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RESEARCH ARTICLE

Effect of hearing aid amplitude compression on emotional speech recognition

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Abstract
Background and Aim: Understanding emotion is crucial for human social interactions. Amplitude compression in hearing aids affects acoustical characteristics of incoming sound, which is necessary for emotion recognition. The present study investigated this effect(s).
Methods: Hearing aid amplitude compression on Persian emotional speech database (ESD) was simulated using MATLAB software. Three types of hearing loss including high tone loss (HTL), low tone loss (LTL), and flat were simulated using three amplification methods, i.e. fast-acting compression (FAC), slow-acting compression (SAC), and linear. Forty normal hearing young adult subjects (aged 20-35 years, mean and SD: 26.98±4.50) with no depression participated in this study. Emotion recognition before and after hearing aid compression simulation was compared statistically using independent t-test considering $p<0.05$ as the significance level.
Results: Fear, sad, angry, and happy emotion recognition are statistically different in all three types of simulated hearing loss, whereas disgust emotion recognition is affected only in LTL. There is no statistical difference in neutral emotion recognition in all three types of simulated hearing loss. There are significant differences in sad, angry, and happy emotion recognition in FAC while SAC does not affect statistical differences in all emotions except in happy utterance. Fear, sad, and angry emotion recognition are statistically different in linear amplification.
Conclusion: Emotion recognition reduces after hearing aid amplitude compression simulation. Statistically significant differences in emotion recognition depend on emotions such as happy, fear, angry, type of simulated hearing loss such as HTL, LTL, and flat; amplification methods such as FAC, SAC, and linear.
Keywords: Emotional speech; emotion perception; hearing aid; amplitude compression

Introduction
Hearing loss is one of the most common impairments in the society. It is estimated that 12.7 percent of adults older than 12 years have bilateral hearing loss in the United States [1]. Digital hearing aid is the most common assistive listening device used to compensate non-treatable hearing loss. It is used by one out of seven individuals aged 50 years and older

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with hearing loss [2]. In digital hearing aids, the sound is processed in different ways in order to enhance listening quality and audibility [3].
In case of hearing loss, hearing threshold of the patient increases while the level of discomfort decreases; as a result, the dynamic range of hearing is reduced. Analog hearing aids (linear amplification) amplify all sound levels until the saturation level of the hearing aids is reached. Digital hearing aids use compression to automatically adjust the incoming sound level according to the patient's dynamic range of hearing [3]. This compression affects both the sound quality and acoustic features of the incoming sound. The effects of hearing aid amplitude compression on speech are widely studied in the literature. Souza [4] has reviewed these effects on speech acoustics, ineligibility, and sound quality.
There are two broad types of compression: fast-acting compression (FAC) and slow-acting compression (SAC) [5]. In FAC system, attack time (the time taken by the sound level output to get within 3 dB of its steady value) and release time (the time taken by the sound level output to get within 4 dB of its steady value) [6] are relatively short with low compression ratio (input-output ratio). In contrast, in SAC system, the attack time and release time are relatively long with moderate to high compression ratio [5].
Emotion in speech is one of the suprasegmental features of language. Humans recognize different emotions that provide rich information about social intention, which is critical for social interactions [7,8]. There are different categories of emotions including happy, fear, angry, disgust, sad, and neutral in different speech emotion databases [9].
There are different developing methods in which computers recognize emotion using acoustical features of utterance [10]. Humans also recognize and understand different emotions using acoustical cues of speech [7] which may be affected due to amplitude compression of hearing aids [11]. The effect(s) on acoustic cues of emotion, that is an important aspect of speech perception, was aimed in this study.

Methods

Forty (20 males and 20 females) young adult subjects age ranged 20-35 years, with mean and standard deviation 26.98±4.50, voluntary participated in this study. All subjects had normal hearing (air conduction hearing threshold <25 dBHL at audiometric frequencies 0.25-8 kHz) without depression (score 0-13) as measured by the validated Persian version of Beck depression inventory II (BDI-II) [12]. Normal hearing required to rule out hearing loss and related auditory processing deficits associated with hearing loss, and depression should not be present so as to ensure that the subjects can identify the emotional status of speech.
After screening for hearing and measuring of BDI score, the subjects were asked to listen to recorded emotional sentences via standard headphone, which is used for high-frequency audiometry (Koss Model R/80, USA), and identify the perceived emotion of the utterance. A total of 216 utterances (108 original utterances and 108 matched simulated utterances) were played in random order for the subjects in two sessions with a 10 minutes break.

