Benefits of Compression Amplification in Telephone Bluetooth-Assistive Listening Devices for People with Hearing Loss

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Abstract

Background: Telephone conversation is one of the main scenarios where people with hearing loss require assistive listening devices (ALDs). Such people experience the greatest degree of difficulty during phone conversations in noisy environments.

Purpose: This study compared the benefits of a linear scheme with a compression amplification scheme fitted with a prescription for sloping-type hearing loss implemented in a Bluetooth ALD in quiet and noisy environments.

Research Design: Word recognition scores (WRSs) for the Mandarin monosyllable recognition test (MMRT) and participants' satisfaction ratings were measured to serve as objective and subjective results, respectively.

Study Sample: Twelve native Mandarin speakers aged 27–68 yr with mild to moderate sensorineural hearing loss participated in this study.

Intervention: A compression amplification scheme with a prescription in maximizing speech intelligibility for sloping-type hearing loss was implemented in a Bluetooth ALD.

Data Collection and Analysis: The MMRT WRSs of participants wearing the Bluetooth ALD were collected. Each test was conducted in a soundproof booth under quiet and 65-dBA speech noise environments. Each participant completed a satisfaction questionnaire administered by an audiologist. The collected WRSs were examined using analyses of variance and the satisfaction ratings were analyzed using Wilcoxon signed rank tests.

Results: The mean MMRT WRSs of the compression amplification scheme were significantly higher than those of the linear scheme (57% and 53% higher in quiet and noisy environments, respectively). The mean satisfaction ratings of both schemes were between neutral and satisfied in the quiet environment, whereas in the noisy environment, the participants were more satisfied with the compression scheme than the linear scheme.

Conclusions: The results demonstrate the effective benefits of the compression amplification scheme fitted with a prescription in maximizing speech intelligibility for sloping-type hearing loss implemented in a Bluetooth ALD for people with mild to moderate hearing loss.

Key Words: assistive listening device, Bluetooth, Mandarin monosyllable recognition test, telephony

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Abbreviations: ADRO = adaptive dynamic range optimization; AGC = automatic gain control; ALD = assistive listening device; AVC = automatic volume control; EQ = equalization; MCL = most comfortable level; MMRT = Mandarin monosyllable recognition test; NAL-NL1 = National Acoustic Laboratories' nonlinear fitting procedure, version 1; RLR = receiving loudness rating; SNR = signal-to-noise ratio; WRS = word recognition score

INTRODUCTION

Assistive listening devices (ALDs) assist people with hearing loss in hearing without the necessity of fittings, such as hearing aids, by audiologists. Through wireless technologies such as induction loop systems, infrared lights, frequency modulation radio signals, and Bluetooth devices, ALDs improve signal-to-noise ratios (SNRs) by enabling sounds at a far distance to be heard by local devices (Hawkins and Schum, 1985). In addition to sound amplification, some ALDs can transmit sounds from phones through technologies such as amplified phones, phone amplifiers (attached or built-in), telephone couplers, and frequency modulation or infrared wireless systems (Dillon, 2001). Given the increasing popularity of portable devices, Bluetooth technology has been used for telephonic ALDs coupled with mobile phones (Qian et al, 2003).

Telephones and televisions are the two major applications of ALDs (Hartley et al, 2010). Telephone applications involve the use of stationary and mobile phones indoors and outdoors. People with hearing loss have difficulty making phone conversations in noisy environments (Kepler et al, 1992). Hearing aid manufacturers have recently incorporated Bluetooth technology into their models (SHT, 2016) to improve the telephonic sound quality; however, the high cost renders such products unaffordable for most people. Simple ALDs such as Bluetooth headsets combined with amplification functions are options in scenarios involving telephone use.

The bandwidth of hands-free terminals, such as Bluetooth headsets, is set equivalent to that of conventional handset telephones at 300–3400 Hz, which enables longer distance calls to be transmitted. For better speech intelligibility and audio quality, a wideband hands-free terminal at 100–8000 Hz was developed using digital encoding schemes such as ITU-T G.722 (ITU, 2011). Wideband audio telephones are expected to be used in services such as high-quality audio conferences, video conferences, and multimedia applications. Although wideband telephonic products are presently available, most equipment in the telephonic transmission path is designed for narrowband transmissions, which limits the final bandwidth.

Under the narrowband bandwidth of typical telephony, noises are often overamplified, resulting in reduced intelligibility in the receiving path (Skinner and Miller, 1983). Commonly available noise reduction algorithms for telephonic applications include spectral subtraction and Wiener filtering (Le Bouquin, 1996; Meyer and Simmer, 1997). Some studies have applied expansion methods to reduce computational power (Zakis and Wise, 2007). The linear amplification scheme used in most hearing devices causes uncomfortably loud sounds (McFerran and Baguley, 2007). The compression limiting of the compression scheme can alleviate acoustic shock and the automatic gain and volume controls such as the background noise rule of adaptive dynamic range optimization (ADRO) can enhance the SNR in the presence of background noise (Hickson, 1994; Wise et al, 2006). Some recently manufactured Bluetooth headsets include compression schemes such as automatic volume adjustment (e.g., Jabra® TALK [Jabra, 2017]); however, such headsets are designed for people without hearing loss, and the clinical benefits for people with hearing loss against the benefits of linear systems remain unknown.

