Objective Measurement of Speech Quality for Hearing Aids

Ying-Hui Lai1  Shih-Tsang Tang2  Kuen-Shian Tsai1  Hsiu-Wen Chang3  
Shuenn-Tsong Young4,*  Woei-Chyn Chu1

1Hearing and Speech Engineering Laboratory, Institute of Biomedical Engineering, National Yang-Ming University, Taipei 112, Taiwan, ROC  
2Department of Biomedical Engineering, Ming Chuan University, Taoyuan 333, Taiwan, ROC  
3Department of Speech and Hearing Disorders and Sciences, National Taipei University of Nursing and Health Sciences, Taipei 112, Taiwan, ROC  
4Holistic Education Center, Mackay Medical College, New Taipei City 252, Taiwan, ROC

Received 29 Nov 2012; Accepted 7 Mar 2013; doi: 10.5405/jmbe.1383

Abstract

Hearing aids are commonly used to overcome impairment associated with hearing loss. Recent surveys have shown that hearing aid users are often dissatisfied with the speech quality. However, only subjective methods (e.g., questionnaires) are used to assess speech quality, and the objective methods used to verify the performance of hearing aids have major limitations. This study proposes an objective method called variations of dynamic range (VDR) score for assessing hearing aid speech quality. The method uses quantitative differences between spectra for aided and unaided speech based on Speechmap. Two experiments were performed in this study: (1) one to verify the correlation between scores for the perceptual evaluation of speech quality (PESQ) and VDR in assessing speech quality produced under three compression ratios (CR) of wide-dynamic-range amplification in one channel, and (2) one to verify that the VDR score is consistent with results from clinical trials in the literature. The experiments involved hearing aids fitted using desired sensation level [input/output] (DSL [i/o]) and adaptive dynamic range optimization (ADRO), and stimulated by speech sounds at moderate and loud levels. The VDR scores were measured using the Audioscan Verifit hearing aid fitting system to assess the speech quality of hearing aids. The results indicate that PESQ scores were 3.56, 2.25, and 1.98, and VDR scores were 2.5, 29, and 36 dB for CRs of 1.0, 2.0, and 4.0, respectively. The VDR and PESQ methods provided similar assessments of speech quality produced by hearing aids fitted for flat mild hearing loss (high and low PESQ and VDR scores, respectively, indicate good speech quality). In addition, the average VDR scores were significantly lower (p < 0.05) for hearing aids fitted using ADRO than those for hearing aids fitted using DSL [i/o]. The VDR scores are consistent with PESQ scores for hearing aids with different prescriptions, and are consistent with clinical reports that found the speech quality for hearing aids fitted using ADRO to be higher than that obtained using DSL [i/o]. These results indicate the potential of the VDR score for accurately assessing the speech quality of hearing aids.

Keywords: Hearing aids, Speech quality, Speechmap, Dynamic range compression, Adaptive dynamic range optimization (ADRO)

1. Introduction

Hearing loss is a relatively common condition (especially among the elderly) that can decrease the quality of life in various ways, including making it difficult to enjoy music and communicate with other people. Sensorineural hearing loss (SNHL) is the most common type of hearing loss [1], which is usually manifested as a reduced sensitivity to soft sounds, with loud sounds producing discomfort [2]. The adverse effects of SNHL can be improved by the use of a hearing aid. However, the characteristics of SNHL are diverse and differ markedly between individuals, which has led to the development of numerous hearing aid fitting strategies (so-called prescriptions) to ensure that the processed sounds are suitable for an individual hearing aid wearer with SNHL [3,4].

Wide dynamic range compression (WDRC) is a common amplification scheme in modern hearing aids. It is a type of nonlinear amplification that applies different gains to different levels and frequencies. The WDRC fitting strategy is designed to make low-level signals audible while maintaining comfort for higher-level inputs [3,5,6]. Several commonly used independent prescriptions are based on WDRC, including NAL-NL1 (National Acoustic Laboratories-Nonlinear Version 1) [3] and DSL input/output (DSL [i/o]) [7]. However, WDRC does not provide high-quality speech, as confirmed by Kochkin [8], who reported that 88.4% of hearing aid users considered it
highly desirable for the speech quality of hearing aids to be improved. Martin et al. [9] proposed an adaptive amplification method called adaptive dynamic range optimization (ADRO), which was shown to improve speech quality. The ADRO structure does not increase the gain across all frequencies and amplitudes in order to compensate for hearing loss; instead, it uses an adaptive process to linearly amplify the most informative audio signal segments so that they become audible [10,11]. Although ADRO has many advantages over WDRC, the ADRO fitting method differs markedly from that of WDRC and there are some difficulties in verifying outcomes, which has resulted in it not being widely implemented in clinical applications.

