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Preferred Low- and High-Frequency Compression Ratios among Hearing Aid Users with Moderately Severe to Profound Hearing Loss

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Abstract

This study aimed to determine the low- and high-frequency compression ratios of a fast-acting device that were preferred by people with moderately severe to profound hearing loss. Three compression ratios (1:1, 1.8:1, and 3:1) were combined in the low and high frequencies to produce nine schemes that were evaluated pair-wise for three weeks in the field using an adaptive procedure. The evaluation was performed by 21 experienced hearing aid users with a moderately severe to profound hearing loss. Diaries and an exit interview were used to monitor preferences. Generally, the subjects preferred lower compression ratios than are typically prescribed, especially in the low frequencies. Specifically, 11 subjects preferred linear amplification in the low frequencies, and 14 subjects preferred more compression in the high than in the low frequencies. Preferences could not be predicted from audiometric data, onset of loss, or past experience with amplification. The data suggest that clients with moderately severe to profound hearing loss should be fitted with low-frequency compression ratios in the range 1:1 to 2:1 and that fine-tuning is essential.

Key Words: Amplification, compression ratios, field evaluation, hearing aids, profound hearing loss, severe hearing loss, wide dynamic range compression

Abbreviations: 1/CR = inverse compression ratio; 3FA = three-frequency average; CR = compression ratio; CT = compression threshold; DRHFA = average dynamic range in the high frequencies; DRLFA = average dynamic range in the low frequencies; DSL[i/o] = Desired Sensation Level; FIG6 = Figure 6; HF = high frequency; HFA = high-frequency average; HTL = hearing threshold level; LDL = loudness discomfort level; LF = low frequency; LFA = low-frequency average; NAL-NL1 = National Acoustic Laboratories nonlinear version 1; NAL-RP = National Acoustic Laboratories revised for profound hearing loss; OSPL90 = output sound pressure level at 90 dB SPL input; REIG = real-ear insertion gain; WDRC = wide dynamic range compression

Sumario

Este estudio trató de determinar las tasas de compresión de alta y baja frecuencia de un dispositivo de acción rápida, que resultara preferido por personas con hipoacusias moderadamente severas a profundas. Se combinaron

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tres tasas de compresión (1:1, 1.8:1, y 3:1) en las frecuencias graves y agudas para producir nueve esquemas que fueron evaluados en el campo, en pares, durante tres semanas, utilizando un procedimiento de adaptación. La evaluación fue realizada por 21 usuarios experimentados de audífono con hipoacusias moderadamente severas a profundas. Se usaron diarios y un cuestionario final para monitorear las preferencias. Generalmente, los sujetos prefirieron menores tasas de compresión de lo que típicamente se prescribe, especialmente en las bajas frecuencias. Específicamente, 11 sujetos prefirieron la amplificación lineal en las frecuencias graves y 14 sujetos prefirieron más compresión en las frecuencias altas. Las preferencias no podían predecirse a partir de los datos audiométricos, del inicio de la pérdida, o por experiencias anteriores con amplificación. Los datos sugieren que los clientes con hipoacusias moderadamente severas a profundas, deberían adaptarse con tasas de compresión en las frecuencias graves en el rango de 1:1 a 2:1, y que un ajuste fino es esencial.

Palabras Clave: Amplificación, tasas de compresión, evaluación de campo, auxiliares auditivos, hipoacusia profunda, hipoacusia severa, compresión de rango dinámico amplio

Abreviaturas: 1/CR = tasa de compresión inversa; 3FA = promedio de tres frecuencias; CR = tasa de compresión; CT = umbral de compresión; DRHFA = promedio de rango dinámico en las frecuencias agudas; DRLFA = promedio de rango dinámico en las frecuencias graves; DSL[i/o] = Nivel Deseado de Sensación; FIG6 = Figura 6; HF = alta frecuencia; HFA = promedio de alta frecuencia; HTL = nivel de umbral auditivo; LDL = nivel de incomodidad sonora; LF = baja frecuencia; LFA = promedio de baja frecuencia; NAL-NL1 = Laboratorios Nacionales de Acústica – versión no lineal 1; NAL-RP = Laboratorios Nacionales de Acústica – revisado para hipoacusia profunda; OSPL90 = nivel de presión sonora de salida a 90 dB SPL de ingreso; REIG = ganancia de inserción de oído real; WDRC = compresión de rango dinámico amplio

A couple of decades ago, when a majority of hearing devices fitted to clients were linear and the focus was on optimizing the gain-frequency response for medium input levels, it was found that listeners with severe to profound hearing loss had different requirements than did listeners with milder loss. For example, while listeners with milder loss chose gain that approximated half the amount of threshold loss (Lybarger, 1944; Byrne and Fifield, 1974; Berger et al, 1980; Lyregaard, 1988; Pascoe, 1988), listeners with severe and profound hearing loss chose additional gain (Schwartz et al, 1988; Byrne et al, 1990). Further, listeners with profound hearing loss generally benefited from having the maximum output level controlled by peak clipping while compression limiting was preferred by listeners with milder loss (e.g., Dawson et al, 1991). This is probably because the greater output level that a peak clipper produced relative to compression limiting more than compensated for the peak clipper's increased distortion for an individual with a profound hearing loss (Dillon, 2001).

Currently, most commercial hearing aids provide wide dynamic range compression (WDRC) in two or more independent frequency bands. From a theoretical point of view, WDRC should be beneficial in particular to the severe to profound hearing loss group because it enables a wide range of input levels to be made audible within this group's very narrow range of residual hearing. Unfortunately, the high gain levels required by this group to make soft sounds audible are likely to cause acoustic feedback. Adjustments made to avoid feedback, if carried out on a broadband basis, may result in loudness insufficiency occurring (Barker et al, 2001). Multiple frequency channels and feedback cancellation offered in newer devices help to somewhat overcome these particular problems.

As the number of devices offering WDRC increased during the 1990s, several prescription procedures for fitting nonlinear hearing aids, both generic and proprietary, were presented: Loudness Growth of Octave Bands (LGOB) by Allen et al (1990), Figure 6 (FIG6) by Killion and Fikret-Pasa (1993), the Independent Hearing Aid Fitting Forum (IHAFF) by Cox (1995), Desired Sensation Level (DSL[i/o]) by Cornelisse et al (1995), Adaptive Speech Alignment (ASA) by Schum

(1996), Widex Senso Loudness Mapping by Ludvigsen (1997), and National Acoustic Laboratories nonlinear version 1 (NAL-NL1) by Dillon (1999). The majority of these procedures have the overall aim of compensating for loudness recruitment across frequencies. Such procedures tend to prescribe a low compression threshold (CT) and compression ratios (CRs) that increase with increasing hearing threshold levels, or decreasing dynamic range. Investigations comparing WDRC to linear amplification in the population with severe to profound hearing loss have yielded mixed outcomes. In particular, several studies have shown that speech intelligibility in the severe to profound hearing loss population decreased when tested with WDRC relative to linear amplification, although when improvements were observed they were restricted to a few specific conditions (for a review, see Souza, 2002). This is thought to be because the compression parameters needed to make the entire speech signal audible for this group (i.e., low CTs, high CRs, and multiple channels) distort important spectral and temporal cues (De Gennero et al, 1986; Verschuure et al, 1993; Plomp, 1994; Souza, 2002).

