Effect of Compression Release Time of a Hearing Aid on Sentence Recognition and the Quality Judgment of Speech

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Abstract

Context: The sentence recognition score and quality of speech differ when hearing aid compression is set at different release times at different signal to noise ratios (SNRs) for the normal and compressed rate of sentences. Aims: To investigate the effect of amplitude-compression release time of a hearing aid on sentence recognition and quality judgment: (1) for normal rate and time-compressed sentences (2) in quiet and noisy conditions. Settings and Design: A post-test repeated measures design. Methods and Material: We recruited fifteen adult participants with bilateral sensorineural hearing loss in each group, the younger (35–45 years), and the older ones (60–70 years). A gap detection test assessed temporal processing ability. We used three compression settings, fast-acting, slow-acting, and linear. Sentence recognition and quality and envelope difference index in normal and altered rates were assessed in quiet and in noise at these three compression settings. Statistical analysis used: A repeated measure ANOVA. Results: We found a significant improvement in recognition of sentences at a normal rate in slow compression release time, compared to fast and linear gain settings at each SNR. Similar results were observed for sentences compressed at the rate of 35% in quiet and +10 dB SNR. Further, the participants preferred the quality of speech in quiet with the hearing aid set to slow compared to fast compression release time. The benefit from the slow compression release time was higher than either linear or fast compression release time on sentence recognition. Further, we saw that there was a negative impact on sentence recognition at 3 dB SNR (normal-rate) and in quiet (35% compression rate) in older adults. Conclusions: The slow compression release time in a hearing aid is superior to the fast one in noisy conditions and also with higher subjective ratings of speech quality in quiet.

Keywords: Hearing aid, noise, speech

Key Messages: Slow compression release time of a hearing aid significantly improves the sentence recognition at high SNRs compared to linear or fast compression release time. The slow compression release time also leads to better sound quality in quiet. Listeners show better performance when the sentences are said at a normal rate than at a 35% compression rate.

INTRODUCTION

Older adults often experience difficulties in understanding speech in noisy environments.[1] The reduced recognition of speech in older adults may be due to: a) reduced audibility and/or upward spread of masking because of their sloping hearing loss[2] b) external noise that masks the soft consonants,[3] fills the space of modulation depth[4,5] and obscures the spectral component of speech.[6] Also, varied rates of speech of the speaker may affect speech perception.[7-9] The conversational rate of the speaker is dependent on the individual and their choice of representation of the content. On average, the conversational rate of adult Kannada-language speakers varies between 2 and 2.5 words per second (wps).[7] In English, the average rate of conversation may vary between 2.5 and 3 wps.[8] Temporal resolution is vital for accurate speech perception.

Received: 11 November 2019
Accepted: 4 February 2020
Published: 18 September 2020

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How to cite this article: 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;21:232-41.
Hearing aids have been extensively used to aid in the speech perception of older adults. Compression release time refers to time taken for the compressor to release from the compressed state with 2 dB of the linear steady state when once the signal has fallen below compression threshold. Compression release time in hearing aid was varied in the past to investigate the temporal envelope of amplified speech. Hearing aids attempt to alleviate hearing loss by providing amplification. Ellison et al. reported a significant effect on long term average speech spectrum by the interaction effect of compression release time constants and the gain set at the prescriptive target in each frequency. Furthermore, with the hearing aid set at fast release time constant as prescribed by either National Acoustic Lab nonlinear (NAL NL-1) or desired sensation level (DSL i/o), higher temporal envelope distortion was observed.

From the literature, we can conclude that a reduction in speech recognition is influenced by audibility, output SNR, temporal distortion, and spectral distortion along with the combination of the relationship between channels and release time specified.

Temporal envelope is a low frequency amplitude modulation conveying segmental and suprasegmental information during speech perception. The envelope difference index (EDI) is defined as an envelope subtraction technique to provide an index quantifying the difference between two temporal envelopes. The EDI ranges from 0 (i.e., perfect correspondence between the envelopes) to 1 (i.e., no correspondence between the envelopes). Moore et al. have reported a consonant-vowel level difference in hearing aids with fast release time, resulting in increased EDI, and hence reduced speech recognition scores. As EDI increased to 0.25 and above, speech recognition decreased for the time-compressed rate of speech but was not significant for the normal rate of speech.