The optimal fitting of a hearing aid for SNHL requires the settings of its prescription to maximize speech recognition and provide comfortable amplification [12], and this requires an appropriate evaluation method. Many subjective and objective evaluation methods have been proposed for comparing hearing aid prescriptions. Questionnaires such as IOI-HA (International Outcome Inventory for Hearing Aids) [13] and COSI (Client-Oriented Scale of Improvement) [14] are commonly used subjective methods for evaluating speech recognition for hearing aids [15]. Sentence and word recognition tests, such as HINT (Hearing in Noise Test) [16], which provides an accurate, reliable, and efficient method of measuring speech intelligibility in noisy conditions, are popular clinical objective evaluation methods. Moreover, various subjective questionnaires have been used in clinical speech quality evaluation methods, such as SSQ (Speech, Spatial, and Qualities of Hearing Scale) [17]. However, this proliferation of subjective and objective methods for ensuring audible and comfortable outcomes has meant that there is no standard objective method for evaluating hearing aid speech quality in clinical applications.

Objective speech quality metrics have been developed for non-hearing-aid applications [18-21]. Digital audio technologies (e.g., earphones, telephones, and mobile phones) often require that the audio signals be digitally coded and decoded at low data rates due to limitations in the capacity of storage devices and/or transmission systems [22], making it necessary to evaluate speech quality after processing. The Perceptual Evaluation of Speech Quality (PESQ) algorithm [23,24] is the current industry standard for the objective assessment of one-way speech quality, and was accepted in February 2001 by the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T) as objective speech quality measurement standard P.862 [23,25]. The PESQ algorithm uses two input signals to compute speech quality, namely an unprocessed speech sample and processed speech. The PESQ score ranges from -0.5 (worst) to 4.5 (best). The mean opinion score (MOS) scale can then be used to transform the PESQ score into a measure related to human perception [24,26] in order to assess speech quality. Although this method is designed to evaluate a full-band audio signal, for hearing aids the ITU-T standard fidelity rating appears to be strongly correlated with the results of subjective assessments of speech quality, particularly for individuals with a flat mild hearing loss in a wide-band channel processing (i.e., the single-channel process of the hearing aid) [27]. Chen [38] predicting the speech intelligibility of cochlear-implant vocoded speech from PESQ method. The results were shown that the language effect impacts the performance of PESQ measures in predicting the intelligibility of vocoded speech. In clinical practice, most cases of hearing loss are high-frequency hearing loss. Single-channel processing in hearing aids is not suitable for such users. Therefore, multi-channel processing is used to overcome this problem. However, the PESQ algorithm in its present state does not include multi-channel processing, and hence is unsuitable for directly assessing the speech quality of multi-channel processing hearing aids [28].

The speech quality of a hearing aid is affected by the compression ratio (CR) setting of the amplifier. Van Buuren’s studies showed that speech quality was no higher for either compression (i.e., CR > 1) or expansion (i.e., CR < 1) than it was for linear amplification, the rated speech quality decreased for CR values above 1.0 (i.e., the linear case) both in normal and hearing-impaired individuals [29,30], and that a high CR tended to distort sounds, reducing intelligibility and speech quality [31].

When a higher CR is used in processing audio signals, the gain is higher for softer sounds than for loud sounds, which produces a lower peak-to-valley (so-called envelope) ratio in Speechmap (Audioscan, Dorchester, Canada) [32]. This decreased envelope value reduces the measured speech quality [6]. The peak-to-valley ratio can be displayed using Speechmap. Speechmap creates a map of the amplified speech region within the residual auditory area using several simulated speech signals, making it suitable for fitting hearing aid prescriptions to real speech. Scollie and Seewald [33] provided evidence that the simulated speech signals used to produce a Speechmap are good predictors of the real speech output from compression-based hearing aids.