Emotional speech database

A validated Persian emotional speech database (ESD) [13] was used in this experiment. ESD contains three major categories of speech emotion based on lexical and articulated emotional voice including congruent, incongruent, and baseline (Fig. 1). The incongruent condition (neutral lexical content articulated in emotional voice) was used in this experiment since the goal of the study is to investigate the effect(s) of hearing aid compression on articulated emotional voice without the lexical cues. Neutral lexical content articulated with neutral voice from baseline category was also included to see whether compression affects this condition. In each selected category, 18 utterances (9 male talker and 9 female talker) were selected.

Hearing aid simulation

A MATLAB-based graphical user interference

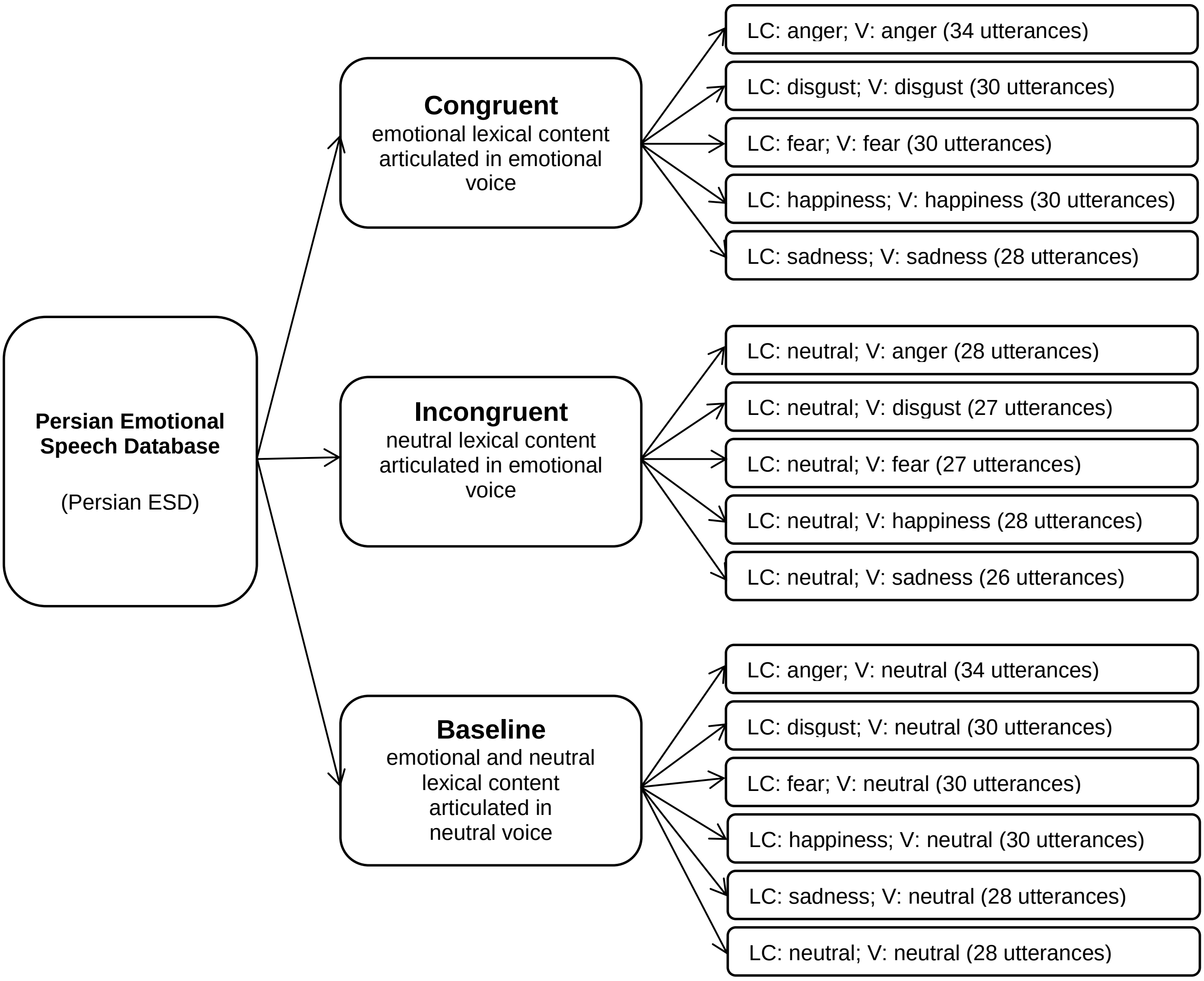

Fig. 1. The chart of validated database used in the study. 18 sentences in each emotion (9 male talker and 9 female talker) of incongruent category and 18 sentences in neutral-neutral category of baseline category were selected (Keshtiari et al. with permission) [13].