A recent study by Souza et al (2005) confirmed that, when compared to linear amplification, multichannel WDRC does not improve speech performance for listeners with severe to profound hearing loss. In this study, 13 adults with a three-frequency-average hearing loss (3FA) ranging from 67 to 92 dB HL were tested. Each subject completed speech recognition tests and a paired comparison test of sound quality preference with four simulated schemes: linear amplification with compression limiting, linear amplification with peak clipping, two-channel WDRC, and three-channel WDRC. The gain-frequency response in all schemes was shaped to the average between the National Acoustic Laboratories (revised, profound) prescription (NAL-RP) and NAL-NL1 for a 70 dB SPL input level. In the WDRC schemes, the CT was fixed at 45 dB SPL, and the CR was set to 3:1 in all channels. Overall, the subjects performed best with the compression limiting scheme, a significantly better performance than with the three-channel WDRC scheme.

On the contrary, four recent studies have suggested that hearing aid users with a severe to profound hearing loss do not perform more poorly with WDRC than with linear amplification across a range of outcome measures, and that in some cases WDRC was significantly better than or preferred to linear amplification (Kam and Wong, 1999; Ringdahl et al, 2000; Barker et al, 2001; Marriage et al, 2005). For example, Kam and Wong (1999) measured the subjective preference for WDRC or linear amplification with respect to loudness, sound clarity, pleasantness, and speech intelligibility in quiet and in noise for low, medium, and high speech levels. In all, 14 adults whose 3FA ranged from 56 to 70 dB HL were fitted according to FIG6 with the single-channel Phonak Piconet P2 AZ device. They found that WDRC was superior to linear amplification for speech intelligibility in quiet for low-level speech, for loudness perception of both high- and low-level speech, and for pleasantness of high-level speech. In the other test conditions, there was no significant difference between WDRC and linear amplification. In the study by Ringdahl et al (2000), 25 adults with an average 3FA hearing loss of about 85 dB HL compared WDRC (proprietary prescription) with linear amplification (NAL-RP) implemented in the three-channel Widex Senso P device. The test device was also compared with the subject's own linear analog device. The three schemes were evaluated in the subjects' own environments using questionnaires and diaries. Speech recognition tests in quiet and in noise were completed in the laboratory. The subjects performed significantly better with the WDRC scheme in quiet. After the evaluation of each scheme in the field, 17 subjects chose the test device implemented with WDRC. The remaining subjects preferred linear amplification as implemented in either the test device (5) or in their own aid (3). Barker et al (2001) found that ten out of sixteen subjects with moderately severe to profound hearing loss (the average loss measured across 0.5, 1, 2, and 4 kHz ranged between 63 and 110 dB HL) preferred 2:1 WDRC over linear amplification as implemented in a single-channel device in their everyday environments. Most of these subjects were fitted with a relatively high CT of around 60 dB SPL, either because this was preferred to a lower CT of about 45 dB SPL or because a low level CT could not be achieved due to feedback. Finally, Marriage et al (2005) tested speech perception (word, sentence, and phrase) in 20 children fitted with multichannel WDRC, linear amplification with output limiting, and linear amplification with peak clipping. The device and prescription procedure used were the five-channel Phonak Supero 412 and DSL, respectively. The children's average loss measured across 1, 2, and 4 kHz ranged from 60 to 118 dB HL. It was reported that for one speech test, children with a profound hearing loss showed a significant benefit from WDRC. In the remaining conditions there was no significant effect of amplification scheme. It was further observed that some children reported a benefit from WDRC when listening to speech in quiet, but they did not like the increased audibility of background noise in noisy environments. It is worth noting that commercial devices were used in each of these four studies, whereas the studies reviewed in Souza (2002) and Souza et al (2005) were based on master hearing aids. Also, some of the studies summarized above used relatively conservative settings of the hearing aid parameters (e.g., high CT, few channels, slow time constants) compared to the parameters used in the studies reviewed in Souza (2002), or did not include individuals with profound hearing loss.

Thus, a question remains to be answered with respect to the optimum compression parameters for listeners with severe to profound hearing loss. Is it possible that, as with prescription of linear amplification and output limiting, we need to take a different approach when selecting the compression parameters for hearing aid users with more severe loss? Maybe, contrary to intuition, the CR should only increase with hearing threshold level until a certain degree from which the optimum ratio reaches a plateau (remains constant) or starts decreasing. Currently, very little information is available about the hearing aid user's preferred CRs in different frequency bands. In particular, we are not aware of any studies that have investigated the preference for CRs among hearing aid users with severe to profound hearing loss. The aim of the study presented here was to determine the preferred CRs in the low and high frequencies by experienced hearing aid users with a moderately severe to profound hearing loss when listening in their everyday environments. Another objective was to study if the preferred CRs could be predicted from some simple audiological data.

METHODOLOGY

Subjects

Twenty-one experienced hearing aid users (7 females and 14 males) were recruited as subjects. All subjects had a sensorineural hearing loss and type A tympanograms. According to the 3FA measured across 0.5, 1, and 2 kHz, 12 subjects had a moderately severe loss (55 dB HL < 3FA ≤ 75 dB HL), and nine subjects had a severe to profound loss (75 dB HL < 3FA < 95 dB HL). Based on the difference between the high-frequency average (HFA) loss measured across 2, 3, and 4 kHz and the low-frequency average (LFA) loss measured across 0.25, 0.5, and 1 kHz, six subjects with a moderately severe loss displayed a flat configuration (-10 dB HL < [HFA - LFA] ≤ 15 dB HL), and six displayed a sloping configuration (15 dB HL < [HFA - LFA] < 40 dB HL). For subjects with a severe to profound loss, the distribution was four flat and five sloping configurations. Fourteen subjects were bilateral hearing aid users, and six subjects were unilateral users who were fitted in their better ear when the difference in 3FA hearing loss across ears exceeded 10 dB. One subject (22) wore a cochlear implant in one ear and a hearing aid in the other.

Of the 21 subjects, eight had a congenital hearing loss, and 13 had a loss that was acquired. At the time of recruitment, ten subjects were wearing WDRC, and 11 subjects (including six with a congenital hearing loss) were wearing linear amplification. This was established by graphing the subjects' own devices in a 2 cc coupler using five input levels. Four of the subjects fitted with WDRC were fitted with a relatively high CT of 55 dB SPL or above. On average, the 3FA hearing loss was higher for subjects with a congenital hearing loss (79.8 dB HL) and subjects fitted with linear amplification (76.1 dB HL) than for subjects with an acquired hearing loss (69 dB HL) and subjects fitted with nonlinear amplification (69.8 dB HL). Subjects' ages ranged from 21 to 82 years with a median age of 62 years. A summary of subject data is shown in Table 1.