This study compared the benefits of incorporating a compression amplification scheme based on a prescription in maximizing speech intelligibility for sloping-type hearing loss into a Bluetooth telephone ALD against the performance of a commercial linear scheme, Sound ID SM100, in quiet and noisy environments. The word recognition scores (WRSs) of Mandarin monosyllable recognition test (MMRT) and participants' satisfaction ratings of overall speech quality served as objective and subjective results, respectively, to assess the benefits of the scheme. The present study hypothesized that the compression ALD offers greater benefits than the linear ALD among listeners with mild to moderate hearing loss in quiet and noisy environments.

MATERIALS AND METHODS

Bluetooth ALDs

The Bluetooth ALD used in this study was a binaural in-ear earphone with amplification, telephony, and music functions (Chang et al, 2017) and a nonoccluded ear plug fitted on either side of the earpiece to alleviate the occlusion effect. Each earpiece was connected to a control box by wires. Installed in the control box were two microphones with beamforming toward the speaker's mouth to detect speech during phone conversations and a digital volume control consisting of 16 levels increasing in increments of 1.8 dB per level. The digital signal processing algorithms, which were coded using the Kalimba digital signal processor of a Cambridge Silicon Radio BlueCore5™ Multimedia Bluetooth chip (CSR, Cambridge, UK), included adaptive noise reduction, multiband equalization (EQ), side tone, a compression scheme consisting of automatic gain control (AGC) and automatic volume control (AVC) that increases the gain by 7–8 dB across frequencies under 65-dBA speech noises, and the output protection limiting algorithm in the telephonic receiving path (Dynamic Hearing, 2008). The digital signal processing algorithm audio path is illustrated in Figure 1.

The following three telephonic profiles were implemented in this study: a mild profile for normal hearing, medium profile for gentle-slope hearing loss adopted from the average audiogram of 60–69 yr olds in the Blue Mountains study (Chia et al, 2007), and maximum profile for sloping-type hearing loss adopted from the audiogram of the early stages of noise-induced hearing loss (Dobie, 2007). Because of the bandwidth of narrowband telephony, the EQs of these three profiles calculated by the audibility rule of the ADRO amplification scheme (Blamey, 2005) were limited to 3400 Hz.

The electroacoustic test procedures for 3G telephonic ALDs are regulated by 3GPP technical specification #26.132 for various acoustic test items under narrowband (100–3400 Hz) or wideband (100–8000 Hz) telephonic transmissions (3GPP, 2004-09). ALDs are positioned on a head and torso simulator equipped with type 3.3 or 3.4 artificial ears. Because of the coding of the speech signals, standard sinusoidal test signals are not applicable for 3G acoustic tests; P.50 speech signals should be used instead (ITU, 1999). Under the receiving path, the receiving frequency responses and receiving loudness ratings (RLRs) are measured with an input level of −16 or −24 dBm0 (0 dBm0 refers to 0.775 V for analog signals or 1 mW when applying to a load of 600 Ω normally used in the phone lines). The receiving frequency responses are measured at the ear reference point and the values relative to P.50 speech signals from 200 to 4000 Hz are calculated. An RLR measurement is conventionally an attenuation value; hence, a higher value represents a quieter headset and a lower value represents a louder headset. The receiving frequency responses and RLRs of the three profiles of the Bluetooth ALD at maximum volume were measured using a *Brüel & Kjær* head and torso simulator type 4128-C and SoundCheck system (Figure 2).

The Sound ID SM100 with a nearly linear scheme was compared with the compression ALD in this study. The SM100 is a monaural Bluetooth ALD with a digital volume control consisting of nine volume levels increasing in increments of 2.8 dB per level. It applies a noise navigation algorithm and linear amplification scheme in the telephonic receiving path with three hearing enhancement programs, namely, mild, moderate, and strong (Sound ID, 2007). The noise navigation algorithm of the SM100 is designed to enhance speech intelligibility at both ends of a phone conversation. In the sending path, the SM100 employs dual microphones for directional voice detection and noise reduction algorithms to reduce wind and general background noise and enhance what is heard by the other party. In the receiving path, similar to the adaptive noise reduction function of the compression ALD, the noise navigation algorithm of the SM100 reduces general background noises detected in the other party's environment and noises in the telephone network to enhance the SNR heard by the ALD user. However, the SM100 is unable to reduce the background noise level in the local environment. The input–output curves of the SM100 measured at 2000 Hz with a type 3.3 artificial ear under quiet and 65-dBA speech noise environments are illustrated in Figure 3, which shows that the SM100 maintains the same responses under both conditions. The receiving frequency responses of the three programs are illustrated and compared with those of the compression ALD in Figure 2.