(GUI), which has been described by Moore et al. [14], was used for hearing aid compression simulation (Fig. 2). Three types of hearing loss were selected: high tone loss (HTL), low tone loss (LTL), and flat with mild to moderate degrees of hearing loss (Fig. 3). In each type, two amplitude compression systems (FAC and SAC) in 5 channels of compression as well as a linear amplification (no compression) were simulated. The compression characteristics are shown in Table 1. The input level of the incoming sound was considered to be 65 dB SPL in simulation.

The gain was calculated by CAMEQ2-HF procedure [15] based on simulated audiograms. Table 2 shows the calculated ideal gain, which was used for selected audiograms in simulation. After simulation, all sounds were normalized to have the same perceived loudness using audacity software (available at: http://www.audacityteam.org). Normalization was conducted because the perceived loudness of simulated sounds differs after simulation and must be ruled out as a confounding factor.

Experiment design

Psychopy v1. 85.3 software [16] was used to

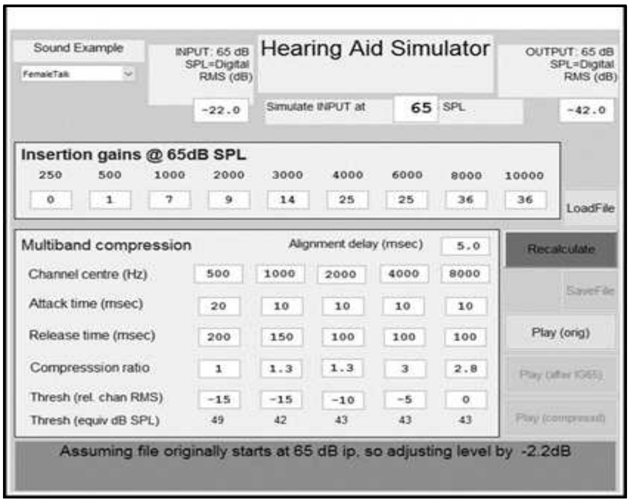

Fig. 2. Matlab-based graphical user interface of hearing aid compression simulator. The values mentioned in the text. SPL; sound pressure level, RMS; root mean square.

design the experiment. Psychopy is an opensource experiment builder for auditory and visual stimulus. The design and order of the experiment are shown in Fig. 4. The experiment began with providing instructions to the subjects, and then, after the training session, the main test started with two trials and a 10-minutes break in between the trials. During each trial, simulated and non-simulated files were randomly played in a loop. The subjects chose their answer using a custom-made iPad keyboard (Air Keyboard App (available at: https://itunes.apple.com/us/app/air-keyboard/id446643462)), which was designed especially for the experiment (Fig. 5). The keyboard was connected to the laptop via a wireless network. Subject responses were stored automatically and

Table 1. Characteristics of simulated amplitude compression

	FAC	SAC
Attack time	10 ms	100 ms
Release time	20 ms	100 ms
Compression ratio	2:1	6:1

FAC; fast-acting compression, SAC; slow-acting compression

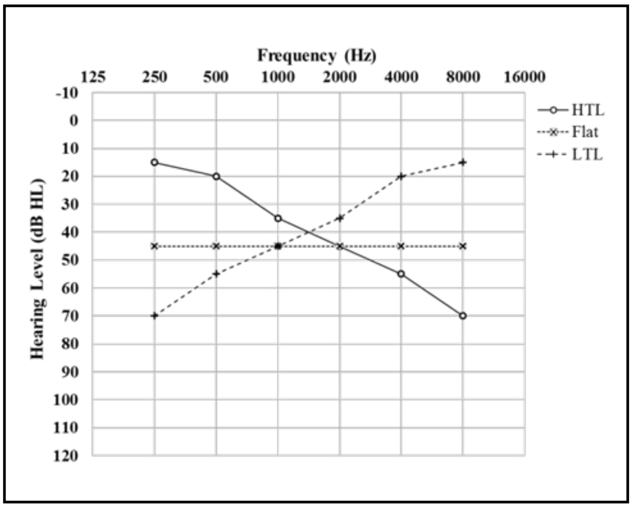

Fig. 3. Three types of hearing loss used for simulation of hearing aid compression. HTL; high tone loss, LTL; low tone loss.

saved in an Excel file format.