Dynamic Range

As part of the assessment, the subjects' average dynamic ranges in the low (DRLFA)

Table 1. Subject Data

ID	Age (years)	Onset of loss	Own device	Previous amplification	Fitted ear/s	Hearing threshold levels (dB HL) 0.25 kHz	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	6 kHz
1	57	acquired	Widex Senso P8	nonlinear	Left	55	50	60	60	70	90	105
					Right	50	45	60	80	85	85	100
2	63	congenital	Phonak Sono Forte	linear	Left	65	85	90	75	70	80	75
					Right	30	75	80	80	70	75	75
3	82	acquired	AH SB 13	nonlinear	Left	45	45	60	80	80	75	85
4	82	acquired	AH SB 13	linear	Left	55	55	55	70	60	70	80
5	76	acquired	Siemens Prisma	linear	Left	55	65	60	70	60	65	60
					Right	70	70	60	60	65	70	75
6	73	acquired	AH LS 16	nonlinear	Left	60	65	75	70	70	90	105
					Right	60	70	75	80	70	85	95
8	73	acquired	AH LS 14	nonlinear	Left	55	60	60	80	100	105	95
9	61	acquired	Siemens Triano	nonlinear	Left	90	85	80	90	85	85	85
					Right	90	85	90	95	100	95	90
10	33	congenital	Siemens S3	linear	Left	55	75	70	90	100	90	100
					Right	55	70	80	85	85	85	90
11	80	acquired	AH SB 13	linear	Left	70	70	60	65	60	75	80
					Right	70	75	70	70	60	70	75
12	21	congenital	AH PB 675	linear	Left	85	85	90	90	85	95	95
					Right	80	80	85	80	70	80	80
13	37	congenital	Oticon 380 P	linear	Left	85	90	90	95	95	120	NM
					Right	85	85	90	90	95	NM	NM
14	55	congenital	Phonak Sono Forte	linear	Left	70	75	90	85	100	115	115
					Right	60	60	95	90	110	115	110
15	71	congenital	AH SB 13	nonlinear	Right	55	55	75	80	80	85	75
17	21	congenital	AH RB 15	nonlinear	Left	55	60	75	80	75	85	70
					Right	55	60	75	80	75	85	80
18	67	acquired	AH PB 675	linear	Left	60	65	75	75	65	80	115
					Right	50	60	70	65	70	75	120
19	67	acquired	AH LS 16 D	nonlinear	Left	80	75	60	65	60	65	70
20	52	congenital	AH PB 675	linear	Left	85	80	75	85	95	120	NM
22	70	acquired	AH PB 675	linear	Right	25	80	75	115	90	95	NM
23	76	acquired	Resound Canta780D	nonlinear	Left	75	70	70	90	100	105	NM
					Right	70	80	75	80	95	95	95
24	81	acquired	Siemens Music Pro	nonlinear	Left	50	50	65	65	65	85	90
					Right	50	55	80	70	80	80	95

Note: AH = Australian Hearing, NM = not measurable.

and high (DRHFA) frequencies were measured across 0.5 and 1 kHz, and 2 and 4 kHz, respectively. This was done by obtaining measurements of the subjects' loudness discomfort level (LDL) with warble tones and subtracting from these the measured hearing threshold levels (HTL). Using a seven-point categorical scale, the subject reported the loudness of the tone, and the ascending order of presentation levels was concluded when the uncomfortably loud category was reached. The tones were presented in 4 dB steps until the subject reported that the tone sounded loud, and then the step size was reduced to 2 dB. The test was repeated four times for each frequency with the starting level selected randomly for each repetition. At the conclusion of the test, the median level that was rated uncomfortably loud was determined. If the uncomfortably loud category was not reached before the limit of the audiometer, then the LDL recorded was the maximum level the audiometer could produce at that frequency plus 5 dB. On average, the subjects' dynamic range was 40.9 dB and 30.7 dB across the low and high frequencies, respectively, ranging from 21 to 57.5 dB in the low frequencies and from 12.5 to 49 dB in the high frequencies.

Test Devices and Earmolds

The test device was the ReSound Canta 780D. This device is a high power, multimemory, multichannel WDRC device with a fixed broadband CT of about 55 dB SPL and fast time constants (5 msec attack and 70–120 msec release). The proprietary fitting software (Aventa, version 1.53) allows gain to be adjusted for two input levels (50 and 80 dB SPL) at six frequencies (0.25, 0.5, 1, 2, 4, and 6 kHz). The gain difference for 50 and 80 dB SPL input is limited to 20 dB at each frequency, which means that CRs can be implemented only in the range of 1 (linear) to 3. Relative to the maximum output level, the output level can be reduced by up to 9 dB at each of the six frequencies mentioned above. Selective features in the test device include feedback canceling, fast-acting noise reduction, microphone directionality, telecoil, and volume control.

New earmolds were made for all subjects at the start of the study. In selecting the earmold style and material, the subject's hearing loss and preference were taken into consideration.

Baseline Response and Fitting

The subjects were initially fitted with a baseline response that was shaped according to either the proprietary (Audiogram+) or the NAL-RP (Byrne et al, 1990) prescription. Across the subjects, NAL-RP, on average, prescribed higher gain than Audiogram+ by 3.3, 3.8, 3.4, 4.1, 9.0, and 13.1 dB at 0.5, 1, 2, 3, 4, and 6 kHz, respectively. Across frequencies, the standard deviation varied from 2.7 dB at 0.5 kHz to 6.2 at 6 kHz. For each subject, targets for both prescriptions (Audiogram+ and NAL-RP) were calculated for a 70 dB SPL input. If the difference curve between the two prescriptions for this input level produced a slope no more than (1) 3 dB/octave from 0.25 to 4 kHz, and (2) 10 dB/octave in any one octave band between 0.25 and 4 kHz, then the Audiogram+ target was used. If the slope of the difference curve exceeded those values, then the subject was fitted with both prescription, and an informal comparison of the two responses was performed.[1] The comparison was made by listening to the experimenter's voice (male), the subject's own voice, recorded traffic noise, recorded male speech in babble noise, and a piece of acoustic/classical music with both programs. If the subject had a clear preference for one of the two responses, the preferred prescription was used as the baseline response. If there was no clear preference based on this comparison test, Audiogram+ was used as the baseline response. The informal comparison of Audiogram+ and NAL-RP was performed by 11 subjects. In all, 14 subjects were fitted with the Audiogram+ response shape, and seven subjects were fitted with the NAL-RP response shape.

Subjects who were wearing linear amplification when recruited were fitted with a linear response, and subjects who were wearing nonlinear amplification were fitted with the proprietary prescribed compression characteristic. The selected baseline response was verified with real-ear insertion gain (REIG) measurements to the appropriate target for a 65 dB SPL input using speech-weighted noise as test signal. It should be noted that where the fitting process was complicated due to leakage created by the probe tube, this was overcome by using liberal amounts of earmold lubricant and/or using a narrow diameter probe tube. Subjective evaluation of the hearing aid output was carried out using a range of broadband stimuli (a low-frequency weighted traffic noise, a high-frequency weighted impulse noise ["ping/clang"], a rattle of popping corn, and speech) to ensure neither loudness discomfort nor problems with output insufficiency occurred.