The compression ALD increased the responses at 2000–3000 Hz as the profile changed from mild to medium or maximum and maintained the same responses <1000 Hz, whereas the SM100 increased the responses within the same frequency range as the profile changed from mild to moderate or strong but reduced the responses <1600 Hz. The fitting rationale of the SM100 at the maximum volume was analyzed using DSL i/o v4.2 (The National Centre for Audiology, Western University, London, Canada); the simulated targets matched the coupler measurements, which were compared with the National Acoustic Laboratories' nonlinear fitting procedure, version 1 (NAL-NL1) targets (ADRO adopts NAL-NL1 prescription when disabling adaptive operations of ADRO rules [Martin et al, 2001]) and the coupler measurements of the compression ALD adjusted to the same loudness as the SM100 in Figure 4. At frequencies >1000 Hz, the

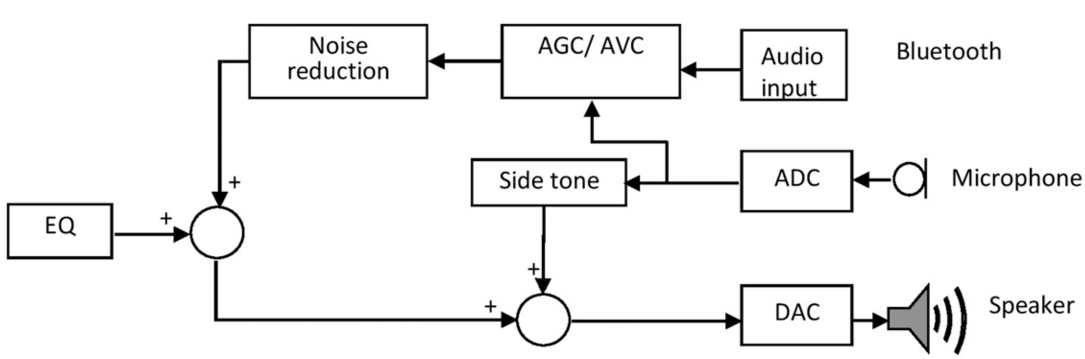
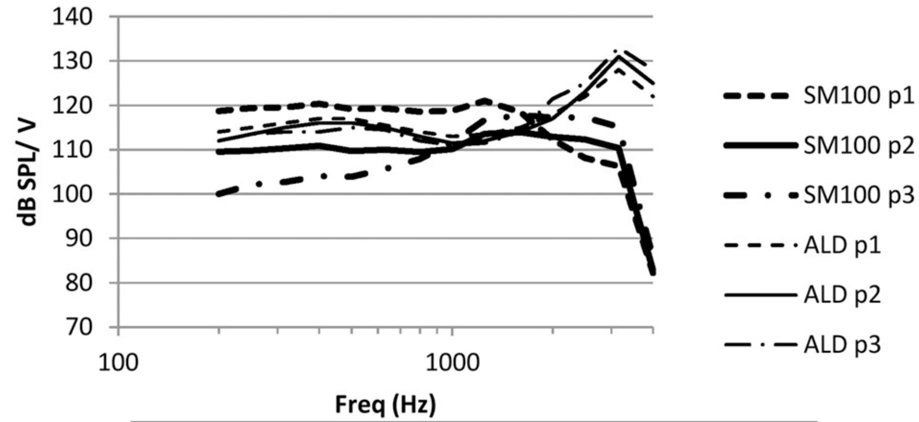


Figure 1. Telephonic receiving signal path. ADC = analog to digital converter; DAC = digital to analog converter.