The present pilot study uses Speechmap to investigate the efficacy of using the dynamic range of speech to evaluate the speech quality of various hearing aid processing schemes. A method called variations of dynamic range (VDR) score, which uses differences in the dynamic range between aided and unaided speech, is proposed to quantify the speech quality obtained using WDRC and ADRO amplification methods. In addition, the feasibility of the VDR method is verified by comparing it with the PESQ algorithm in single-channel processing.

2. Methods

This section first introduces Speechmap, which is the main evaluation tool for the proposed method, and then presents the proposed VDR method. A comparison of PESQ and VDR follows, with the efficacy of the VDR method tested using two general hearing aid amplifiers.

2.1 Speechmap

Speechmap expresses the dynamic range of speech as the distribution of the sound pressure level (SPL) in each 1/3-octave frequency band. The SPLs are determined by calculating
the spectrum for a series of short time periods of the speech signal. The Audioscan Verifit hearing aid fitting system uses a 128-ms time period and 100 levels in each 1/3-octave frequency band for a 12.8-s signal to create a Speechmap. The level in each band that is exceeded by 1% of the samples (called L1 or the 99th percentile) is referred to as the speech peak for that band. The level in each band that is exceeded by 70% of the samples (called L70 or the 30th percentile) is called the speech valley.

A Speechmap is shown in Fig. 1. The top, bottom, and middle curves of the green region are the L1, L70, and long-term-average speech spectrum (LTASS) curves, respectively. The dynamic range of a Speechmap is calculated as the difference between L1 and L70, which is often called the speech envelope, speech region, or speech banana. The blue and dotted lines are the hearing thresholds at different frequencies, and the asterisks are the derived loudness discomfort levels (LDLs). A Speechmap with peaks above the threshold will be detectable, one that is entirely above the threshold will be maximally audible, and one that extends above the LDL will be uncomfortable [34].

![Image of Speechmap](image)

**Figure 1. An example Speechmap.**

The speech envelope is significant to both speech detection and speech understanding. Generally, speech will be detectable if the 99th percentile is at or near the threshold. The SII (Speech Intelligibility Index) is maximized when the entire speech envelope is above the threshold. The speech-reception threshold is attained when the LTASS is at the threshold. The speech envelope varies between individual speakers, is reduced by syllabic compressors, and clearly shows the effects of changes to the compression parameters.

### 2.2 VDR method

The proposed VDR method involves assessing the speech quality based on determining the differences in dynamic range between unaided and aided speech, called the VDR score. The stages of the VDR method are shown in Fig. 2. The unaided and aided speech signals are first measured and presented in the Speechmap. Then, the VDR score is determined as follows:

$$\text{VDR score} = \sum_{f=250}^{6000} \left| S_f^S - S_{fP} \right|$$  \hspace{1cm} (1)

where $S_f^S$ and $S_{fP}$ are the dynamic ranges within a specified frequency band for unaided and aided speech, respectively. The absolute deviations between $S_f^S$ and $S_{fP}$ are calculated from 250 Hz to 6 kHz in each 1/3-octave band in units of decibels. When $S_f^S$ is larger than $S_{fP}$, the aided speech has been compressed; otherwise, the aided speech has been expanded. The VDR score is a measure of the distortion of the aided speech. The VDR score increases when the aided speech is compressed or expanded, which is hypothesized to affect the speech quality.

### 2.3 Experiment 1: VDR and PESQ

PESQ is the recommended measurement for assessing the speech quality of a narrowband handset telephone or earphone [24,25]. The results of PESQ evaluation are principally modeled to MOSs that cover a scale from 1 (poor) to 5 (excellent). Therefore, the PESQ method was adopted as a benchmark to verify the VDR score. Experiment 1 was conducted to address two specific aims: (1) using PESQ to determine whether aided speech subjected to a higher compression will have a lower speech quality, and (2) to verify whether the PESQ evaluation and VDR score provide the same assessment trend.