In selecting the optimum compression parameter in hearing aid, an understanding of it on a sound quality is imperative. The preferences of sound quality by hearing-impaired listeners were significantly affected by compression release time constants, background noise, and high compression ratio. If there is a difference in performance on rate altered sentence recognition between time constants of compression, it might help an audiologist to select the best release time at the time of programming. Also, there is a need to understand how environmental factors (rate and noise) interact with each of the amplification strategies (linear, fast, and slow compression release times) and affect sound quality.

The present study aims to determine the effect of compression release time constants on intelligibility and sound quality of speech (clean and degraded) in younger and older adults with hearing loss. The sources of signal degradation included noise, time compression, and their combination. The research questions were: 1) Will there be a reduction in the speech recognition score for fast over slow compression release time constants? 2) Will there be a difference in performance based on the rate of speech and SNR? 3) Will the older adult be more affected by the compression-related distortions than younger adults?

**SUBJECTS AND METHODS**

A repeated measures design was used to study the effects of compression release time of a hearing aid on sentence recognition and sound quality of normal and 35% compressed rate of sentences embedded in different SNRs by young and older adults with bilateral sensorineural hearing loss.

**Participant selection criteria**

We included thirty participants in this study. The younger group consisted of fifteen participants aged from 35 to 45 years (mean = 38.9 years; SD ± 4.2). These participants had bilateral sensorineural hearing loss with the hearing threshold between 45 to 55 dB HL at octave frequencies from 250 to 8000 Hz. The older group consisted of 15 participants aged from 60 to 70 years (mean age = 66 years; SD ± 3.6). Older adult participants had acquired bilateral symmetrical sensorineural sloping hearing loss. The sloping hearing loss is defined as the difference between low and high frequencies of at least 20 dB. The participants had to have a speech recognition score of ≥70% for sentences at a normal rate and in quiet, to ensure a measurable score at lesser SNRs with a 35% compressed rate of sentences. All participants of the study were native speakers of Kannada, an Indian Dravidian language, had relatively similar thresholds, at least at the low-frequency range and normal middle ear status with Type ‘A’ tympanogram. None of the participants had complaints of any other otological and neurological disorders. Also, a mini-mental state examination was performed on older adult participants to ensure normal cognitive function. The ethical committee of XXXX has approved to conduct the study. An informed consent was obtained from participants of the study.

**Stimuli**

Twenty-four lists of Kannada sentences prepared by Geetha et al., which were: low predictive; natural, phonemically, and phonetically balanced; semantically and syntactically correct were used. These sentences were used to assess the recognition in different experimental conditions. Each list comprises ten sentences, with five target words per sentence. Twelve lists of sentences were utilized to test sentence recognition at a normal rate of speech. Another set of twelve lists of sentences was compressed at a rate of 35%. The normal and compressed rate of sentence lists were mixed with speech-shaped noise at three SNRs (+10 dB, +5 dB and +3 dB) with noise level always set to 65 dB SPL.

**Preparation of compressed rate of sentences**

Praat software (Version 4.6.09) was used to change the rate of sentences (35% compression) using the Time-Domain
Pitch- Synchronous Overlap-and-Add (TD-PSOLA) algorithm, developed by Moulises. The 'lengthen' option was used to alter the tempo of the signal without affecting its pitch. Initially, each sentence was decomposed into short-time signals based on synchronous pitch marks. A factor of 0.65 was specified to compress the original sentence by 35%, achieved by removing the same pitch period within each short-time signal. This method preserved the intelligibility in the rate compressed version of the sentence.

To calculate the rate of speech of the compressed sentences, pauses between words in each sentence were removed. The rate of speech in each sentence was calculated as the number of words/sec (wps). The average rate of speech in the 35% compression condition was 2.5 to 3 words/sec. The normal rate of uncompressed speech is 2 to 2.5 wps.

