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Effect of Adaptive Compression and Fast-Acting WDRC Strategies on Sentence Recognition in Noise in Mandarin-Speaking Pediatric Hearing Aid Users

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Haihong Liu*†
Yuanhu Liu*†
Ying Li*
Xin Jin*
Jing Li*
Yi Zhou*
Wentong Ge*
Xin Ni*

Abstract

Background: Wide dynamic range compression (WDRC) has been widely used in hearing aid technology. However, several reports indicate that WDRC may improve audibility at the expense of speech intelligibility. As such, a modified amplification compression scheme, named adaptive compression, was developed. However, the effect of compression strategies on speech perception in pediatric hearing aid users has not been clearly reported.

Purpose: The purpose of the present study was to investigate the effect of adaptive compression and fast-acting WDRC processing strategies on sentence recognition in noise with Mandarin, pediatric hearing aid users.

Research Design: This study was set up using a double-blind, within-subject, repeated-measures design.

Study Sample: Twenty-six children who spoke Mandarin Chinese as their primary language and had bilateral sensorineural hearing loss participated in the study.

Data Collection and Analysis: Sentence recognition in noise was evaluated in behind-the-ear technology with both adaptive compression processing and fast-acting WDRC processing and was selected randomly for each child. Percent correct sentence recognition in noise with fast-acting WDRC and adaptive compression was collected from each participant. Correlation analysis was performed to examine the effect of gender, age at assessment, and hearing threshold of the better ear on signal-to-noise ratio, and a paired-samples *t* test was employed to compare the performance of the adaptive compression strategy and fast-acting WDRC processing.

Results: The mean percentage correct of sentence recognition in noise with behind-the-ear technology with fast-acting WDRC and adaptive compression processing were 62.24% and 68.71%, respectively. The paired-samples *t* test showed that the performance of the adaptive compression strategy was significantly better than the fast-acting WDRC processing ($t = 3.190$, $p = 0.004$).

Conclusions: Compared with the fast-acting WDRC, adaptive compression provided better sentence recognition in noise for Mandarin pediatric hearing aid users.

*Beijing Key Laboratory for Pediatric Otolaryngology, Head and Neck Science, Department of Otolaryngology Head and Neck Surgery, Beijing Pediatric Research Institute, Beijing Children's Hospital, Capital Medical University, Beijing, China; †These authors contributed equally to the work

Corresponding author: Xin Ni, Beijing Children's Hospital, Capital Medical University, Beijing 100045, China; E-mail: nixin@bch.com.cn

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Key Words: adaptive compression, children, hearing aid, noise, sentence recognition, WDRC

Abbreviations: SNR = signal-to-noise ratio; WDRC = wide dynamic range compression

INTRODUCTION

Wide dynamic range compression (WDRC) has been widely used in modern hearing aid amplification schemes because it provides individuals with improved audibility and greater listening comfort across a wide range of input levels, without the need for frequent volume control adjustments compared with linear circuits (Jenstad et al, 2000). Children can benefit from the use of WDRC processing, because many of them are too young to efficiently control loudness levels themselves, their everyday listening environments are unpredictable with fluctuating noise levels (Cruckley et al, 2011), and there are to variations in speaker position and distance (Stelmachowicz et al, 1993).

Traditional WDRC operates with fixed attack and release times. In contrast, adaptive compression applies different time constants based on how much the input changes. When the change in input is small, a slow time constant is applied. When the change in input is large, a fast time constant is applied. The goal of fast-acting compression is to reduce the dynamic range of continuous speech over the short term with a response fast enough to apply gain to low-level phonemes and less gain to high-level phonemes. On the other hand, the goal of a slow-acting system is to limit the compression on the short-term variations of speech and instead modulate levels of sounds over the long term. Both of these two amplitude compression approaches have strengths and weaknesses. Slow-acting compression may result in inadequate amplification of low-level input for a substantial period following a loud input. Fast-acting compression may distort sound quality, or decrease the signal-to-noise ratio (SNR) by amplifying low-level background noise. Previous reports indicate that adaptive compression may provide loudness comfort but still maintain audibility of soft sounds (Jenstad and Souza, 2005; Naylor and Johannesson, 2009; Pittman et al, 2014). A recent report indicated that adaptive compression may improve the long-term SNR for speech in noise (Lai et al, 2013). However, most compression strategies were designed based on English, which is different from Mandarin. Mandarin is a widely used tonal language, and tones are heavily loaded with lexical, semantic, and grammatical information. The effect of compression strategies on sentence recognition in Mandarin hearing aid children has not been reported. The purpose of the present study was to investigate the effect of the adaptive compression and traditional fast-acting WDRC strategies on sentence recognition in noise with Mandarin speaking, pediatric hearing aid users.

