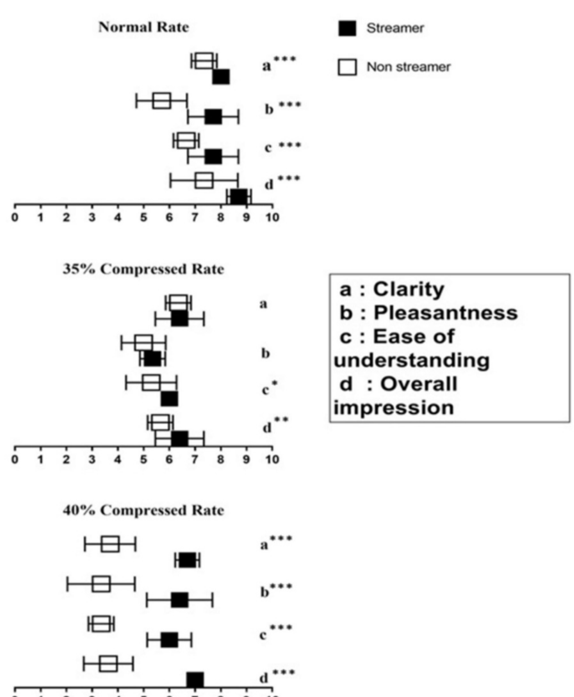

Fig. 5 Mean and standard deviation of quality rating across speech rates with and without the Bluetooth.

Table 2 Paired sample *t*-test results for the subjective quality rating across rates of speech with and without using Bluetooth coupling

Parameter (Bluetooth Vs acoustic)	Normal		35% compression		40% compression	
	t-value	*p*-value	t-value	*p*-value	t-value	*p*-value
Clarity	5.9	$< 0.01^*$	0.27	0.79	15.63	$< 0.01^*$
Pleasantness	4.7	$< 0.01^*$	1.2	0.25	6.04	$< 0.01^*$
Ease of understanding	5.7	$< 0.01^*$	3.2	0.01^*	9.05	$< 0.01^*$
Overall impression	4.6	$< 0.01^*$	2.68	0.01^*	15.37	$< 0.01^*$

$p < 0.05$.

and pleasantness' parameter at the 35% compression rate, the quality was rated significantly higher when the streamer was used.

Discussion

The present study aimed to investigate if the better SNR and clarity offered by Bluetooth coupling of the hearing aid and the television can improve audiovisual speech recognition and quality by offsetting the decreased temporal processing abilities in older adults with sloping hearing loss. We used speech at normal rate, 35% compression, and 40% compression conditions and measured audiovisual speech recognition and subjective quality rating with and without the streamer coupled with the hearing aid.

It was observed that speech recognition scores decreased with an increase in the speech rate. This reduction with time compression in older individuals has been attributed to a reduction in processing efficiency with age.[15–18] At least two major sources of distortions may be responsible for this; the first is due to the compression of speech rate that leads to the reduction of the interphonemic gap of both consonants and vowels, and a decrease in the pause length between words, though the spectral properties of the stimulus are spared by and large.[17] Next is the compression amplification in the hearing aid amplifier.[19–23] Non-linear compression is particularly deleterious especially at faster attack and release times and leads to an output that has low modulation depth and is spectrally distorted.[19,21] The two forms of distortions interact with the third distortion – the deficit in temporal processing with age.

Reduced temporal processing abilities in older adults is well established as seen through measures of gap detection in tones and noise, duration discrimination, co-modulation masking release, etc.[24–26] Wingfield et al.[15] reported that increments in speech rate decreased speech recognition in older subjects with normal hearing sensitivity, but not in younger subjects. Similarly, older individuals with hearing loss perform poorer compared with younger subjects with a similar degree of loss with time-compressed speech.[27,28] The interactive effects of age and hearing loss render the auditory system unable to keep up with the compression of the already brief and rapid fluctuations in consonants.[16,18,29,30]