**Generation of noise to the normal and compressed rate of sentence lists**

We generated speech-shaped noise with a simple finite impulse response (FIR) filter matching the speaker spectrum for speech target, as given by Versfeld et al. Each of the twelve lists of the normal and compressed rate of sentences was grouped into four sets. Each set comprised of three lists of sentences. The noise level was fixed, and the speech level was varied to generate the specified SNR. The noise preceded the onset of a sentence by 1000 ms and continued till 1000 ms after the end of each sentence. The noise was ramped using the cosine square function with a duration of 100 ms on the onset and offset of the stimulus.

**Hearing aid**

We selected a behind-the-ear, four-channel hearing aid, Oticon Altus P, with the option of varying the compression release time. We set the attack time to 5 ms, release time to 40 ms (fast) in one program, and 640 ms (slow) in another program. The compression threshold and ratio in each channel for the two programs were assigned by the NAL NL-1 prescriptive formula with respect to the hearing threshold at different frequencies. In the third program, the linear gain formula of NAL NL 1 was used, that is, the compression ratio of 1:1. The volume control was disabled to ensure no change in gain during the data collection. These hearing aids had a fitting range to suit hearing losses ranging from mild to a severe degree.

**Verification of time constant in hearing aid**

The IEC 60118-8:2005 standard was used to verify the hearing aid time constants. The Fonix 7000 real ear measurement system was utilized to perform this test. The probe tube microphone was connected to one end of the two CC coupler (HA-2), and an adaptor connected to the hearing aid to the other end. The hearing aid was kept at the reference test position in the anechoic test chamber, with a constant power supply of appropriate voltage from a battery substitution pill. The input signal was abruptly increased from 55 to 90 dB SPL to verify the attack time, and the attack time measured was 4 ms. Further, to verify the release time, the input signal was abruptly reduced from 90 to 55 dB SPL. The exact release times measured were 30 ms (fast) and 590 ms (slow) set at two different programs. A similar procedure was carried out for another test hearing aid. The attack time was 3 ms, and the release times measured were 35 ms and 580 ms in the two different programs. It was ensured that the electro-acoustic measurement of hearing aids was assessed at the beginning of the data collection and repeated every three months until the completion of data collection.

**Optimizing the hearing aid**

The Real-Ear Unaided Response (REUR) was measured using digi speech at 65 dB SPL. Digi speech is a composite of pure tones (from 100 Hz to 8000 Hz) with a crest factor of 6 dB. The hearing aids with custom soft ear molds were fitted to both ears of every participant, and a Real Ear Aided Response (REAR) was measured at 65 dB SPL for digi speech. The REAR was subtracted from the REUR to obtain the Real Ear Insertion Gain (REIG) and was kept in check such that the hearing aid gain closely matched the prescriptive target. It was confirmed that the gain at each frequency closely matched within a range of 3 to 5 dB of the prescriptive target with respect to the participant’s hearing loss.

Further, to optimize the gain in hearing aids, each of the recorded Ling six sound was presented at 65 dB SPL. Each participant was instructed to judge the quality of the sound. Based on the subjective preference, the gain in hearing aids at each frequency corresponding to the frequency of Ling six sounds were either increased or decreased. The hearing aids were fine-tuned by manipulating the gain for the audibility of the Ling six sounds. A similar procedure was performed for each of the set programs (slow, fast, and linear). In the linear program, it was observed that after Ling six based fitting, the gain was 6 to 10 dB higher than the prescriptive target of the 65 dB SPL curve for the low frequencies (250 and 500 Hz). However, for the other two programs (slow and fast), an increment in the gain of 2 to 4.5 dB was required.