Adjustment Period

After the fitting of the selected baseline response, subjects were given three weeks to adjust to the test device in their own environments. During the adjustment period, feedback canceling was enabled, noise reduction was disabled, and the omnidirectional microphone was selected. One week following fitting, subjects attended a follow-up appointment to review their progress and resolve any difficulties experienced with the device(s) such as feedback, occlusion effect, mold comfort, and preferred gain. Gain adjustments were made for seven subjects (2, 4, 6, 18, 20, 22, and 23). For six of these subjects, gain was increased by 3 to 10 dB at frequencies below 1 kHz. For the remaining subject (22), gain was reduced 5–10 dB at all frequencies above 0.5 kHz. If required, the adjustment period was extended to ensure any problems were resolved before the comparison of test schemes commenced. Subjects were given access to the hearing aid volume control and telecoil during the adjustment period.

Compression Schemes

Nine test schemes comprising three levels of compression (1:1, 1.8:1, and 3:1) in the low frequencies (0.25, 0.5, and 1 kHz) combined with the same three levels of compression in the high frequencies (2, 4, and 6 kHz) were included for evaluation (see Figure 1). These three ratios provided a choice between the traditional linear setting, a moderate CR corresponding to that prescribed, on average, in the low frequencies for the subject group by NAL-NL1 and Audiogram+ (1.8:1), and a high CR (3:1) prescribed by many loudness normalization procedures in the low or high frequencies. For each individual, all test schemes used the fine-tuned baseline response shape and produced the same output for a 65 dB SPL speech input as verified by REIG measurements. The output setting also remained the same, unless the subjective evaluation of output (described above) that was carried out for each scheme suggested otherwise. The test schemes were implemented using feedback canceling where needed, but noise reduction, directionality, and the volume control were disabled. Throughout the paper, the test schemes will be referred to by the CR implemented in the low frequencies (LF) followed by the CR implemented in the high frequencies (HF): (CR LF, CR HF).

Field Evaluation

The test schemes were evaluated through two tournaments in the field using an adaptive paired comparison procedure by implementing two compression schemes at a time into two memories of the test device.

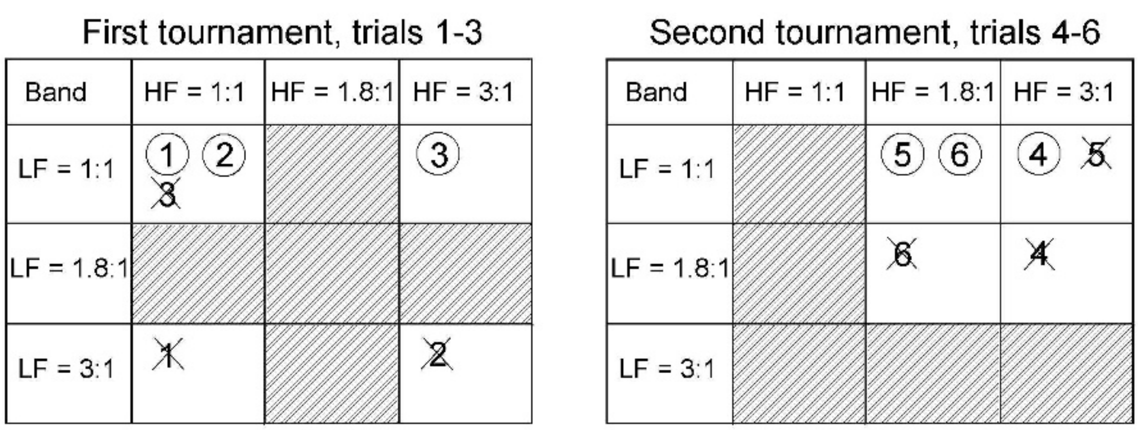

Figure 1. An overview of the nine test schemes and an example of the execution of the two tournaments. The numbers in the cells indicate the test period in which the compression characteristic was evaluated. A circle around the number indicates that the compression characteristic was preferred to that compared and hence included in the next test period. A cross through the number indicates that the compression characteristic was not preferred and therefore excluded from subsequent evaluations. The shaded cells indicate compression characteristics that were not included in the evaluation for that tournament. See text for further explanation.

Each tournament comprised three consecutive three-week test periods. After each test period, the preferred scheme proceeded to the next field test, in which it was compared to a new scheme, while the rejected scheme was discarded from the evaluation. An example is outlined in Figure 1. In the first tournament, all subjects compared the four schemes that included all combinations of linear amplification and 3:1 compression (i.e., the four corner schemes in Figure 1). Subjects who adjusted to the test device wearing linear amplification first compared the (1:1, 1:1) scheme with the (1:1, 3:1), (3:1, 1:1), or (3:1, 3:1) scheme, selected in a balanced way across these subjects. Subjects who adjusted to the test device wearing nonlinear amplification first compared whichever of schemes (1:1, 3:1), (3:1, 1:1), and (3:1, 3:1) was closest to the proprietary prescribed compression characteristics with one of the remaining three schemes selected in a balanced way across these subjects. This starting point ensured that no subject was severely disadvantaged during the study by wearing two greatly unacceptable amplification characteristics. In the example shown in Figure 1, the (1:1, 1:1) and (3:1, 1:1) schemes were compared in the first field test. The winner was the (1:1, 1:1) scheme that subsequently was compared with the (3:1, 3:1) scheme in the second field test. The (1:1, 1:1) scheme was again the winner and was finally compared with the (1:1, 3:1) scheme that was the winner of the third and last field test of the first tournament.

In the second tournament, the subjects completed a pair-wise comparison of their preferred corner scheme with each of the three adjacent compression schemes, including 1.8:1 compression, in the same adaptive manner as above. In the example shown in Figure 1, the winning corner scheme (1:1, 3:1) was first compared to the (1.8:1, 3:1) scheme in the fourth field test. As the (1:1, 3:1) scheme again was the winner, it was subsequently compared to one of the remaining adjacent schemes, in this case the (1:1, 1.8:1) scheme. With the (1:1, 1.8:1) scheme as the winner of the fifth field test, this scheme was then compared to the (1.8:1, 1.8:1) scheme, which was rejected in the sixth and final field test. In this example, the (1:1, 1.8:1) scheme was the overall winner. Due to this test procedure, no subject evaluated more than seven of the nine test schemes.

During the test period, the subjects were instructed to make a thorough comparison of the schemes in six individually selected listening situations experienced on at least a weekly basis. Where possible, the six situations included a one-to-one conversation in quiet situation, a comfort in noise situation (typically shopping at the supermarket, or driving in a car), and a group conversation situation. After each comparison, the subject was asked to fill in a diary form in which the performance of each scheme was rated on a scale from 0 (very poor) to 10 (very good). A copy of the diary form is shown in Appendix 1. Following each test period, an exit questionnaire (Appendix 1) was also completed. Subjects were asked about their preferred program and preference strength, perceived difference (if any) between the programs they had just evaluated, their overall preference in quiet and loud situations, and the volume of their own voice. Usage and technical difficulties encountered during the test period were also recorded.

Throughout the evaluation, the subjects had access to a telecoil program in a third memory of the test device. However, this program did not form part of the evaluation.