Data analysis

SPSS 24 was used for analyzing data. Normality of data distribution was explored via Kolmogorov-Smirnov test. Distribution of data was normal, and independent samples t-test was further conducted to investigate the significant differences in simulated and non-simulated emotion recognition groups.

Results

Effects of hearing loss type

Emotion recognition is reduced in all simulated types of hearing loss (Fig. 6 A-C). Fear, disgust, angry and happy emotion recognitions are statistically different in all three types of simulated hearing loss when compared to matched emotion recognition of original utterances. Disgust emotion recognition was only affected in LTL. There is no statistical difference for neutral emotion recognition in all three types of simulated hearing loss and matched emotion recognition of original utterances. The significance values are shown in Table 3.

Effects of amplification method

Emotion recognition is also reduced in different

Table 2. Ideal gain of selected audiograms based on CAMEQ2-HF formula

Audiogram configuration		Audiometric frequencies											
		0.125	0.25	0.50	0.75	1.00	1.50	2.00	3.00	4.00	6.00	8.00	10.00
HTL	**Hearing Threshold (dBHL)**	20	20	25	28	30	35	40	50	60	65	70	70
	Ideal gain (dB)	0.0	2.5	4.8	7.0	11.9	13.5	16.6	17.3	26.8	29.1	35.3	40.4
LTL	**Hearing Threshold (dBHL)**	70	70	70	68	65	62	60	50	40	30	25	20
	Ideal gain (dB)	22.5	25.0	22.0	20.4	25.7	24.0	24.8	17.3	17.0	10.4	6.2	4.3
Flat	**Hearing Threshold (dBHL)**	45	45	45	45	45	45	45	45	45	45	45	45
	Ideal gain (dB)	11.3	13.7	12.5	12.7	17.8	17.4	18.6	15.6	19.5	18.4	19.1	22.4

HTL; high tone loss, LTL; low tone loss

amplification methods (Fig. 6 D-E). Statistical analysis of emotion recognition based on compression speed indicates significant differences in sad, angry, and happy emotion recognition in FAC when compared to matched emotion recognition of original utterances. Fast compression does not affect emotion recognition of fear, disgust, and neutral emotions statistically. SAC does not affect statistical differences of emotion recognition in all emotions except in happy utterance. On comparing linear amplification and no amplification, it was found that fear, sad, and angry emotion recognition are statistically different while there are no statistical differences in emotion recognition of disgust, neutral, and happy emotions.

Discussion

Emotion recognition has been widely studied in different fields of science, from engineering and human-machine interaction and emotion recognition by computers [10] to neuroscience and the brain structures which are activated and responsible for emotion recognition [17]. Many reports in the literature imply reduced emotion recognition in individuals with hearing loss who use hearing aids. Sensorineural hearing loss negatively impacts psychoacoustical abilities, which are needed to perceive emotions such as frequency discrimination or frequency and time resolution [18].

Most and Aviner [19] studied auditory, visual, and auditory-visual emotion recognition in 40

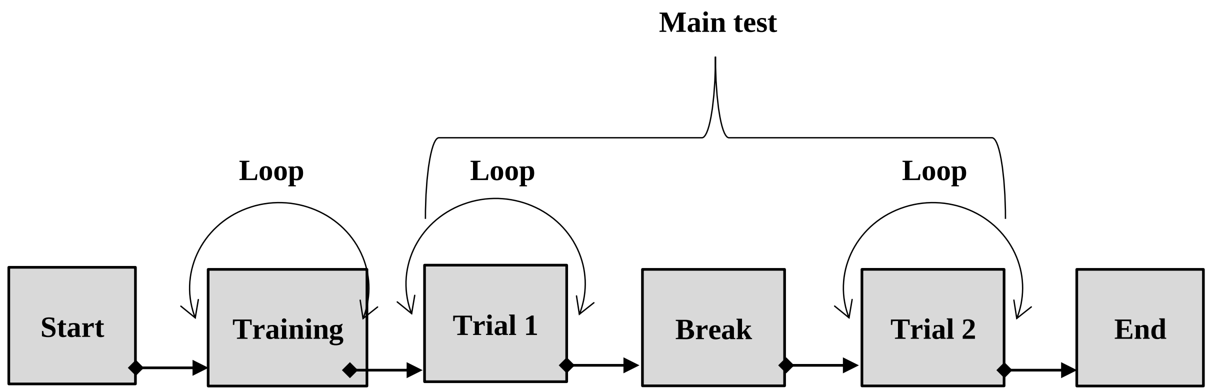

Fig. 4. Block diagram of experiment designed by Psychopy software.