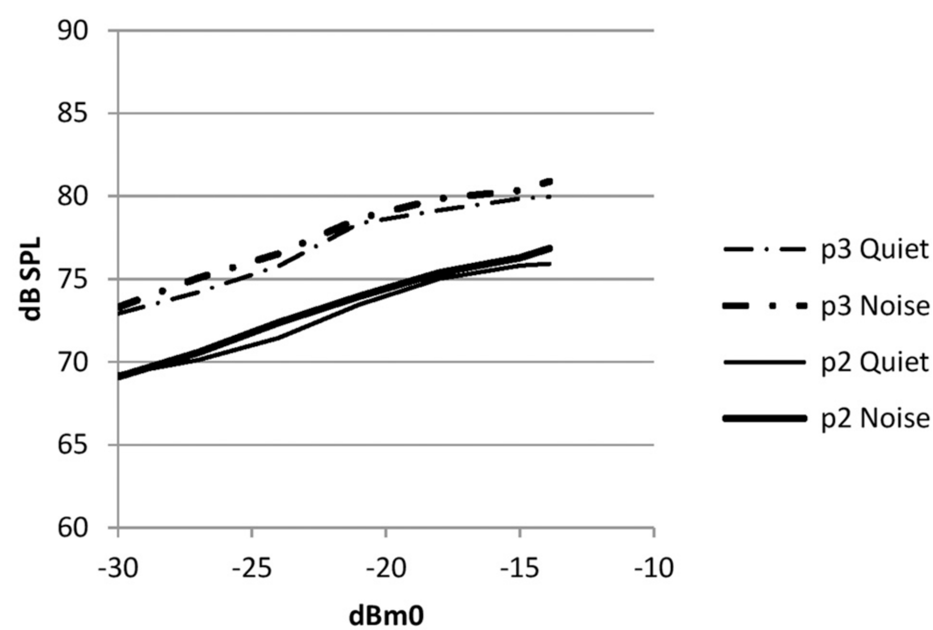


RLR (dB)	P1	P2	P3
Comp-ALD	-12.7	-11.8	-12.3
SM100	-13.6	-6.6	-5.5

*Input level: -24 dBm0 (-26.2 dBV) of P.50 speech signals
**p1, p2, and p3 indicate mild, medium, and maximum profiles for compression ALD, respectively, and mild, moderate, and strong profiles for the SM100, respectively.

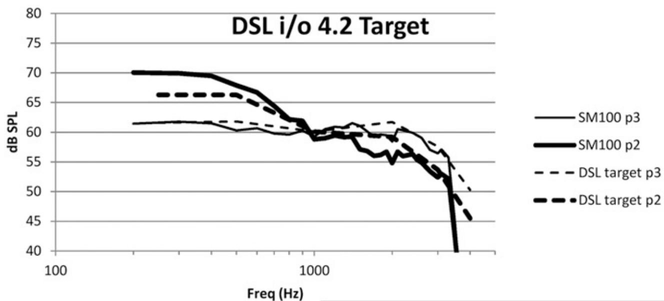
Figure 2. Receiving frequency responses (dB SPL/V) and RLR (dB) of the compression ALD and SM100 for the three profiles at maximum volume.

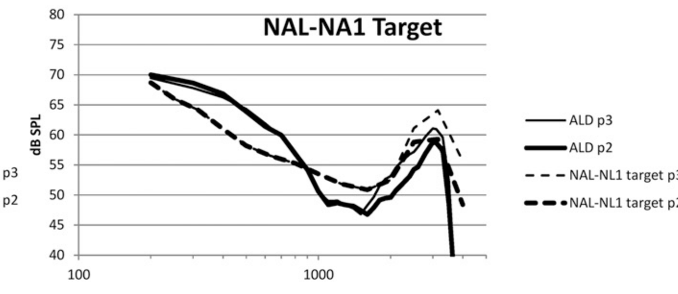
audiograms of the SM100 and the compression ALD are comparable, whereas <1000 Hz, the targets and thresholds of the SM100 are overestimated because earmold leakage in a real ear was not considered in the target calculation. In a real ear, the real ear–aided response <1000 Hz is reduced because of the leakage of the SM100 noncustomized earmold, resulting in the corresponding thresholds being comparable with those of the compression ALD. Thus, the two devices were comparable under the same loudness level. Although the maximum responses of the compression ALD in the medium and maximum profiles were higher than those of the



*p2 and p3 indicate moderate and strong profiles for the SM100, respectively.

Figure 3. Input–output curves for the SM100 measured at 2000 Hz with P.50 speech signals in the quiet and 65-dBA speech noise environments.





Audiogram (dB HL)						
Freq (Hz)	250	500	1000	2000	3000	4000
SM100 p2	25	25	15	10	10	10
ALD p2	0	0	0	5	10	15
SM100 p3	15	15	15	15	18	20
ALD p3	0	0	0	5	18	30

Figure 4. Simulated targets and HA1 coupler measurements of the SM100 at maximum volume and the compression ALD adjusted to the same loudness as the SM100 with an input of −24 dBm0 P.50 speech. The NAL-NL1 targets were transferred from gains to sound pressure levels and corrected to the coupler response based on the real-ear to coupler difference (Munro and Davis, 2003).

SM100, the actual volume setting based on the participants' most comfortable levels (MCLs) in the pretests revealed that the participants set the compression ALD volume lower than that of the SM100. If the participants wished to increase the volume even when the SM100 was set to maximum volume, the operator would increase the signal level by using the computer software. Therefore, the two devices were comparable in terms of the medium and maximum profiles under the participants' MCLs. The mild profiles with various frequency responses >1600 Hz between the compression ALD and SM100 were excluded in the following measurements.

Measurements

MMRT word lists (Tsai et al, 2009) exhibiting familiarity, homogeneity, and phonemic balance were used in word recognition tests to verify the benefits of the telephone Bluetooth ALD in quiet and noisy environments. The MMRT word lists were constructed from homogeneous monosyllables with low interitem and intersubject variability compared with traditional word lists. Each participant was seated in a soundproof booth facing a speaker at a 90° angle from which speech-weighted broadband noises emanated. The speaker was 1 m away from the participant and calibrated using a Grason-Stadler GSI 61 audiometer (Eden Prairie, MN) with an external input for calibration signals of 1000 Hz issued from the MMRT audio compact disc through a standard procedure before the test (ANSI, 2004). The measurement setup is illustrated in Figure 5. Under the quiet condition, no noise was played. Under the noise condition, the speaker produced speech-weighted broadband noises at a fixed level of 65 dBA in the direction of the unfitted ear throughout the test. Each MMRT word list consisted of 25 phonemically balanced words and was played using Adobe Audition 2.0 on a notebook computer through a Bluetooth transmitter paired with the Bluetooth ALD worn by each participant and set to his or her MCL. The participants were encouraged to guess and repeat what they heard and an audiologist scored each response as correct or incorrect. Each participant's score was a percentage of complete whole word answers.