RESULTS

Figure 2 shows how closely the fine-tuned responses obtained for a 65 dB SPL input, on average, matched both prescriptive targets. The results are shown separately for subjects fitted with Audiogram+ and subjects fitted with NAL-RP. For both subject groups, the fittings were closer to the Audiogram+ target than the NAL-RP target. Generally, subjects were underfitted in the high frequencies, especially relative to the NAL-RP target. The most common reasons for the deviations from the target were feedback and the electroacoustic characteristic of the test device, which had a dip around 3 kHz. Table 2 lists the average inverse compression ratios (1/CRs)[2] achieved across the low and high frequencies. There was no difficulty achieving the linear or 1.8:1 CRs. However, on average, a slightly lower than 3:1 CR was achieved, especially in the low frequencies (2.6:1). This was usually because maximum gain was reached for the 50 dB SPL input level at one or more frequencies.

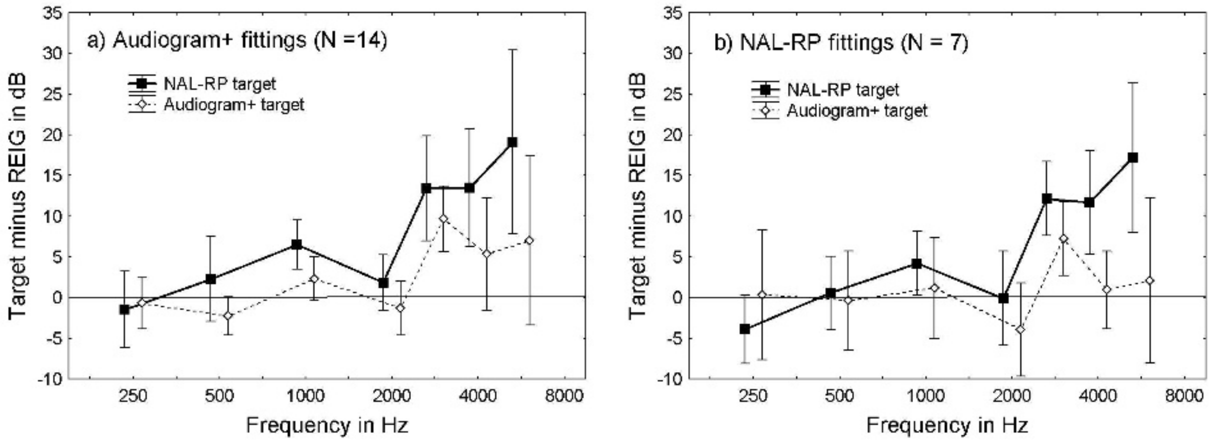

Figure 2. The average difference between Audiogram+ and NAL-RP targets and the REIG of the fine-tuned responses for subjects fitted according to (a) the Audiogram+ prescription and (b) the NAL-RP prescription. The bars show ±1 SD.

Figure 3 shows how the average output sound pressure level for a 90 dB SPL input (OSPL90) measured across the low (0.25, 0.5, and 1 kHz) and high (2, 3, and 4 kHz) frequencies for schemes with 1.8:1 and 3:1 compression related to the OSPL90 level measured in the same frequency bands for linear amplification. For most subjects, the OSPL90 level was reduced by 10–20 dB when compression was implemented. This suggests that for most subjects, input levels above 90 dB SPL were required to saturate the hearing aid.

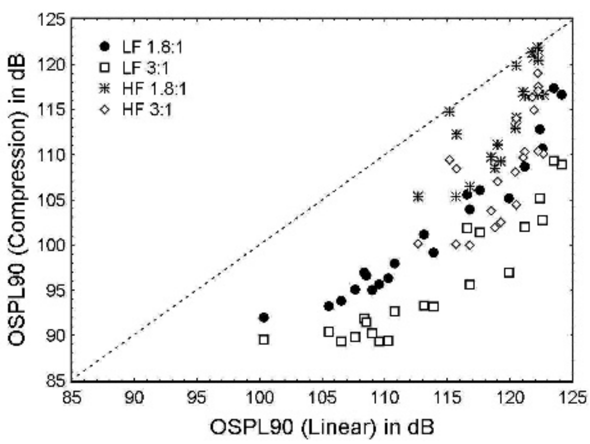

Figure 3. The average OSPL90 levels measured across the low and high frequencies when 1.8:1 or 3:1 compression was implemented as a function of the average OSPL90 levels measured for linear amplification in the same frequency bands. The levels refer to a 2 cc coupler.

Preferences

At the end of the first tournament, the (1:1, 3:1) scheme was the overall winner for nine subjects, while seven subjects chose linear amplification and five subjects chose the (3:1, 3:1) scheme. No subjects selected the (3:1, 1:1) scheme. If the winning scheme had been chosen by pure chance, one would have expected that each of the four corner schemes had been chosen by 25% of subjects (5.25 persons). According to a chi-square test, the observed subject distribution across the four schemes was significantly different from that expected by pure chance ($\chi = 8.52$, $p < 0.036$).

Using the preference strength (no difference, hardly any difference, better, or much better) reported in the exit interview after each field test, the four corner schemes were ranked from most (1) to least (4) preferred for each subject. Whenever the preference strength indicated a tie between two schemes, these schemes shared a ranking score. For example, subject 24 first compared the linear scheme with the (1:1, 3:1) scheme. The subject chose the (1:1, 3:1) scheme and reported this scheme to be "hardly any different" from linear. In the following two trials, the (1:1, 3:1) scheme was compared to the (3:1, 1:1) and (3:1, 3:1) schemes, respectively. At the end of both these trials, the (1:1, 3:1) scheme was preferred and reported to be "better" than the (3:1, 1:1) and (3:1, 3:1) schemes. That is, the (1:1, 3:1) scheme was the overall winner, and the

Table 2. The Mean of the Inverse of the Actual CRs Implemented for Subjects in Each Frequency Band

Band	CR = 1 (1/CR = 1.0)	CR = 1.8 (1/CR = 0.56)	CR = 3 (1/CR = 0.33)
Low frequency	1.0 (0.00)	0.57 (0.02)	0.38 (0.06)
High frequency	1.0 (0.00)	0.56 (0.01)	0.35 (0.02)

Note: The standard deviation values are shown in parentheses.

preference for the (1:1, 3:1) scheme was equally strong when compared to the latter two schemes than when compared to the linear scheme. Hence, for this subject, the (1:1, 3:1) scheme was assigned a ranking score of 1; linear received a ranking score of 2; and, as there was a tie between the (3:1, 1:1) and the (3:1, 3:1) schemes, they each received a ranking score of 3.5. Fourteen subjects produced a tie between two schemes, and one subject produced a tie between three schemes. Figure 4a shows the average ranking score that each of the four schemes received. According to a Friedman analysis of variance, there was a significant difference in the ranking order ($p = 0.003$), with the (1:1, 3:1) scheme ranked highest, on average, and the (3:1, 1:1) scheme ranked lowest. The Kendall coefficient of concordance (W), which expresses the degree of agreement between subjects in ranking the four schemes, was a moderate 0.22 (range from 0 to 1). As the sum of squares of the observed deviations from the mean of the sum of ranks ($s = 436$) was greater than the critical value for the 5% level of significance, $s(4,21) \approx 270$, the association between subjects was, however, considered significant (Siegel, 1956). That is, the ranking order of schemes was somewhat consistent across subjects. Overall, the outcome of the first tournament suggested that differences in CRs affected preferences and that a general lower CR was preferred in the low than in the high frequencies.