**PROCEDURE**

The study was carried out in three experiments. In experiment-1, gap detection threshold and sentence recognition in different conditions were tested. In experiment-2, the sound quality of the output of hearing aid at different release times was assessed in quiet and at different SNRs. In experiment-3, EDI was computed from the output of the hearing aid. Tests were performed in a sound-treated, double-walled room with the ambient noise levels within permissible limits as recommended by the American National Standards Institute (ANSI, 1999).
**Experiment 1: Psychoacoustic test and speech perception in quiet and noise**

**Gap detection threshold.**

The gap detection threshold (GDT) is the ability to detect rapid changes in a signal over time, which reflects the temporal resolving power of the auditory system. Older adults with hearing loss often exhibit subtle temporal processing impairment.[27-29] Therefore, GDT test was performed to assess temporal resolution in the participants. The task was to detect a brief pause in broadband white noise presented binaurally, at the listener’s most comfortable level. We estimated the detection thresholds using a three alternative forced-choice method one-up two-down adaptive procedure.[30] Each interval contained a 500 ms broadband noise, a brief, temporally centered gap was introduced at random intervals. The initial gap duration was 20 ms, and it was adjusted in 0.5 ms steps. The stimulus was generated in MATLAB at a sampling rate of 22000 Hz and routed to headphones through an audiometer.

The adaptive tracking procedure stopped after 12 reversals, and the threshold was obtained by averaging the gap-duration values of the last four reversals.

**Sentence recognition test.**

Sentence recognition of normal and 35 % compressed rate of sentences was assessed in different compression release time constants in quiet and at three SNRs. Twenty-four lists were used for the same. Four sets of three randomly selected lists were created for normal and compressed-rate speech, that is, 12 lists per speech rate were tested. The first set was presented in quiet for both the conditions. The second, third, and fourth sets were presented in noise, and the speech level was adjusted to 10, 5, and 3 dB SNR, respectively. These 24 lists of sentences were stored on a personal laptop. The sentences were delivered through a loudspeaker of an audiometer. The loudspeaker located at an azimuth of 00. It was ensured that during the presentation of the stimuli, the average deflection on the volume unit (VU) meter was 0 dB. The hearing aids were fit binaurally, set at either linear or compression release time constant (slow or fast) programs, and it was randomized across participants. The participant sat comfortably at a distance of one meter from the loudspeaker. The ten sentences from each list were randomly presented at 65 dB SPL in quiet and at specified SNRs (+3, +5 and +10 dB SNR), with the noise level fixed at 65 dB SPL. Each participant was instructed to repeat the sentence heard. In total, the recognition of sentences was assessed from 24 lists under different experimental conditions [2 rates × 4 (quiet and 3 SNRs) × 3 strategies]. The presentation of stimuli under different experimental conditions was counterbalanced across participants. An observer manually assigned one mark for correct identification of each target word in each sentence, such that, the maximum marks assigned for each experimental condition was 50. Participants were given sufficient breaks during the testing. The testing duration per participant was approximately one-hour.

**Experiment 2: Quality judgment**

Compression time constants and rate of speech alter the temporal envelope and may influence the perceived sound quality. A paired comparison method was used to judge the quality of each amplification strategy (linear, slow and fast) for the normal and compressed rate of a sentence, in quiet and at different SNRs. The participants were instructed to listen to a pair of sentences delivered sequentially by two different hearing aid strategies and select the one which had better sound quality. Each pair was presented thrice in a random order, resulting in a total of nine paired comparisons (3 strategies × 3 times). Based on the participant’s selection of better quality, a preference score was given to that particular hearing aid strategy. A similar procedure was carried out in each experimental condition with a quality judgment for normal and compressed rates of sentences in quiet and at different SNRs. The presentation order of hearing aid strategies in each experimental condition was counterbalanced across participants.

**Envelope difference index.**

The sentences (unprocessed and processed, corresponding to unaided and aided listening) from all 16 lists were analyzed for temporal content using envelope difference index (EDI). The EDI algorithm developed by Fortune et al.[31] was adopted to determine the extent of temporal alteration caused by the time constant set in the hearing aid for every experimental condition. The unaided stimulus and aided version of the stimulus were rectified, digitally low-pass filtered (Butterworth 6thorder filter with a 50 Hz cutoff), and sampled down (sampling frequency of 6 kHz). Further, the mean amplitude was calculated from the enveloped of the sampled down stimulus. Each sampled data point in the envelope was scaled to the mean amplitude by dividing every value by the mean amplitude.[13] This provided a common reference for comparing the two envelopes to obtain the EDI. The EDI was calculated using the equation suggested by Fortune et al.[31] The equation is given below.

$$EDI = \sum_{n=1}^{N} \frac{|Env1n - Env2n|}{2N},$$

where ‘Env1n’ is the processed waveform of a given sentence, ‘Env2n’ is the unprocessed waveform of that sentence; and N is the number of samples in each waveform.
RESULTS

Experiment 1

Gap detection threshold.