Questionnaire

A questionnaire was designed to evaluate overall telephonic speech quality based on indoor and outdoor trials conducted after the audiometric tests. Other standard questionnaires such as the abbreviated profile of hearing aid benefits were not adopted because they are commonly used to rate participant satisfaction in various scenarios, whereas the purpose of the questionnaire in this study was primarily to assess the overall telephonic sound quality in quiet and noisy environments. The rating system was based on a 5-point Likert scale (Alcántara et al, 2003) involving the following responses: very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied. The questionnaire is presented in the Appendix.

Participants

Twelve native Mandarin speakers (eight men and four women) aged 27–68 yr (mean age = 46 yr) participated in this study. Per their average hearing thresholds (at 500, 1000, and 2000 Hz), eight participants (five men and three women) had mild hearing loss and four (three men and one woman) had moderate hearing loss. The possibility of central auditory processing disorder was excluded by physicians by accessing the participants'

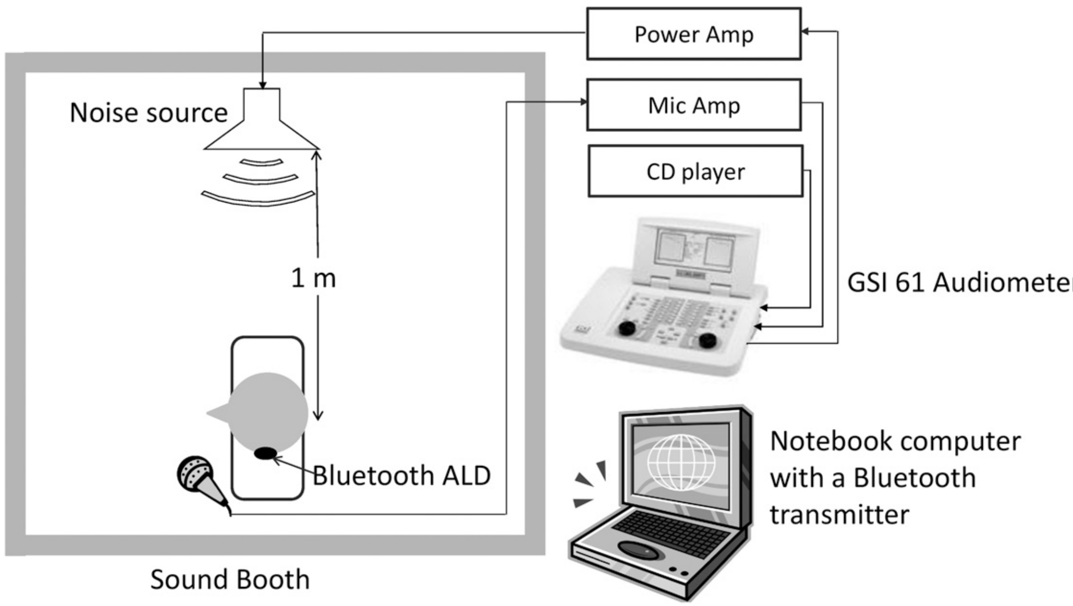


Figure 5. Experimental setup.

case histories and confirming that they experienced no conversational difficulties before first noticing their hearing loss. Among the 12 participants, only one (with mild hearing loss) had experience of using a hearing aid. Table 1 shows the gender, average ages, hearing thresholds, and traditional Mandarin WRSs of the participants. Because of the small sample size, power analyses were conducted to test the sufficiency of the sample size. In general applications, power (1-β) >0.8 is considered sufficient for rejecting the null hypothesis (Pagano and Gauvreau, 2000).

The protocol was approved by the Chung Shan Medical University Hospital Institutional Review Board (Project CS08067). All participants provided informed consent.

Procedures

All audiometric tests were conducted in a soundproof booth. The following data were collected for all participants before ALD testing: pure-tone thresholds (air and bone conductions), speech reception thresholds, traditional Mandarin WRSs (Wang and Su, 1979), uncomfortable levels, and tympanograms.

Each participant tested the compression ALD with medium and maximum profiles first (linear Sound ID SM100 with moderate and strong profiles) and subsequently selected the preferred profile while listening to a trial Mandarin speech in the quiet test room. To avoid the phonetically balanced maximum (PB_{max}) when operating ALDs above the MCL, each participant gradually increased the volume from the minimum to his or her MCL, regardless of intelligibility. In addition, when testing the second ALD, the participants ensured that both devices were operating at the same loudness level. If a participant wished to increase volume further on reaching the maximum volume level, especially when testing the SM100, the researcher increased the signal level by using the Audition software until the participant's MCL was reached. The settings were confirmed and recorded by the researcher. Subsequently, to experience the connectivity of the Bluetooth transmission, each participant wore the ALD and conducted indoor and outdoor phone calls with the researcher from a mobile phone paired with the compression ALD and SM100, respectively.