METHODS

Participants

Participants were recruited from the Pediatric Audiology Center of Beijing Children's Hospital, Capital Medical University. The inclusion criteria were as follows: (a) participants had bilateral sensorineural hearing loss; (b) participants' hearing loss was symmetrical, and had no interaural differences >25 dB HL at any one frequency from 250 to 8000 Hz; (c) Mandarin Chinese was the primary language of communication; (d) participants had no identified cognitive and/or retro-cochlear disorder; (e) hearing aids were the only technology used by the participant; and (f) participants had no other identified disability besides hearing loss. According to the inclusion criteria, 26 children participated in the study, including 14 males and 12 females, ages ranging from 5 to 14 yr (mean age = 7.7 yr). Audiometry showed that sloping hearing loss dominated the configuration of hearing loss (audiometry was performed with an insert earphone, for children who could not cooperate with the pure-tone audiometry, hearing thresholds were obtained by play audiometry). Detailed hearing thresholds were shown in Figure 1. Informed consent forms were signed by the parents of the participants before the assessments were administered, and ethics approval was obtained from the institutional review board of Beijing Children's Hospital, Capital Medical University.

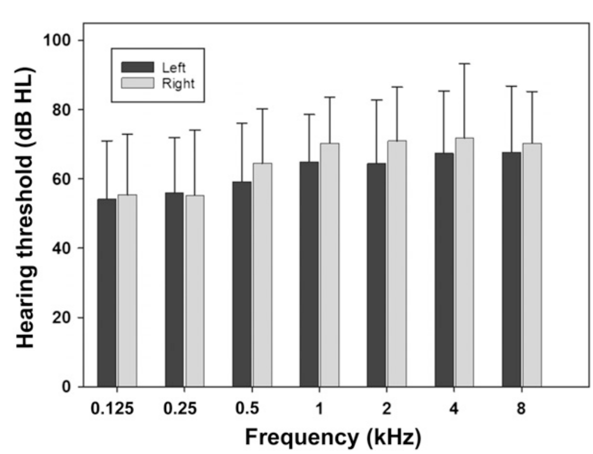

Figure 1. Hearing threshold levels of participants. The x axis represents the frequency (kHz) and the y axis represents the threshold (dB HL).

Procedure

Hearing aids were fit bilaterally using the Desired Sensation Level version 5.0 prescriptive method. Hearing aid settings were as follows: microphone response was set to omnidirectional, noise reduction and binaural broadband were set to off, and the adaptation manager was set at level 3. An unvented ear mold was coupled to the hearing aids with standard size 13 tubing. Verification was performed with Aurical FreeFit® (Otometrics, Copenhagen, Denmark) real-ear measurement to adjust the gain response and output to match the prescribed target.