The mean and standard deviation (SD) of GDT (in ms) was lower in the younger adult group (9.95±0.43) than the older adult group (15.18±0.53). An independent sample t-test was carried out to examine the effect of groups on gap detection threshold. The results revealed a significantly reduced temporal processing ability, as reflected in GDT \(t(28) = 4.829, P < 0.001\) in the older adult group (OAG) than the younger adult group (YAG).

Sentence recognition test.

Figure 1 shows sentence recognition scores for all experimental conditions. For each combination of parameters, slow compression release time constant resulted in higher speech recognition scores than the linear and fast strategies. All variables were normally distributed according to the Kolmogorov-Smirnov test, and the variances were homogeneous according to Levene’s test (p > 0.05 in both cases). Therefore, a parametric statistical analysis was conducted. In order to assess the effect of strategy in each SNR on the recognition of normal and compressed rates of sentences from the study, a three-way Analysis of Variance (ANOVA) with strategy (linear, fast and slow), SNR (Quiet, +10 dB, +5 dB and +3 dB) and compression rate (normal and 35% compressed rate) as within-subject factors and group (YAG and OAG) as the between-subject factor was conducted. The results revealed significant main effects of strategy \(F(2, 56) = 63.84, P < 0.001\), SNR \(F(3, 84) = 206.13, P < 0.001\) and compression rate \(F(1, 28) = 768.35, P < 0.001\). Further, a significant two-way interaction was observed between rate and SNR \(F(3, 84) = 3.21, P < 0.05\) as well as a significant three-way interaction between strategy, SNR and compression rate \(F(6, 168) = 7.11, P < 0.05\). There was a significant effect of groups \(F(1, 28) = 41.92, P < 0.001\) on sentence recognition.

Also, all pairwise comparisons are reported with Bonferroni’s corrected alpha value. Only two Bonferroni pairwise comparisons were conducted to evaluate the effect of strategies on sentence recognition in each SNR and rate of a sentence from younger and older adult groups. This was done to compare sentence recognition scores with linear gain setting to the best setting amongst fast and slow compression gain. In the literature, the discussion is mostly between fast and slow compression rates of speech recognition, so the linear gain is solely...
compared to the winner of fast vs. slow-release times. The power of significance was 0.025 instead of 0.05 for these comparisons. For both groups in quiet and at each SNR, the performance on the normal rate of sentence recognition was significantly higher with the slow compression release time compared to the fast ($P < 0.025$) or linear compression release time ($P < 0.025$).

Further, the results showed that in both groups, the slow compression release time improved sentence recognition at the normal rate compared to fast and linear compression release times for each SNR ($P < 0.025$ in both cases). However, in the compressed rate of the sentences, the recognition improved for slow compression release time in both groups in quiet and at 10 dB SNR only. A significant main effect of age [$F (1,28) = 41.92, P < 0.001$] was observed on the sentence recognition from the previous ANOVA without interactions and was concluded that YAG is uniformly better than OAG and the effect is strong. The lack of a significant interaction between age and rate suggests that the time compression release time does not influence the difference.

**Benefit from strategies of hearing aid.**

The amount of benefit (in percentage) from different processing strategies on sentence recognition was assessed. This was performed in conditions where a significant difference was found between strategies. Table 1 presents the benefit of using slow-acting compression over fast-acting or linear gain. The benefit on sentence recognition was higher from slow compression release time compared to linear and fast compression release time.