#### 2.3.1 Apparatus

An off-the-shelf one-channel digital hearing aid with a digital signal processor was used (GA 3285, Sound Design Technologies, Aescu Technology, Taiwan). The main compression characteristics of this device, including the CR, compression threshold, and gain, are all adjustable. The PESQ evaluation software was implemented in C code [23,24]. More details about PESQ can be found elsewhere [23-25]. In addition, the Speechmap was measured using the Audioscan Verifit hearing aid fitting system.

![Diagram of processing](image)

**Figure 2. Block diagram of processing performed to obtain the VDR score.**
2.3.2. Procedure

The PESQ method was designed to evaluate the speech quality over a wide bandwidth [22,24]. Therefore, for the PESQ characteristics, the experimental condition was designed with a flat mild hearing loss in a one-channel hearing aid. The hearing aid was fitted with a linear gain that according to suggest of DSL 4.0 prescription [3] in 35 dB flat hearing loss type. The low and high thresholds (the so-called knee point of the compressor) were fixed at 30 and 110 dB SPL, respectively, associated with three identical CRs of 1.0, 2.0, and 4.0. Male English speech at 65 dB SPL was used for stimulation under both the unaided and aided conditions. In addition, all measurement results were simulated using the Audioscan Verifit system via a 2-cc coupler.

The three CRs of aided speech were first evaluated using PESQ. The VDR evaluation followed using the same three CRs at six frequencies, namely 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 6 kHz; these frequencies are commonly used for hearing threshold measurements. Finally, these two objective speech quality measurement methods were used to verify whether the VDR can provide the same assessment trend as that obtained using PESQ.

2.4 Experiment 2: VDR test for hearing aid amplifiers

Clinical trials of ADRO amplification have revealed that it provides very similar patterns of benefits in cochlear implants [35,36] and hearing aids [11], showing improved speech perception under quiet and background noise conditions, together with higher speech quality than that obtained with compression amplification [10]. Therefore, Experiment 2 was conducted to test and verify that the VDR score provides similar assessments to those obtained in clinical trials of ADRO, and provides higher speech quality than that obtained with WDRC amplification.

2.4.1. Apparatus

Currently there is no commercially available hearing aid that implements both WDRC and ADRO amplification schemes, and thus two hearing aids were used in this study. In order to avoid errors arising from the use of different hearing aids, their electroacoustic characteristics were carefully considered. The criteria for hearing aid selection were (1) a difference between the maximum output sound level and reference test gain of the two hearing aids of less than 5 dB, (2) a total harmonic distortion of less than 3%, (3) an equivalent input noise level of less than 28 dB SPL, and (4) frequency response curves that were as similar as possible. Phonak Savia 311 and INTERTON BIONIC Nano devices were chosen for use in this study; their technical data are presented in Table 1.

The DSL[i/o] prescription (which represents WDRC) was implemented for the Phonak Savia 311 hearing aid and the ADRO prescription was implemented for the INTERTON BIONIC Nano hearing aid. Both hearing aids were programmed using their respective fitting applications. The electroacoustic performances of the hearing aids were measured using the Audioscan Verifit system via a 2-cc coupler.

<table>
<thead>
<tr>
<th>Hearing aid</th>
<th>OSPL 90° maximum (dB SPL)</th>
<th>Reference test gain (dB)</th>
<th>Frequency range (Hz)</th>
<th>THDa</th>
<th>Equivalent input noise level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phonak Savia 311</td>
<td>130</td>
<td>50</td>
<td>100-6500</td>
<td>2%/1%/1%</td>
<td>&lt; 22 dB SPL</td>
</tr>
<tr>
<td>INTERTON BIONIC Nano</td>
<td>125</td>
<td>52</td>
<td>200-6400</td>
<td>1%/1%/1%</td>
<td>&lt; 25 dB SPL</td>
</tr>
</tbody>
</table>

Table 1. Technical data of Phonak Savia 311 and INTERTON BIONIC Nano devices. The data were measured for a 2-cc coupler based on the ANSI S3.22 (1996) standard.

2.4.2. Procedure

The prescriptions for the two hearing aids were set according to the audiograms of eight study subjects with SNHL. The audiograms, shown in Fig. 3, can be roughly divided into two categories: flat hearing loss and high-frequency hearing loss. In order to control the experimental variables, the functions of the Phonak Savia 311 and INTERTON BIONIC Nano hearing aids were set to be as consistent as possible. For example, the functions of noise reduction and feedback cancellation were turned off in order to reduce the possible effects of their specific types of signal processing. In addition, the vent size of the ear mold was assumed to be zero, and long-term user experience was used to ensure that the target gain of each prescription could be achieved. All measurements with the Audioscan Verifit system were performed in a soundproof booth, with the results simulated for a 2-cc coupler.