A double-blind, within-participants, repeated-measures design was used in the evaluation. Both the participants and the assessment audiologists were blinded to which hearing aid was using adaptive compression and which had WDRC (different audiologists performed the fitting and sentence recognition test). Sentence recognition in four-person babble noise was conducted using the easy version of the Mandarin Bamford-Kowal-Bench Speech-in-Noise Test (Xi et al, 2012), which consists of 16 sentence lists, with 20 sentences in each list, each sentence containing six to eight Mandarin syllables (three to four key words). As the sentence lists were equivalent, one list was randomly selected during the test for each child, and the test was administrated in a sound-treated booth with a noise floor that was measured below 20 dBA. In the pilot study, we found that the position of the speakers influenced perception performance. According to the pilot study, speech and babble noise were presented separately through two independent speakers placed 1 m away from the participant, at left and right 45° azimuth, respectively. That is, the center of the participant's head is 1 m from each speaker, and the speakers are separated by a 90° azimuth. During the speech perception test, the babble noise always came from the worse ear, the speech always came from the better ear. Participants responded by verbally repeating the sentence they heard and results were scored as the percentage of key words correctly identified. Speech recognition testing was completed in random order using behind-the-ear hearing instruments with adaptive compression processing (Oticon Sensei Pro 13P, Egedal, Denmark) and fast-acting WDRC processing (Oticon Sensei 13P). Detailed information about the hearing aids is shown in Table 1. During the evaluation, the speech stimuli were fixed at 65 dB SPL. Before the formal assessment, an appropriate SNR was found for each participant to avoid ceiling and floor effects, which assures the assessment was neither too hard nor too easy. Once the appropriate SNR was determined for a specific child, it was employed for both adaptive compression and WDRC conditions. That is, each child was assessed at only one SNR. The participants' responses to speech tests were scored by two independent examiners. When the responses were scored differently between the examiners, they would ask the child to repeat the response and rescore. When the rescore was still different, the response would be excluded from the final analysis. Speech testing was completed in one 20-min session. Participants were allowed to take breaks whenever they felt tired or when the examiners observed fatigue.

Table 1. Hearing Aid Details

Feature	Sensei Pro	Sensei
Bandwidth	10 kHz	10 kHz
Frequency channels	16	16
Maximum output	135 dB SPL	135 dB SPL
Compression type	Adaptive compression	Fast-acting WDRC
Attack/release time	<10/80–400 msec	8–11/10–40 msec

RESULTS

Distribution of SNR

The distribution of the SNR used with the participants during speech testing is plotted in Figure 2. The SNR was set at −6, 3, 6, 9, 12, and 15 dB during the evaluation 4.2%, 8.3%, 50.0%, 25.0%, 8.3%, and 4.2% of the time, respectively. The distribution indicated that 6 and 9 dB were the most frequently used SNRs. Correlation analysis was employed to explore the relationship between the SNR and the pure-tone average thresholds. Analysis indicated that a correlation existed between the average hearing thresholds of the better ear and the SNR ($r = 0.4$, $p = 0.043$). That is, the better the pure-tone average thresholds, the more challenging the condition in which the child could perform the assessment. A correlation also existed between the age at assessment and the SNR ($r = -0.44$, $p = 0.023$). Correlation analysis was also performed to examine the effect of the participants' gender on SNR. Analysis indicated that participants' gender does not correlate with SNR ($r = 0.005$, $p = 0.980$).

Effect of Compression Strategy on Sentence Recognition in Noise

The mean percent correct sentence recognition in noise with fast-acting WDRC and adaptive compression was 62.24% and 68.71%, respectively. The distribution of age, average threshold of the better ear, and performance with fast-acting WDRC and adaptive compression strategies is shown in Table 2. Sentence recognition with fast-acting WDRC and adaptive compression at each SNR and the overall average performance are plotted in Figure 3. A paired-samples

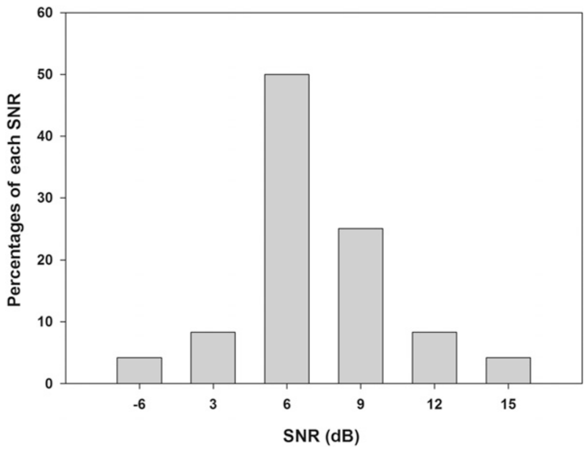

Figure 2. Distribution of the SNR in sentence recognition. The *x* axis represents the SNR and the *y* axis represents how frequently each SNR setting was used in sentence recognition (in percent). Each child was assessed at one specific SNR, which was determined before the formal assessment to avoid the ceiling and floor effect.

t test indicated that the performance of adaptive compression was significantly better than that of fast-acting WDRC ($t = 3.190, p = 0.004$). As shown in Figure 3, the sentence recognition scores distributed consistently in each SNR condition, that is, speech recognition with adaptive compression was better than with fast-acting WDRC.