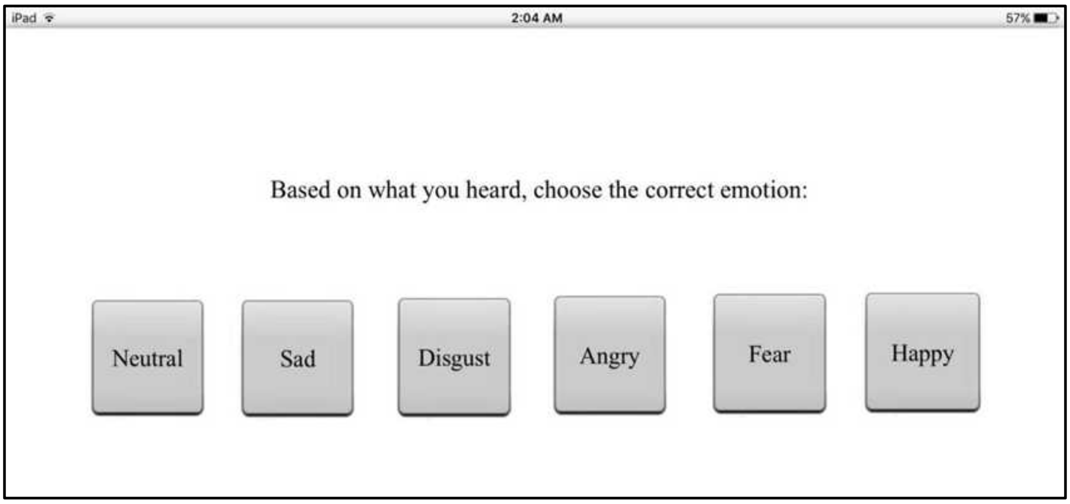

Fig. 5. Custom-made iPad keyboard which is used to collect responses from subjects. Each block was defined for one emotion and touching them send a number to laptop wirelessly and stored via Psychopy software in an excel format. The texts in the figure were originally in Persian language and are translated here.

hearing loss patients with hearing aids and cochlear implant (CI). Their results indicated there are significant differences in all types of emotion recognition in both hearing aid and CI users when compared with normal hearing peers. The results may be due to hearing loss itself or assistive listening device processing (hearing aid and CI). The present study shows the effect of hearing aid processing regarding amplitude compression on emotion recognition and rules out auditory deficits associated with hearing loss. Amplitude compression reduces emotion recognition, especially when FAC is simulated. Goy et al.'s [11] study on 11 older adults with hearing loss indicated that word recognition improves after use of hearing aid but less improvement was reported for voice emotion. They concluded that this result may be due to hearing aid processing or damaged auditory system. The poor performance of individuals with hearing loss may be due to hearing loss itself or the use of hearing aids, which

Table 3. P-value of simulated and non-simulated emotion recognition comparison using independent t-test

	Type of simulated hearing loss			Simulated compression speed		
	HTL	**LTL**	**Flat**	**Fast**	**Slow**	**Linear**
Fear	0.010*	0.001*	0.001*	0.075	0.115	0.001*
Disgust	0.522	0.029*	1.000	0.354	0.310	0.676
Neutral	0.101	0.154	0.704	0.057	0.654	0.314
Sad	0.024*	0.017*	0.007*	0.001*	0.114	0.033*
Angry	0.019*	0.003*	0.016*	0.010*	0.132	0.001*
Happy	0.002*	0.024*	0.002*	0.001*	0.002*	0.053