Figure 3. Audiograms of eight study subjects (S1 to S8) with SNHL.

The system was calibrated before each experiment. The samples of male English speech were the same as those used in Experiment 1. Speech levels of 65 and 75 dB SPL were used, which were defined as moderate and loud speech, respectively. The unaided Speechmaps for the two speech levels were recorded, and the VDR scores at the six frequencies used in Experiment 1, namely 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 6 kHz, were calculated.
3. Results

3.1 Results of Experiment 1

The evaluation results of PESQ and VDR methods for the three investigated CRs are given in Table 2. The PESQ scores decreased with increasing CR; they were 3.56, 2.25, and 1.98 for CRs of 1.0, 2.0, and 4.0, respectively. The VDR scores increased with increasing CR; they were 2.5, 29, and 36 dB for CRs of 1.0, 2.0, and 4.0, respectively. Note that higher PESQ scores and lower VDR scores indicate higher speech quality.

Table 2. PESQ and VDR scores with three CRs in a one-channel hearing aid for flat mild hearing loss.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>CR</th>
<th>PESQ</th>
<th>VDR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.0</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>2.5</td>
<td>29.0</td>
<td>36.0</td>
</tr>
<tr>
<td>Loud</td>
<td>25.5</td>
<td>22.5</td>
<td>1.98</td>
</tr>
</tbody>
</table>

3.2 Results of Experiment 2

The VDR scores for unaided speech at moderate and loud speech levels are listed in Table 3. For the moderate speech level, they were 21, 24, 30.5, 28, 21.5, and 17.5 dB for frequencies of 250 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz, and 6 kHz, respectively; the corresponding values for the loud speech level were 21, 26.5, 34.5, 31, 26, and 21 dB.

Table 3. Unaided speech dynamic ranges for moderate and loud speech levels.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Speech level</th>
<th>250 Hz</th>
<th>500 Hz</th>
<th>1 kHz</th>
<th>2 kHz</th>
<th>4 kHz</th>
<th>6 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>21 dB</td>
<td>24 dB</td>
<td>30.5 dB</td>
<td>28 dB</td>
<td>21.5 dB</td>
<td>17.5 dB</td>
<td></td>
</tr>
<tr>
<td>Loud</td>
<td>21 dB</td>
<td>26.5 dB</td>
<td>34.5 dB</td>
<td>31 dB</td>
<td>26 dB</td>
<td>21 dB</td>
<td></td>
</tr>
</tbody>
</table>

Example VDR scores at moderate and loud speech levels are shown in Fig. 4 for subject 7, who exhibited typical high-frequency hearing loss. The scores of DSL [i/o] and ADRO were 23 and 16.5 dB, respectively, at the moderate speech level, and 44 and 27.5 dB, respectively, at the loud speech level. The average VDR scores for all eight subjects for each condition are shown in Fig. 5. The mean VDR scores of DSL [i/o] and ADRO were 24 and 20 dB, respectively, at the moderate speech level, and 46 and 23 dB, respectively, at the loud speech level.

The results were further analyzed using the paired-samples t test, with results shown in Table 4. The t value for the comparison between DSL [i/o] and ADRO was 2.462 at the moderate speech level (p < 0.05) and 8.7102 at the loud speech level (p < 0.001). The results demonstrate that there was a statistically significant difference (p < 0.05) between DSL [i/o] and ADRO at both moderate and loud speech levels.

Table 4. Statistical analysis of the VDR scores of the two prescriptions (DSL [i/o] and ADRO) at moderate and loud speech levels.