For objective measurements, data were collected randomly for the following conditions: quiet versus noisy and SM100 versus compression ALD. The compression ALD was worn and tested binaurally with each participant's preferred aided ear facing away from the

Table 1. Mean and Standard Deviation for Age, Pure-Tone Averages (PTAs), Speech Reception Thresholds (SRTs), and Traditional WRSs

	Average Age (Yr)	Male	Female	PTA_t (dB HL)	PTA_b (dB HL)	SRT (dB HL)	WRS (%)
Mild (n = 8)	49 (14)	6	2	27.3 (7.3)	27.6 (6.8)	25.9 (6.5)	96.5 (2.1)
Moderate (n = 4)	39 (15)	3	1	42.5 (10.0)	46.0 (3.3)	45.0 (6.1)	82.5 (7.2)
Total (n = 12)	46 (15)	9	3	32.4 (10.9)	33.8 (10.7)	32.3 (11.2)	91.8 (8.0)

Notes: PTA refers to the average threshold at frequencies of 500, 1000, and 2000 Hz. Subscript t represents test ear data. Subscript b represents binaural average data.

speaker. For subjective measurement, the participants were asked to rate the overall telephonic speech quality of both devices in quiet and noisy environments.

RESULTS

Among the 12 participants, 10 selected the medium profile and two selected the maximum profile for the compression ALD. For the SM100, 10 selected the moderate profile and two selected the strong profile. The following MMRT WRSs and satisfaction ratings were obtained based on these selected profiles.

MMRT WRSs

The mean MMRT WRSs in quiet and noisy environments under compression ALD and linear SM100 conditions are shown in Figure 6. A one-way analysis of variance indicated significant differences among the mean WRSs obtained under both test conditions in the quiet environment [$F_{(1,24)} = 85.206, p < 0.001$; 1-β = 1.0] and noisy environment [$F_{(1,24)} = 56.76$, $p < 0.001$; 1-β = 1.0]. The mean WRSs for the compression ALD were 57% and 53% higher than those of the linear SM100 in quiet and noisy environments, respectively. The power results of 1-β (1.0 in quiet and noisy environments under both conditions) confirm the sufficiency of the sample size.

Satisfaction Ratings

The mean satisfaction ratings of overall speech quality in quiet and noisy environments are shown in Figure 7. The mean satisfaction ratings of the compression ALD and SM100 are between neutral and satisfactory in the quiet environment. A Wilcoxon signed rank test revealed no significant differences in satisfaction between the compression ALD and SM100 in the quiet environment. An additional test demonstrated a significant difference in satisfaction between the compression ALD and SM100 in the noisy environment ($z = -2.05$, $p < 0.05$). In addition, the median score of the compression ALD was higher than that of the SM100 (4.0 and 3.5 for the compression ALD and SM100, respectively), indicating that the participants were more satisfied with the compression ALD than with the SM100.

DISCUSSION

The mean traditional Mandarin WRSs (Table 1) measured using the TDH39P audiometric earphone were higher than the mean MMRT WRSs measured using the Bluetooth ALDs in the quiet environment (Figure 6). This variation is a result of the difference in bandwidth between the TDH39P audiometric earphone (100–8000 Hz) and telephonic receiving path of the Bluetooth ALD (100–3400 Hz). These results support those of Skinner and Miller (1983), who observed that a limited amplification bandwidth of telephony reduced speech intelligibility.

Regarding the MMRT WRSs in the quiet environment, the one-way analysis of variance revealed that the mean WRS of the compression ALD was significantly higher than that of the SM100. Under the same loudness for both devices as adjusted by the participants in the trial session, this significant difference may be the result of higher outputs of the compression ALD at 3150 Hz prescribed by ADRO than those of the SM100 prescribed by DSL i/o (Figure 4), as well as the binaural effect of the compression ALD. To further