HTL; high tone loss, LTL; low tone loss, *significant

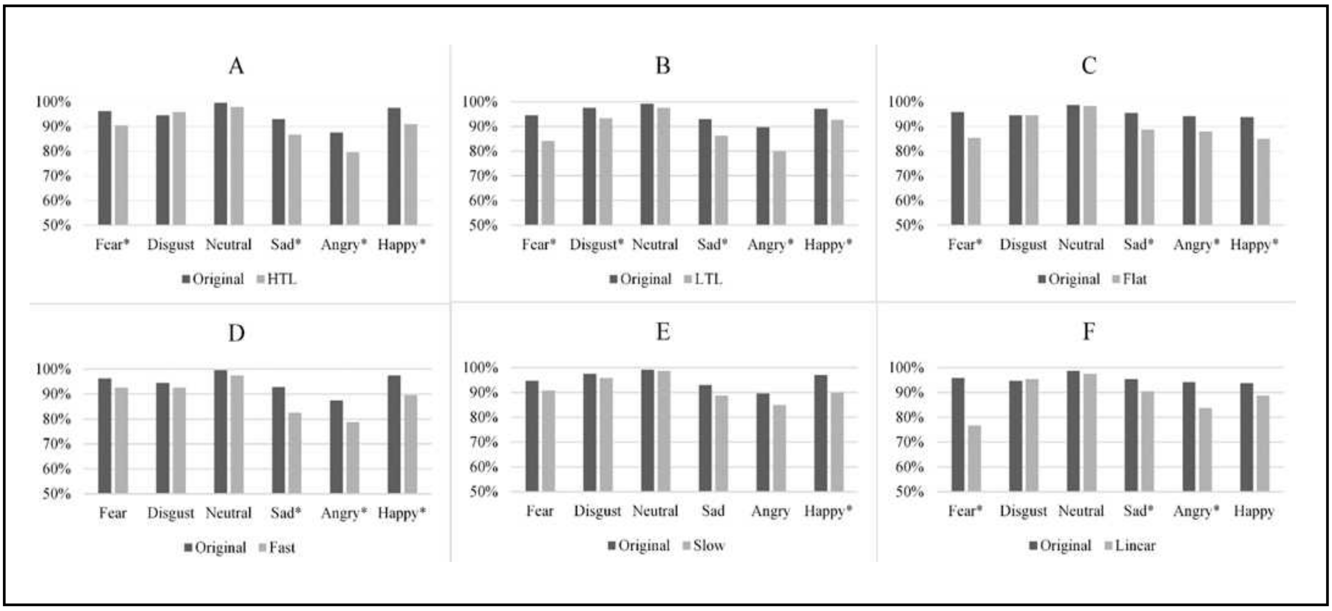

Fig 6. Comparison of simulating hearing loss type (A-C), compression speed (D-E), and linear amplification on emotion recognition. HTL; high tone loss, LTL; low tone loss. *significant

alter acoustical cues of emotion. The results of the present study indicate emotion recognition reduced due to amplitude compression processing of the hearing aids.

Murray and Arnott [20] indicated that the emotional aspect of an utterance is conveyed mostly by fundamental frequency changes, then duration, and lastly by intensity. Other authors [7,21] also mentioned the energy distribution in spectral range (especially high frequency to low frequency ratio), formant location, and the rate of speech as acoustical cues in emotion recognition. All these acoustical parameters are affected by the type of hearing loss, calculated gain in each frequency, and amplification method. The significant differences and reduction in emotion recognition in this study may be due to acoustic changes affected by different gains at different frequencies and also different amplification methods. All of these changes in hearing aids not only affect temporal envelope of speech but also affects the acoustical fine structures. Further studies should investigate the exact acoustical changes in hearing aids and the resulting effect(s) on emotion recognition. Based on the results of this study, the best compression characteristics with the least effect on emotion recognition is SAC, and it is recommended to be considered in hearing aid fitting by audiologists.

Conclusion

In this study, we investigated the effects of simulated hearing aid amplitude compression on emotional speech recognition. Data analysis indicates a significant reduction of emotion recognition after amplitude compression simulation. Fear, sad, angry, and happy emotion recognition are reduced significantly in all the three types of simulated hearing loss (HTL, LTL and flat). In contrast, the neutral emotion recognition does not affect in all three simulated types of hearing loss. In disgust emotion, a significant reduction is observed only in LTL.

On exploring the effects of amplification method on emotion recognition, we found no statistical differences in all emotions (except happy) when SAC was applied while in FAC and linear amplifications, emotion recognition of four and three emotions out of six emotions were reduced, respectively.

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Conflict of interest

The authors declared no conflicts of interest.

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