At the end of the second tournament, the (1:1, 1.8:1) scheme was the overall winner for seven subjects, and the (1.8:1, 1.8:1) and the (1.8:1, 3:1) schemes were the overall winners for four subjects each. Three subjects chose the (1:1, 3:1) scheme, while linear amplification, the (1.8:1, 1:1) scheme, and the (3:1, 3:1) scheme were each chosen by one subject (see Table 3). According to Table 3, there were also proportionally more preferences for the (1.8:1, 1.8:1) scheme (44% of subjects who evaluated it preferred it to another three schemes) than for any of the other schemes (percentages varied from 33% for the [1:1, 3:1] scheme to 0% for the [3:1, 1.8:1] scheme). In this case, the criterion for the chi-square test (that at least 80% of the expected frequencies are greater than five) was not met. Consequently, the observed

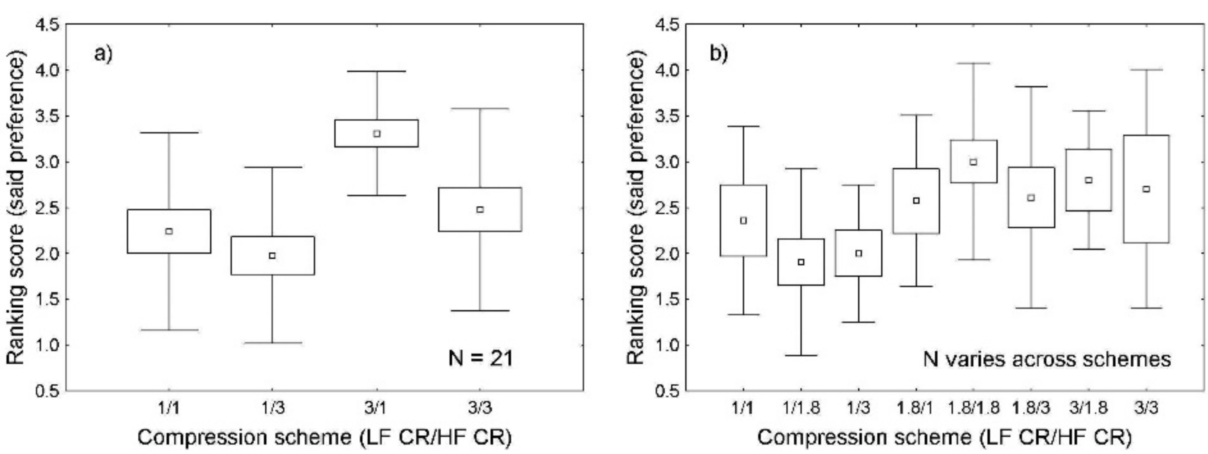

Figure 4. The average ranking score obtained based on reported preference and preference strength for each scheme compared (a) in the first tournament and (b) in the second tournament. The most preferred scheme has the lowest ranking score. The boxes show ±1 SE and the whiskers show ±1 SD.

Table 3. The Number of Subjects Who Selected Each Scheme as the Overall Winner at the End of the Second Tournament

Band	HF = 1:1	HF = 1.8:1	HF = 3:1
LF = 1:1	1 (7)	7 (16)	3 (9)
LF = 1.8:1	1 (7)	4 (21)	4 (14)
LF = 3:1	0 (0)	0 (5)	1 (5)

distribution could not be tested statistically against the expected distribution.

Again, based on the reported preference strength, the four schemes evaluated by each subject in the second tournament were ranked from most (1) to least (4) preferred. In this case, seven subjects produced a tie between two schemes; two subjects produced two pairs of ties; and one subject produced a tie between three schemes. On average, the (1:1, 1.8:1) and the (1:1, 3:1) schemes were most preferred (see Figure 4b). However, according to a Kruskal-Wallis ANOVA by ranks test, the average ranking scores across schemes were not significantly different ($p = 0.1$). Neither was there a significant trend within each group of flat, sloping, moderately severe, or severe to profound loss based on fourteen, seven, twelve, and nine subjects, respectively ($p > 0.28$). The nonsignificant results are likely due to a combination of a variable number of observations obtained across schemes, a greater number of schemes being part of the second tournament, fewer marked preferences (i.e., lower preference strengths, due to smaller differences between the schemes compared), and individual differences in preferences. In summary, the findings suggest that the subjects in general ranked linear amplification in the low frequencies highly, and generally rejected less compression in the high than in the low frequencies. However, the preferences were somehow unique to the individuals.

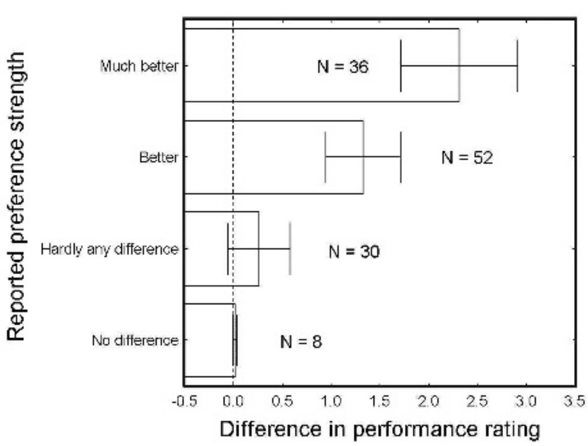

Figure 5. The relationship between the preference strength chosen between the preferred and the rejected schemes in the exit questionnaire and the difference in performance rating of the same schemes from the diary forms. The whiskers show the 95% confidence bands.

Performance Ratings

After each test period, the performance ratings from the diaries were averaged across listening situations for each scheme. Figure 5 shows the relationship between the average difference in performance rating between the preferred and the rejected scheme and the average preference strength reported at the exit interview. The good relationship between these two parameters suggests that the subjects were consistent when evaluating the schemes. In 89% of the 63 comparison trials conducted during the first tournament, the subjects reported a preference for the scheme to which they gave the highest average performance rating. This percentage dropped to 83% in the second tournament where the schemes compared varied less in gain applied across input levels. In both tournaments, the inconsistent responses were produced by different subjects in different field tests and were not related to a particular pair of schemes. Overall, for the inconsistent cases (18 in all), the difference in performance rating was less than or equal to 0.2 units in 11 cases and was less than or equal to 0.5 units in 15 cases, confirming that the subjects found the performance of each scheme in these cases about equal. Ranking the schemes based on performance rating revealed the same outcome as presented above on the basis of preference strength.

Prediction of the Preferred CRs

Although there was a heavy weighting of preferences toward linear amplification in the low frequencies and 1.8:1 compression in the high frequencies, these CRs were not preferred by all subjects. Given the variation in several audiologic parameters across the subject group, an investigation was performed into the possible prediction of the individually preferred CRs in the low and high frequencies. For the compression scheme(s) ranked highest according to reported preference and preference strength at the end of the second tournament, the actual 1/CR in the low and high frequencies, respectively, was calculated for each subject. In three cases where two or three schemes were equally preferred according to the reported preference strength, the 1/CRs were further averaged across schemes. A Spearman Rank order correlation analysis revealed no significant correlation between the preferred 1/CR in either band and various audiometric parameters, including the HTL at 0.5 kHz, HTL at 4 kHz, 3FA, LFA, HFA, slope, DRLFA, and DRHFA ($|r| < 0.27$; $p > 0.05$).