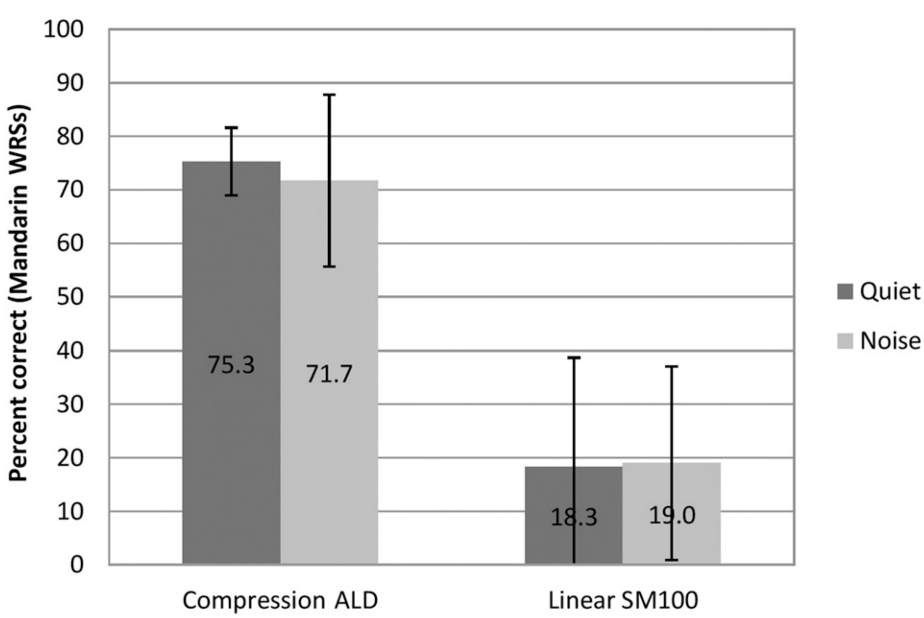


Figure 6. Mean MMRT WRSs and standard deviation (%) in quiet and noisy environments under compression ALD and linear SM100 conditions.

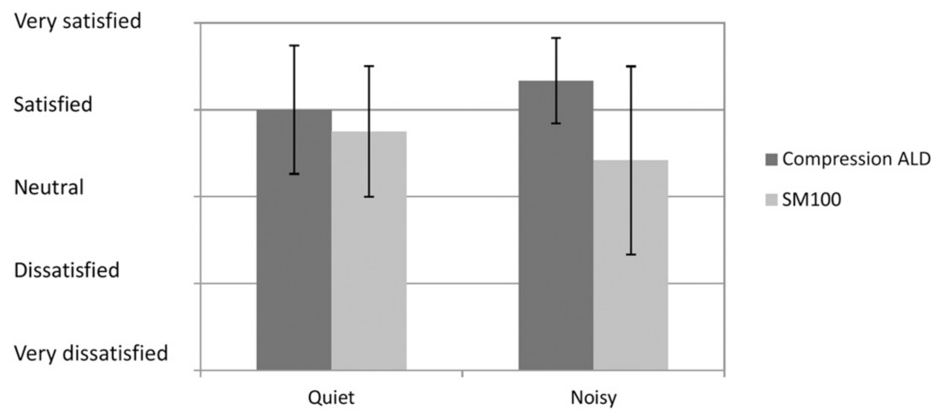


Figure 7. Mean satisfaction ratings and standard deviation of overall speech quality of the compression ALD and SM100 in the quiet and noisy environments.

verify the speech intelligibility of the two devices, the speech intelligibility index was measured by placing the ALD on a *Brüel & Kjær* head and torso simulator with a probe microphone tube inserted into the canal and connected to a Frye 7000 hearing aid analyzer (Frye Electronics, Inc., Beaverton, OR). At an input of −24 dBm0 P.50 speech, the speech intelligibility index scores were higher for the compression ALD than for the SM100 (Figure 8). The NAL-NL1 prescription adopted by ADRO for the fixed-gain ALD contributed more speech intelligibility than did DSL i/o, which explains the higher WRSs for the compression ALD in the quiet environment.

In the noisy environment, the mean MMRT WRS obtained using the compression ALD was significantly higher than that obtained using the SM100 because of the AVC function of the compression ALD that increased output levels across frequencies by 7–8 dB under 65-dBA speech-weighted noises. By contrast, the SM100 maintained the same levels in the quiet and noisy environments; thus, intelligibility was significantly reduced in the SM100. In addition, the nonoccluded earplugs of the compression ALD contributed to higher WRSs because they behaved as a low-pass filter that filtered out the high-frequency content of the speech noise, resulting in less interference than in the SM100, where noises enter an open ear. Although both devices employed noise reduction algorithms, the AVC function played a key role in improving the SNRs because the purpose of the noise reduction algorithm is to reduce the general background noise picked up in the other party's environment, which in our test was minimal compared with those in the local environment. However, the noise reduction algorithm was unable to reduce the local background noise. The noise results agreed with those of Wise et al (2006), who reported that the WRSs of an ADRO scheme with adaptive gain