We found that Bluetooth transmission resulted in significant improvement of the audiovisual speech recognition scores compared with conventional hearing aid alone at faster rates. The use of Bluetooth as the transmission mode can reduce distortion by improving the SNR of speech at the hearing aid output due to the exclusion of environmental noise and room reverberation. Sherbecoe and Studebaker[31] measured the audibility index for the Connected Speech test, a measure of perception of everyday speech and found that 75.5% of the speech recognition came from 315 to 3,150 Hz, and that 37.2% of this information was concentrated between 1,600 and 3,150 Hz. It is precisely in the low and mid-frequency regions that the Bluetooth transmission improves the SNR, thus resulting in better performance.[9] The advantages that we found with Bluetooth use in the quiet condition are pertinent. Nullification of distance-induced sound quality distortion and room reverberation effects were thus appreciated by older individuals with hearing loss, though more in terms of the improvement in quality rather than in speech intelligibility. Larger effects are bound to be there in a noisier environment, and future studies must focus on this direction. The fact that speech recognition scores significantly improved at the highest compression condition also indicates that Bluetooth transmission may help address the effects of poor temporal processing due to aging and hearing loss.

The quality of speech was rated higher in almost all domains across conditions with Bluetooth coupling compared with just conventional hearing aid use. This finding is similar to sizeable improvements in quality previously reported.[9,10] Smith and Davis[10] reported that listeners described that they could follow the emotion and the speaker's mood much better with Bluetooth and were amazed that they could hear a film well. Electromagnetic transmission (versus acoustic) ensures that reflections from room surfaces do not distort the direct signal from the source. Thus, along with SNR enhancement, reverberation effects are nullified, contributing to increased clarity.[32,33] Finally, Bluetooth has low interference transmission and generates low strength electromagnetic fields that are not adequate to create audible interference.[34]

Conclusion

Bluetooth coupling between the hearing aid and television leads to enhancement in audiovisual speech recognition, particularly at faster speech rates in older listeners with hearing loss. Improvement in signal quality is also well appreciated by the listeners, even in the quiet condition. It is recommended that older individuals, especially those who enjoy watching television use this assistive technology regularly to have a fluid and less effortful experience.

Conflict of Interests

The authors have no conflict of interests to declare.