A multi-regression analysis using the preferred 1/CR as the dependent variable and the audiometric parameters above as independent variables produced no significant model ($p > 0.16$). That is, no combination of the audiometric parameters could predict the preferred 1/CR either in the low- or in the high-frequency band better than pure chance.

Further, the Mann-Whitney U test showed no significant difference ($p > 0.28$) between the preferred 1/CRs across onset of loss (acquired vs. congenital) or past experience with amplification (linear vs. nonlinear).

Figure 6 shows the preferred 1/CRs for each of the two frequency bands as a function of the average hearing loss. A closer look at the filled circles in Figure 6a reveals that all five subjects with a LFA HTL above 75 dB HL preferred linear amplification (1/CR = 1); five subjects with a LFA HTL around 70 dB HL preferred about 1.8:1 compression (1/CR = 0.56); and of the remaining 11 subjects with a LFA HTL of 67 dB HL and below, half selected linear amplification and half selected 1.8:1 compression. This pattern may suggest that in the low-frequency band there is a nonlinear relationship between the two parameters, where the optimum CR falls between linear and 1.8:1 compression in an increasing manner (1/CR decreases) when the LFA HTL increases from a moderate to severe loss after which the optimum CR decreases (1/CR increases) to reach linear for a profound hearing loss (see Figure 6a).

Also shown in Figure 6 are the average prescribed 1/CRs by Audiogram+ and NAL-NL1. The NAL-NL1 prescribed CRs were obtained with the NAL-NL1 stand-alone software version 1.4 using two frequency channels, a wideband CT of 55 dB SPL, and wideband limiting. Both procedures tend to prescribe an increasingly higher CR (lower 1/CR) with increasing HTL in the low frequencies. A similar pattern is seen for Audiogram+ in the high frequencies where NAL-NL1 tends to prescribe a decreasing

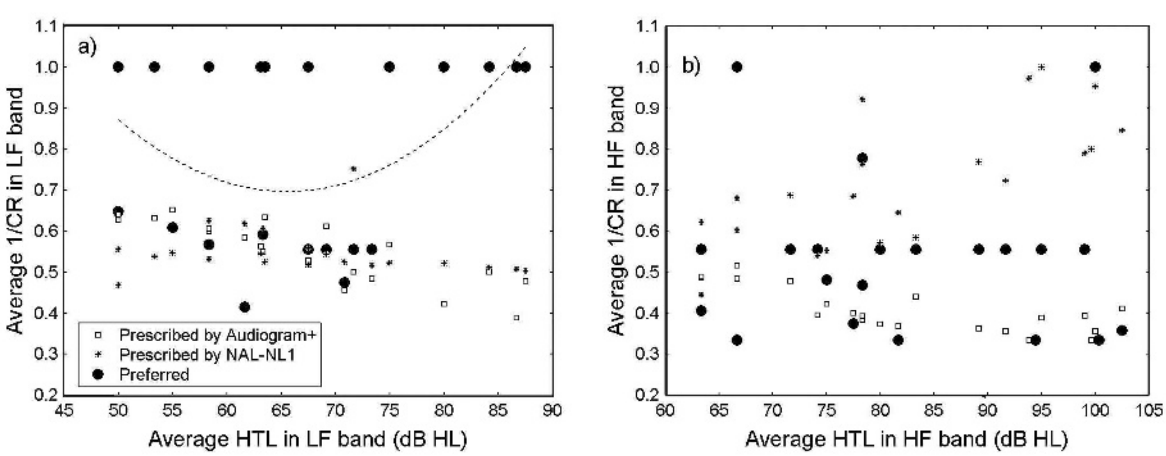

Figure 6. The average preferred 1/CRs (filled circles) and the prescribed 1/CRs by Audiogram+ (open squares) and NAL-NL1 (asterisk) as a function of the average hearing loss across (a) the low frequencies and (b) the high frequencies. The broken line in (a) shows the quadratic polynomial fit to the preferred 1/CRs.

CR (increasing 1/CR) with increasing HTL. This trend is an inherent consequence of the way NAL-NL1 was derived, to maximize predicted intelligibility while controlling loudness, and is not based on any additional assumptions or empirical findings. Note that many subjects preferred CRs lower than those prescribed by both Audiogram+ and NAL-NL1 in the low frequencies. Subjects with a severe to profound hearing loss in the high frequencies were more likely to prefer CRs lower than those prescribed by Audiogram+ but higher than those prescribed by NAL-NL1.

DISCUSSION

The findings of this study suggest that listeners with moderately severe to severe to profound hearing loss preferred lower CRs than would intuitively be prescribed, or would be prescribed by many generic and proprietary fitting methods, especially in the low frequencies and especially for subjects with a severe or profound hearing loss. For example, across this subject group, the average preferred CR in the low frequencies was 1.3:1 compared to 1.8:1 prescribed by both Audiogram+ and NAL-NL1. In the high frequencies, the average preferred CR was 1.9:1 compared to 2.5:1 and 1.4:1 prescribed by Audiogram+ and NAL-NL1, respectively.

As all test schemes provided the same output for a midlevel sound input (65 dB SPL), the differences between schemes were most pronounced for low and high input levels. That is, the more compression that was applied in a frequency band, the more the low-level sounds were emphasized and the more the high-level sounds were reduced in that band relative to linear amplification. There is some indication in the literature that hearing aid users who have not been exposed to weak environmental sounds for some time do not always appreciate their existence and therefore prefer a lower CR and/or a higher CT (Dillon et al, 1998; Ringdahl et al, 2000; Marriage et al, 2005). During the field tests, subjects were invited to describe the performance of the two schemes in the listening situations in which the performance of the schemes was rated. Often, however, the comments were comparative (e.g., scheme A is slightly louder than scheme B), and as many subjects compared different pairs during the two tournaments, analyses of the diary comments across subjects were complicated. Therefore, we were unable to conclude from the diary entries if low CRs were preferred in this study because the subjects preferred not to have low-level environmental sounds emphasized, or because they preferred more gain for high-level sounds before limiting, or a combination of both. Whereas it was difficult to get a clear picture of why certain characteristics were preferred to others, it was apparent that most preferences were made on the basis of increased speech understanding rather than the annoyance of low-level or high-level noise. Somewhat supporting this observation is the fact that in the exit interview, the difference in satisfaction rating of each pair of schemes for quiet and loud situations was significantly correlated ($r = 0.73$, $p < 0.001$). That is, the scheme that was rated highest for quiet situations was generally also rated highest for loud situations. It is possible that linear amplification for low frequencies was preferred by many of the subjects because it better preserved segmented, prosodic cues than was possible for higher CRs.