DISCUSSION

Research has reported that WDRC may reduce speech perception, especially in noisy conditions (Plomp, 1988; Lai et al, 2013; Wu and Stangl, 2013). This may be due to the improved audibility at the expense of speech clarity. Specifically, the spectrum of an individual phoneme varies rapidly over time, and clear speech depends on spectral and temporal contrast, while WDRC degrades spectral and temporal cues, which may lead to inferior speech perception performance in noisy environments. Plomp's report indicated that the following two arguments in favor of amplitude compression were not valid: first, to compensate for the effects of loudness recruitment and second, to get weak consonants beyond a threshold. The author concluded that in multichannel hearing aids, automatic gain control with time constants of 0.25–0.5 sec should be given preference to amplitude (Plomp, 1988). To deal with the negative effects of amplitude compression on speech perception and speech intelligibility, a modified amplification compression scheme was investigated. Lai et al (2013) showed that an adaptive compression-ratio amplification strategy, which used the characteristics of the input signal to adaptively adjust the compression ratio, named adaptive WDRC, provide better long-term SNR performance. Furthermore, the benefit of linear amplification has been reported (Cox and Alexander, 1993). Some reports also indicate that compared with linear processing, the WDRC strategy creates a noisier sound and made listeners reluctant to accept noise (Wu and Stangl, 2013). Wu and Stangl (2013) reported that WDRC could worsen the acceptable noise level by 1.5 dB (acceptable noise level represents the maximum noise level that an individual is willing to accept, i.e., the lowest SNR that a listener is willing to accept). Research by Davies-Venn et al (2009) found that fast-acting WDRC provided an audibility advantage for an input signal at 50 dB SPL; consequently their study indicated that severe hearing loss participants benefited from fast-acting WDRC amplification for low-level speech. However, for conversational and higher levels of input signals, fast-acting WDRC amplification degraded performance, which may be the result of WDRC not conferring significant audibility for conversational and high-level inputs. Hickson et al (1995) investigated consonant perception between linear and compression amplification. There was not a difference between linear and compression amplification in quiet, but linear amplification was better in babble noise. However, some comparisons also exhibited inconsistent results. Kam and Wong (1999) compared the performance of WDRC and linear amplification. Outcome measures included speech recognition, speech reception threshold, and subjective preference. Results showed that WDRC exhibited better speech intelligibility in quiet for low-level input signals, and no difference in speech intelligibility was found in noise conditions. Subjective assessment indicated that participants with sensorineural hearing loss preferred WDRC for loudness to high- and low-level input signals. Davies-Venn et al (2007) compared the speech and music quality for linear and WDRC amplification strategies. Their report indicated that participants showed a preference for WDRC for speech quality, especially at high input levels, and showed an equivalent rating for music quality. Some reports showed better benefits for WDRC over

Table 2. Distribution of Average Age, PTA of the Better Ear, and Performance with Traditional Fast-Acting WDRC and Adaptive Compression Strategies for Each SNR

SNR	N	Age	PTA of Better Ear	Fast-Acting WDRC	Adaptive Compression
−6	1	10.25	49.15	78.00	78.80
3	2	5.00	45.00	50.00	70.00
6	13	8.00	58.71	67.63	74.73
9	7	6.83	61.07	54.00	61.33
12	2	7.00	55.35	71.00	74.50
15	1	7.00	72.14	40.00	50.00

Note: PTA of better ear: average threshold of the pure-tone thresholds at 0.5, 1.0, 2.0, and 4.0 kHz of the better ear. PTA = pure-tone average.