References

1 Depp CA, Schkade DA, Thompson WK, Jeste DV. Age, affective experience, and television use. Am J Prev Med 2010;39(02):173–178
2 Kochkin S. MarkeTrak VII: Customer satisfaction with hearing instruments in the digital age. Hear J 2005;58(09):30
3 Lin FR, Yaffe K, Xia J, et al; Health ABC Study Group. Hearing loss and cognitive decline in older adults. JAMA Intern Med 2013;173(04):293–299
4 Peelle JE, Troiani V, Grossman M, Wingfield A. Hearing loss in older adults affects neural systems supporting speech comprehension. J Neurosci 2011;31(35):12638–12643
5 Meister H, Rählmann S, Walger M, Margolf-Hackl S, Kießling J. Hearing aid fitting in older persons with hearing impairment: the influence of cognitive function, age, and hearing loss on hearing aid benefit. Clin Interv Aging 2015;10:435–443
6 Picou EM. MarkeTrak 10 (MT10) Survey Results Demonstrate High Satisfaction with and Benefits from Hearing Aids. Semin Hear 2020;41(01):21–36
7 Jilla AM, Johnson CE, Danhauer JL, et al. Predictors of Hearing Aid Use in the Advanced Digital Era: An Investigation of Benefit, Satisfaction, and Self-Efficacy. J Am Acad Audiol 2020;31(02):87–95
8 Edwards B. The future of hearing aid technology. Trends Amplif 2007;11(01):31–45
9 Kim M-B, Chung W-H, Choi J, et al. Effect of a Bluetooth-implemented hearing aid on speech recognition performance: subjective and objective measurement. Ann Otol Rhinol Laryngol 2014;123(06):395–401
10 Smith P, Davis A. The benefits of using bluetooth accessories with hearing aids. Int J Audiol 2014;53(10):770–773
11 Venkateshan S. Ethical guidelines for bio behavioral research. All India Institute of Speech and Hearing; 2009
12 Geetha C, Kumar KSS, Manjula P, Pavan M. Development and standardisation of the sentence identification test in the Kannada language. J Hear Sci 2014;4(01):18–26
13 Shetty HN, Raju S. Effect of compression release time of a hearing aid on sentence recognition and the quality judgment of speech. Noise Health 2019;21(103):232–241
14 Boike KT, Souza PE. Effect of compression ratio on speech recognition and speech-quality ratings with wide dynamic range compression amplification. J Speech Lang Hear Res 2000;43(02):456–468
15 Wingfield A, Poon LW, Lombardi L, Lowe D. Speed of processing in normal aging: effects of speech rate, linguistic structure, and processing time. J Gerontol 1985;40(05):579–585
16 Gordon-Salant S, Fitzgibbons PJ. Recognition of multiply degraded speech by young and elderly listeners. J Speech Hear Res 1995;38(05):1150–1156
17 Gordon-Salant S. Hearing loss and aging: new research findings and clinical implications. J Rehabil Res Dev 2005;42(4, Suppl 2)9–24
18 Jenstad LM, Souza PE. Temporal envelope changes of compression and speech rate: combined effects on recognition for older adults. J Speech Lang Hear Res 2007;50(05):1123–1138
19 Van Tasell DJ. Hearing loss, speech, and hearing aids. J Speech Hear Res 1993;36(02):228–244
20 Bustamante DK, Braida LD. Multiband compression limiting for hearing-impaired listeners. J Rehabil Res Dev 1987;24(04):149–160
21 Verschuure J, Maas AJJ, Stikvoort E, de Jong RM, Goedegebure A, Dreschler WA. Compression and its effect on the speech signal. Ear Hear 1996;17(02):162–175
22 Plomp R. The negative effect of amplitude compression in multichannel hearing aids in the light of the modulation-transfer function. J Acoust Soc Am 1988;83(06):2322–2327
23 Arehart KH, Souza P, Baca R, Kates JM. Working memory, age, and hearing loss: susceptibility to hearing aid distortion. Ear Hear 2013;34(03):251–260
24 Schneider B, Speranza F, Pichora-Fuller MK. Age-related changes in temporal resolution: envelope and intensity effects. Can J Exp Psychol 1998;52(04):184–191
25 Snell KB. Age-related changes in temporal gap detection. J Acoust Soc Am 1997;101(04):2214–2220
26 Gatehouse S. Factors that influence the benefit from amplification in the elderly. Acta Otolaryngol Suppl 1990;476(476):262–268, discussion 269
27 Letowski TR, Poch NE. Understanding of time compressed speech in older adults. J Acoust Soc Am 1994;95(05):433–439
28 Vaughan NE, Letowski T. Effects of age, speech rate, and type of test on temporal auditory processing. J Speech Lang Hear Res 1997;40(05):1192–1200
29 Wingfield A, McCoy SL, Peelle JE, Tun PA, Cox LC. Effects of adult aging and hearing loss on comprehension of rapid speech varying in syntactic complexity. J Am Acad Audiol 2006;17(07):487–497
30 Gordon-Salant S, Zion DJ, Espy-Wilson C. Recognition of time-compressed speech does not predict recognition of natural fast-rate speech by older listeners. J Acoust Soc Am 2014;136(04):EL268–EL274
31 Sherbecoe RL, Studebaker GA. Audibility-index functions for the connected speech test. Ear Hear 2002;23(05):385–398
32 Finitzo-Hieber T, Tillman TW. Room acoustics effects on monosyllabic word discrimination ability for normal and hearing-impaired children. J Speech Hear Res 1978;21(03):440–458
33 Nabelek AK, Pickett JM. Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. J Speech Hear Res 1974;17(04):724–739
34 Levitt H. Historically, the paths of hearing aids and telephones have often intertwined. Hear J 2007;60(11):20–24