**Experiment-2**

**Quality judgment.**

In the presence of noise, none of the participants reported a preference for any hearing aid setting. Thus, the analysis of quality judgment was carried out only in the quiet condition for the normal and compressed rate of sentences. For the normal rate of sentences, nine younger adult participants judged the highest quality of speech in slow compression release time. Three participants preferred fast compression release time, and three participants preferred linear amplification. In the older adult group, eleven individuals judged the highest quality for slow compression release time, two preferred linear gain, and two chose fast compression release time in hearing aid. A separate one-way repeated measures analysis of variance ANOVA was carried out in each group for rating quality judgment on preference scores obtained across hearing aid strategies (linear, slow, and fast compression release times) for the normal rate of sentences, in the quiet condition. The results revealed a significant effect of hearing aid strategies on preference scores in the younger adult group [$F (2, 28) = 61.58, P < 0.001$] and in the older adult group [$F (2, 28) = 11.53, P < 0.001$]. To examine the preference in strategies for the quality among the individuals of the older adult group, a post hoc Tukey HSD was performed. Post hoc comparisons indicated that a higher preference score for the quality judgment was noted in slow than fast compression release time constant. This effect was significant ($P < 0.001$). Another pairwise comparison showed a significant difference in preference score ($P < 0.001$) for slow compression release time constant than linear hearing aid setting. However, a preference score of quality did not significantly differ from the fast compression release time and linear hearing aid settings. Similar results were observed for quality judgment in individuals with the older adult group.

For the compressed rate of sentences in the quiet condition, a preference score on the quality judgment was documented across hearing aid settings in each group. In the younger adult group, it was observed that seven participants judged the highest quality of sound in slow compression release time. Five participants preferred fast compression release time, and three participants preferred linear amplification. In the older adult group, it was found that eight participants judged the highest quality for slow compression release time in hearing aid. Four participants preferred linear, and three participants preferred fast compression release time. A separate one-way repeated measures analysis of variance was performed in each group for judgment of quality on preference scores obtained by three different hearing aid strategies to the compressed rate of sentences, in the quiet condition. The results revealed a significant difference on preference scores in hearing aid.

| Groups  | Rate of Speech | SNRs          | Benefit (Slow—linear) in % | Benefit (Slow—fast) in % |
|---------|----------------|---------------|----------------------------|--------------------------|
| YAG     | Normal         | +10 dB SNR    | 16.57                      | 17.87                    |
|         |                | +5 dB SNR     | 8.00                       | 5.70                     |
|         | 35% compressed rate | Quiet        | 10.05                      | 11.31                    |
|         |                | +10 dB SNR    | 7.72                       | 7.54                     |
| OAG     | Normal         | +10 dB SNR    | 8.46                       | 15.20                    |
|         |                | +5 dB SNR     | 7.30                       | 4.56                     |
|         | 35% compressed rate | Quiet        | 10.87                      | 12.91                    |
|         |                | +10 dB SNR    | 10.68                      | 9.77                     |
strategies in younger adult group \[F (2, 28) = 5.62, P < 0.05\]
and in older adult group \[F (2, 28) = 4.94, P < 0.05\]. To
investigate the hearing aid strategy causing a significant
effect on preference score, a post hoc Tukey HSD was
performed. This test was conducted separately for each
group. The test result indicated that a significantly higher
preference score for the quality judgment was observed in the
slow compression release time constant than in the fast
compression release time constant \((P < 0.05)\) and linear
strategy \((P < 0.05)\). A preference score of quality on the
compressed rate of sentences did not differ significantly when
hearing aid was programmed to fast compression time and
linear settings. Similar results were noted in each group.

**Experiment 3**

*Envelope difference index.*

EDI was computed for ten sentences from each experimental
condition on the average hearing loss of OAG and YAG. Figure 2
shows that in each group, the mean EDI value was lower in the
slow compression release time than in the fast or the linear
hearing aid processed signals. This indicates that the envelopes
were more similar in the slow than in the fast compression release
time. Also, irrespective of processing strategies, EDI values were
more affected in the 35 % compressed rate of sentences than the
normal rate of the sentence due to frequent change in gain.
Further, an increase in temporal alteration was seen at low SNRs
with the fast rate of speech.