<table>
<thead>
<tr>
<th>Speech level</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate</td>
<td>2.462</td>
<td>7</td>
<td>0.043</td>
</tr>
<tr>
<td>Loud</td>
<td>8.7102</td>
<td>7</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

4. Discussion

Questionnaires are still the main method used to evaluate the speech quality experienced by hearing aid users. Questionnaires are effective and specific, but they also have some disadvantages due to their subjective nature, such as the possible ambiguity when the hearing aid user complains that the sound is unnatural. Moreover, they are normally costly and time-consuming. Therefore, an objective assessment method that provides a convenient, easy, rapid, and objective index of the distortion and speech quality of hearing aid processing would be helpful to audiologists; the proposed VDR method is such a method.

Experiment 1 revealed that PESQ scores are strongly correlated with subjective speech quality assessments [27] for a single-channel hearing aid in the case of flat mild hearing loss. The trends in PESQ and VDR scores with increasing CR were similar to those found in another laboratory-based study [29] with flat mild hearing loss. However, the most common type of hearing impairment is high-frequency hearing loss. Although the PESQ method could reliably assess the speech quality for flat mild hearing loss, it needs to be modified to allow for the effects of other types of hearing loss [27]. The proposed method provided an assessment trend similar to that obtained using clinical subjective methods [5, 29] and the PESQ method.
Many studies have reported that compression or expansion processing decreases speech quality [29,30]. The WDRC-based DSL[j/o] prescription reduces speech dynamic range and is likely to adversely affect speech quality [10,11]. Van Buuren et al. [29] found that speech quality was no higher for either compression or expansion procedures than for linear procedures, and Blamey et al. [10] found that fast-acting compression processing with high CRs distorted speech signals and thereby adversely affected speech quality. Clinical trials of ADRO and WDRC have also shown that the former provides clinically significant improvements in speech quality [11,37].

In Experiment 2, the VDR method was used to quantify the changes in Speechmaps produced by two real hearing aid amplifiers (implementing WDRC and ADRO). The VDR score was lower for ADRO than that for WDRC at both moderate and loud speech levels. This result was expected and reasonable given the design rationales of these two amplification schemes. ADRO is an adaptive linear amplification scheme that does not involve compression, instead merely shifting the entire Speechmap and hence preserving the dynamic range, whereas WDRC involves compression processing. As a result, the VDR score would theoretically be lower for ADRO than for WDRC. Based on the VDR scores found in the present study, the speech quality is higher for ADRO than for WDRC, which is highly consistent with information in the literature.

The results of Experiments 1 and 2 support the correctness of the VDR score. Therefore, the VDR score is a useful objective indicator for assessing the speech quality of signals processed by hearing aids, with a lower VDR score indicating less distortion and hence higher speech quality. One of the aims of this pilot study was to confirm that the VDR score is related to changes in the Speechmap and the speech quality. The VDR score was tested by evaluating the distortion between aided and unaided speech in the Speechmap, and this information was used to assess speech quality. Compression or expansion will produce distortion and decrease speech quality, and hence a higher VDR score is associated with lower speech quality. However, the current VDR method can only determine the speech quality at the stage of comparing. Therefore, in future a method that transforms the VDR score into a measure related to human perception, just as the MOS scales of PESQ, will be developed.

The concept of the VDR score could also be used as a reference for prescription design, such as when deciding which CR is optimal for a particular hearing-impaired individual in terms of minimizing the distortion and thereby maximizing the speech quality of a hearing aid for that person. The VDR score has the potential to predict the effect of certain prescriptions on aided speech in an individual subject, including by determining objective changes in the Speechmap and subjective preferences about speech quality. A limitation of this study is that the experiments involved software simulations only, without the use of any actual human subjects with hearing aids. Therefore, the overall effectiveness of the VDR method for real human subjects needs to be investigated in future studies.

5. Conclusion

This study proposed an objective VDR method for assessing the speech quality of hearing aids. In experiments, the method provided assessments of speech quality that were similar to those obtained using the PESQ method. In addition, the average VDR score was lower for ADRO than for WDRC at both moderate and loud speech levels. This implies that the speech quality is higher for ADRO than for WDRC, which is consistent with the clinical literature. The VDR method could therefore be a convenient and objective index for adjusting the parameters of hearing aids in order to provide higher speech quality for hearing aid users.

Acknowledgements

This research was supported by the National Science Council of Taiwan (grant no. NSC 100-2220-E-715-001). The authors would like to thank Hui-Chen Lee of Taipei Veterans General Hospital for help with the statistical analyses.

References