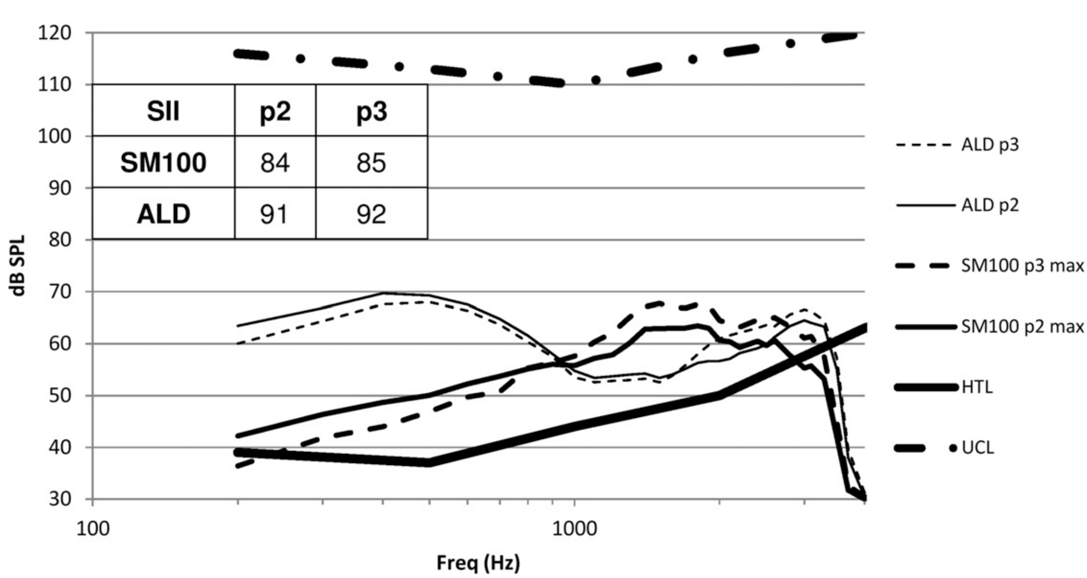


Figure 8. Speech intelligibility index of the SM100 at maximum volume and the compression ALD adjusted to the same loudness as the SM100. The thresholds are from the average data of the 12 participants. HTL = hearing threshold level; UCL = uncomfortable level.

control were significantly higher than those of an output-limiting scheme implemented in a wired headset under 55- and 65-dBA simulated call center background noises. The AVC function can improve the SNR when the user is unable to adjust the volume control in scenarios such as driving or when the user frequently moves between environments with contrasting background noise levels.

The mean satisfaction ratings for the compression ALD and SM100 were between neutral and satisfactory in the quiet environment; however, no significant differences revealed as demonstrated in the MMRT WRSs. In the noisy environment, the participants were more satisfied with the compression ALD than with the SM100, which agrees with the MMRT results. Because hearing loss accompanied with a reduced SNR for background noise represents one of the major barriers to individuals with hearing loss in understanding speech over the telephone (Kepler et al, 1992), the satisfaction difference between the compression ALD and SM100 is likely more significant in noisy environments according to the fact that the compression ALD provided more benefits than the SM100 in the objective measurements in both environments. These results indicate that the compression scheme, especially the AVC function, effectively provided more benefits than did the linear scheme in terms of speech intelligibility and speech quality in the telephonic receiving path in the noisy environment.

Based on objective and subjective measurements of telephonic speech received via a Bluetooth connection in quiet and noisy environments, this study demonstrated that a compression amplification scheme with a prescription fitting for sloping-type hearing loss to maximize speech intelligibility was beneficial for people with mild to moderate hearing loss. Although the Bluetooth ALD was designed for use with mobile phones, it cannot be used with stationary phones. The SM100, which served as the benchmark product in this study, is no longer available on the market. Recent products with a linear scheme in telephony such as the Sound World Solutions CS50+ (SWS, 2015) are presently available. Future studies should consider adopting a wideband (100–8000 Hz) Bluetooth headset and comparing the benefits of compression and linear schemes. In addition, other types of nonlinear amplification schemes such as ADRO are candidates for future research.

CONCLUSION

This study compared the benefits of a linear scheme with those of a compression amplification scheme fitted with a prescription for sloping-type hearing loss implemented in a Bluetooth ALD in quiet and noisy environments and using MMRT WRSs and participant satisfaction as objective and subjective results, respectively. The WRSs of the compression scheme were significantly higher than those of the linear scheme (57% and 53% higher in quiet and noisy environments, respectively). The mean of the satisfaction ratings indicated that the participants had neutral feelings or were satisfied with the overall speech quality of both devices in quiet environments; however, no significant statistical differences were observed. In the noisy environment, the participants were more satisfied with the compression scheme than the linear scheme, which agreed with the MMRT results. The benchmark results indicate that the compression scheme effectively provided more benefits than did the linear scheme in the noisy environment. The results demonstrate the benefits of the compression amplification scheme fitted with a prescription in maximizing speech intelligibility for sloping-type hearing loss implemented in a Bluetooth ALD for people with mild to moderate hearing loss.

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APPENDIX

Questionnaire Name:____________________ Date:_____________

We are interested in your comments on the performance of the assistive listening device in quiet and noisy situations. Please provide answers to the questionnaire that best reflect your experiences. Please feel free to expand on your answers if there is anything else about the device that you think we should know. Your feedback will help us make improvements to the device.

Thank you for your time.

Please indicate whether the assistive listening device helped you to hear more clearly in the following situations:

	Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied
Talking on mobile phone, indoors in quiet	☐	☐	☐	☐	☐
Talking on mobile phone, outdoors in noise	☐	☐	☐	☐	☐

Thank you.