In order to assess the effect of strategy in each SNR on the
EDI computed from normal and compressed rates of
sentences from the study, a three-way Analysis of
Variance (ANOVA) with strategy (fast and slow), SNR
(Quiet, (+10 dB, +5 dB and +3 dB) and compression rate
(normal and 35 % compressed rate) as within-subjects
factor and group (YAG and OAG) as between-subject
factor was conducted. The results revealed that there was a
significant main effect of strategy \([F (1, 28) = 101.98, P <
0.001]\), SNRs \([F (3, 84) = 450.20, P < 0.001]\) and
compression rate \([F (1, 28) = 1248.46, P < 0.001]\) on EDI.

**Figure 2:** Mean envelope difference index scores obtained from slow and fast strategies in two listener groups for the normal and compressed rate of the sentence in quiet condition and at three SNRs conditions. Error bars represent the standard deviation of the mean. The number of asterisks represents \(P < 0.001***; P < 0.01**; P < 0.025\).
In addition, a three-way interaction revealed that the effect of strategy had a significant interaction with SNR and compression rate of sentence on EDI [F (3, 84) = 9.00, \( P < 0.001 \)] with between groups [F (1, 18) = 5.42, \( P < 0.05 \)]. Further, Bonferroni pairwise comparisons with corrected alpha values were conducted to evaluate the effect of strategies on EDI for each SNR and rate of the sentence in the younger and older adult groups. In Figure 2, in YAG, the EDI value obtained from fast compression release time (\( P < 0.01 \)) was significantly higher than in slow compression release time in quiet condition and at +10 dB SNR (\( P < 0.01 \)). This suggests that at the SNRs with no significant effect, noise alters the envelope of sentence similarly for a fast and slow compression release time. A similar result was obtained for a 35 % compressed rate of sentences in quiet conditions (\( P < 0.001 \)). It can be inferred that the combined effect of rate and noise alters the envelope of the sentence in a similar way when processed through either fast or slow compression release time. Whereas, in OAG, it was noted that in each SNR, temporal alteration in sentences from fast compression release time was significantly higher than slow compression release time. Further, in a 35 % compressed rate of sentences in the quiet condition, EDI computed from fast compression release time was significantly affected than in the slow compression release time condition (\( P < 0.001 \)) due to frequent change in gain.

The relationship between EDI and sentence recognition scores in each experimental condition

The data of EDI and sentence recognition scores in two strategies (fast and slow) were subjected to the Pearson correlation coefficient. Similarly, in each group, the relationship between EDI and sentence recognition scores was performed in quiet and at three different SNRs. In YAG, there was no correlation between EDI and sentence recognition scores in each experimental condition. Whereas, in OAG, a significant negative correlation was observed between EDI and sentence recognition score at 3 dB SNR (\( r = -0.708, N = 45, P < 0.001 \)). It indicates that sentence recognition decreased with an increase in temporal alteration caused by compression release time reflected in EDI, especially at 3 dB SNR for the normal rate. In addition, when the rate of sentence compressed by 35 %, in quiet condition, a significant moderate negative correlation was found between EDI and recognition of sentence (\( r = -0.516, N = 45, P < 0.01 \)). It suggests that in the compressed rate of the sentences in quiet condition, the recognition scores decreased with an increase in temporal alteration caused by compression release time.

**DISCUSSION**

Perception of speech in quiet

In both age groups, the mean recognition score was higher in slow compression release time than fast compression release time and linear amplification. The participants significantly preferred slow release time hearing aid on quality judgment compared to fast and linear strategies in hearing aid. One possible reason could be that in slow compression release time, there is less frequent variation in the gain. The compression for a vowel (higher in intensity) is not released at the transition from vowel to the consonant boundary (lower in intensity) but remains stable when the consonant is presented. This led to a smoothened speech envelope which preserved the temporal cue in speech better in slower release time than fast compression release time. The present study is in consonance with the research report of Neuman et al.[16] who stated that slow compression release time gave rise to higher pleasantness and clarity than fast compression release time due to less frequent change in gain across stimuli. The slow compression provided lesser gain than the linear setting, but then it is surprising that speech recognition was worse in the linear setting in quiet. The exact reason is not known and requires another experiment to investigate the output SNR within-channel and across channels (global) from the recorded amplified speech (compression and linear) at low and high-level input speech.