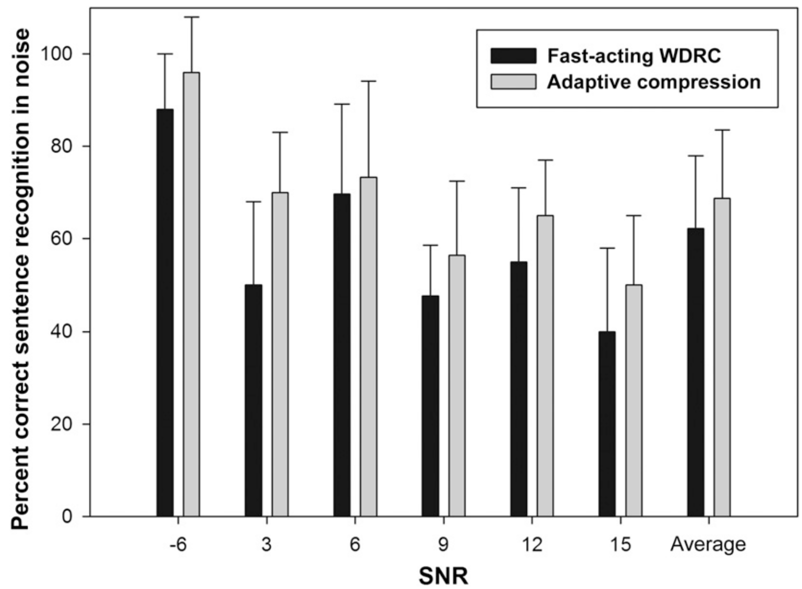

Figure 3. Sentence recognition performance with fast-acting WDRC and adaptive compression. The *x* axis represents the SNR and the *y* axis represents the percent correct of sentence recognition in noise with each SNR.

linear amplification for listening comfort, listener's satisfaction, and speech intelligibility (Marriage et al, 2005; Gatehouse et al, 2006a). The reason for the discrepancy may be due to the auditory status of the participants (i.e., configuration of the audiometric threshold, dynamic range, and the characteristics of the input level). Specifically, better performance with linear amplification may be associated with flat audiometric configuration, and wider auditory dynamic range (Gatehouse et al, 2006b).

Currently, most studies focus on adult hearing aid users with little attention given to pediatric hearing aid users. According to the guidelines of pediatric amplification proposed by the AAA, the system should employ an amplitude compression strategy that offers the flexibility to restore audibility for low-level inputs while maintaining comfort for high-level inputs. At the same time, the system should avoid unnecessary distortion (Moodie et al, 2016). Previous studies indicate that adults with lower cognitive abilities have more difficulty with the subtle signal distortion caused by fast-acting compression than their peers with better cognitive ability (Souza, 2002; Gatehouse et al, 2006b; Cox and Xu, 2010). Pittman et al (2014) compared the effects of fast, slow, and adaptive amplitude compression on speech and environmental sound perception. Their study indicated that amplitude compression significantly affected perception performance participants with hearing loss achieved optimal performance with adaptive compression.

The present study investigated and compared the speech recognition performance of pediatric hearing aid users with adaptive compression and fast-acting WDRC strategies. The result indicated better speech recognition in noise for those children using adaptive compression technology compared to fast-acting WDRC. Lai et al (2013) also reported that adaptive compression provided better long-term SNR performance than traditional static WDRC amplification. From the present results, we believe there are two important points to consider. First, sentence recognition in noise was evaluated immediately after children were fit with their new hearing aid. The effects of acclimatization were not evaluated. This suggests that the improvement in speech recognition in noise is likely due to the characteristics of the processing strategy. Second, the results highlighted the importance of children's sensitivity to compression strategies implemented in hearing aids. These should be considered when selecting and fitting hearing aids to children with hearing loss. As noted above, a limitation of the present study was that the assessment was performed immediately after the hearing aid was fit. Further longitudinal study will take the acclimatization effect into account.

CONCLUSION

The present study compared sentence recognition in noise between adaptive compression amplification and traditional fast-acting WDRC amplitude compression in Mandarin-speaking pediatric hearing aid users. The results indicated that the adaptive compression amplification strategy provided better sentence recognition in noise than fast-acting WDRC.

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