The compression of the sentences by 35% resulted in temporal alteration as the gaps between the phonemes were reduced. The results revealed that, in each group, recognition of sentence was found to be significantly higher in slow compression release time than fast compression release time and linear amplification. The result is consistent with the study by Jenstad and Souza,[13] who reported that the recognition score for the compressed rate of sentences with the slow compression release time was best due to lower temporal alteration than other strategies. This was reflected in the envelope difference index in which temporal alteration is less in slow compression release time than fast compression release time. Another reason for better speech recognition in slow compression release time in hearing aid is due to the significantly higher quality judgment as compared to fast compression release time, which is in consonance with the study of Neuman et al.[16] It was found that seven younger adults (43%) and eight older adults (53%) preferred slow release time on quality judgment. Irrespective of the group, the benefit received was more for slow than fast compression release time. Quality judgment scores increased with reduced temporal alteration caused by compression release time constants in hearing aid. This is due to the lesser frequent gain change associated with the slow release time setting in the hearing aid, even though the consonant-vowel or vowel-consonant context occurs rapidly in a sentence. Moreover, in older adults, the temporal alteration reflected by EDI was negatively correlated with sentence recognition. Older adults have reduced temporal resolution abilities, as reflected in GDT. This led to the utilization of a few of the temporal cues for the perception of the compressed rate of sentences, as processed by the hearing aid in the slow release time setting. Thus, older listeners are more affected by the compression-related distortions than younger listeners.
Perception of speech in noise

The participants from each group faced a challenge to recognize the sentences in noise, although the hearing loss was alleviated by amplification. In both groups, for each SNR, the mean sentence recognition was significantly higher in the slow compression release time than the fast compression release time and the linear amplification. The participants reported that loudness of noise was lower with slower compression release time than the other two strategies (fast compression release time and linear amplification). This might be because of the activation of slow compression was acted not only on speech but also on the noise, especially at silences/pauses across the sentences.

Though the sentence recognition was higher and the benefit was larger in slow compression release time than fast compression release time, the preference of compression release time constants on the quality of sentences was not quantified by any of the participants when presented at different SNRs. This indicates that noise has a deleterious effect on the quality of speech despite varying the release time in the hearing aid. Although the compressed rate of sentence recognition at each SNRs was found to be better in slow compression release than fast compression release time, a significant difference was found at 10 dB SNR. This was true in each group. We can infer that the available temporal cues of the compressed rate of sentences in noise are maximally utilized by participants of each group when compression release time of the hearing aid was set to slow. However, at reduced SNRs, the sentence recognition scores deteriorated due to the combined effect of the compressed rate of sentence and noise. This combined effect (rate and noise) altered two dimensions of speech (temporal and spectral), leading to a reduction in the overall quality of the speech signal. The temporal envelope was altered by the compressed rate of sentences and noise, and the spectral component was altered by noise. Accordingly, all the participants reported no preferences on quality judgment irrespective of strategies set in hearing aids. The result of recognition performance of a 35% compressed rate of a sentence obtained in the present study aligns with the report of Harris and Reitz, who stated that multiple degradations of sentences by noise and time compression could have larger acoustic distortions. Thus, the benefit from slow compression release time was higher than the fast compression release time on sentence recognition.

The amount of benefit was more substantial for high than low SNR. To substantiate the above finding, distortion to the envelope of sentence reflected by EDI was relatively less for slow compression release time than fast compression release time.

CONCLUSION

Both age groups showed better speech recognition in slow compression release time than either fast compression release time or linear gain on sentence recognition. Also, irrespective of rate, the amount of benefit from slow compression release time over the other two strategies was larger for high SNR than low SNR. To substantiate the above finding, distortion to the envelope of sentence reflected by EDI was relatively less for slow compression release time than fast compression release time.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Acknowledgement

The authors would like to thank the Director of All India Institute of Speech and Hearing for granting permission to carry out the study. The authors would like to thank all the participants of the study for their co-operation. Sincere thanks to HOD, Department of Audiology, for approving to use the infrastructure for testing.

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