All but two subjects preferred compression in the high-frequency band and preferred more or equivalent compression in the high than in the low frequencies (cf. Table 3). There are two plausible explanations for why a relatively higher CR was often preferred in the high-frequency band and consequently why the (3:1, 1:1) scheme was rejected by all subjects. A higher CR in the high frequencies would emphasize the weaker high-frequency speech components for softer voices while making louder sounds, especially loud noises, less sharp and metallic sounding. For example, there are some sporadic observations in the literature suggesting that not all hearing aid users like the full NAL-RP prescription across the high frequencies (Keidser, 1995; Keidser et al, 2005). Of course, it is not known whether the eight subjects who selected 3:1 compression in the high frequencies would benefit from even higher CRs in this frequency band. However, any CR higher than 3:1 is likely to have an adverse effect on speech intelligibility as discussed in the introduction and as demonstrated by Souza et al (2005).

To minimize testing time, an adaptive test procedure was used to find the subjects' preferred CRs in the low and high frequencies. Using an adaptive test procedure, as compared to a round robin test, introduces a risk of the subjects inadvertently ending up on a wrong path and consequently showing a preference for a scheme that is not the optimum solution for the individual. However, there are several indications that these data are rather robust. First, the subjects mostly had a clear preference for one of the compared schemes when interviewed at the end of each field trial. In only 8 of 126 comparisons did a subject report that there was no difference between the two schemes just trialed (cf. Figure 5). Second, in 108 of the 126 comparisons, the reported preference at the end of the field test was in perfect agreement with the average performance rating produced during the field test, even if the difference in performance was said to be small. Finally, the observed subject distribution across schemes, after the first tournament, was significantly different to the one that would occur if the subjects had chosen their preferred scheme by pure chance. A more important issue of concern is probably the limited length of each field trial, as there have been suggestions that hearing aid users with severe to profound hearing loss who have worn linear amplification for a long time may take at least a month, or longer, to adjust to compression (Kuk, 2001; Kuk et al, 2003). That is, some subjects who adjusted to the test device wearing linear amplification may only have started to appreciate the benefit of compression during the testing and may have preferred higher CRs had they been able to revisit such schemes that were rejected during the first tournament.

Of the 11 subjects who wore linear amplification when entering the study, ten preferred compression in at least one frequency band at the end of the study. Only one of these subjects (20) preferred linear amplification throughout the study. This subject had a congenital hearing loss. During the adjustment period it was necessary to boost the gain by about 10 dB relative to the NAL-RP target at frequencies below 1 kHz to match the gain-frequency response of the subject's own aid to make the aid loud enough to be acceptable to the subject. As the test device in linear mode provided higher OSPL90 levels (about 10 dB) across the high frequencies than the subject's own aid and matched the OSPL90 level across the low frequencies, high level sounds were assumed to be louder overall to the subject with the test device than with his own device. The compression schemes subsequently fitted to this subject were all dismissed as being too soft. This particular case suggests that not all clients with a severe or profound hearing loss may adjust to WDRC, which is in agreement with Ringdahl et al (2000) and Barker et al (2001).

In general, the preferred CRs were lower than those prescribed by Audiogram+ and NAL-NL1 (LF band), and they were presumably also lower, on average, than the CRs fitted to subjects in Kam and Wong (1999), Ringdahl et al (2000), Barker et al (2001), and Marriage et al (2005), who all demonstrated a positive overall response to WDRC. It is possible that the preference for the lower CRs was a result of the combination of other parameters used in this study, such as a medium level CT and fast time constants, and therefore the results should not be generalized to slow-acting compression or other specific compression configurations such as the one (a multi-channel, slow-acting, low-CT WDRC device) described in Kuk and Ludvigsen (2000). A practical limitation of this study was that compression was varied in only two bands using a fixed cross-over frequency. One may argue that most commercial devices provide many more compression channels than two and that a finer division of frequency bands and independently selected cross-over frequencies may have revealed a different result. On the other hand, there is very little evidence that hearing aid users, at least with a mild to moderate-severe hearing loss, obtain additional benefit when increasing the number of compression channels above two or three (Hickson, 1994; Keidser and Grant, 2001). Indeed, there is evidence that more bands can be detrimental (De Gennaro et al, 1986). Note that the fact that some subjects were fitted to the Audiogram+ target and others to the NAL-RP target is not considered to have compromised the study outcome, especially as the fine-tuned responses, irrespective of the target used, were, on average, closer to the Audiogram+ than the NAL-RP target (cf. Figure 2).

We could not find any simple audiological parameters that could predict the CRs preferred by the individual, an outcome that would have been desirable from a prescription point of view. It is, of course, possible that individual preferences were strongly linked to the specific environments encountered by the individual and particular hearing needs rather than to the audiometric data. The most striking observation, however, was the possible nonlinear relationship between the preferred 1/CR in the low frequencies and the LFA HTL shown in Figure 6a. Although this relationship is based on a relatively small number of observations (21), the quadratic shape of the fitted curve seems plausible as it suggests that no compression should be prescribed to clients with hearing in the normal range as well as to clients with a profound hearing loss, and that the maximum CR is prescribed to clients with a hearing loss somewhere in the moderately severe to severe range. Data are currently insufficient to be sure about the exact location and magnitude of the maximum CR, though according to this data set the magnitude is likely to be less than 3:1 compression. The quadratic relationship would further suggest that some intermediate values between 1:1 and 1.8:1 compression that were not included in this evaluation are better for many of the subjects in the low frequencies. Clearly, more data are needed in this area before a firm conclusion can be made. If we had to make a recommendation based on the current data, it would be to fit clients with a LFA between 55 and 75 dB HL with a CR in the low frequencies according to the fitted quadratic polynomial in Figure 6a, that is, $CR = 1/(3.8314 - 0.0957*LFA + 0.00073*LFA^2)$, while clients with a LFA > 75 dB HL are fitted with linear amplification. For all clients with a severe or profound hearing loss, we would recommend 1.8:1 compression in the high frequencies (cf. Figure 6b). These recommendations need to be clinically verified, but they are expected to be reasonable starting points when fitting fast-acting WDRC devices to clients with severe to profound hearing loss as long as appropriate follow-up is provided.

The study revealed that some of the subjects who were used to linear amplification needed more persuasion and support to get used to the test device during the adjustment period and to get started on the trial. Further, some highly motivated subjects expressed marginal satisfaction with compression at the end of the trial whereas other subjects who went into the trial saying that they did not like compression ended up preferring the device and compression. Such experiences demonstrate that clinicians must be prepared to provide sufficient support for this client group to facilitate fine-tuning. For example, we found that the subjects benefited from a discussion about adjustment and their perceptual experiences with compression. Many subjects also appreciated the adaptive procedure in finding their preferred response, suggesting that a trial of various compression options with extra follow-up appointments could be beneficial.

CONCLUSION

In this study, 21 experienced hearing aid users with moderately severe to severe-to-profound hearing loss compared pairs of compression schemes in the field in an adaptive manner to determine the preferred CRs in the low and high frequencies of a fast-acting device. The data demonstrated that linear amplification, on average, was rated highest in the low frequencies and was, in particular, preferred by those with a low-frequency hearing loss greater than 75 dB HL. Further, the CR preferred in the high frequencies was generally higher than or equal to that preferred in the low frequencies. Using linear statistical models, the preferred 1/CRs could not be predicted from simple audiometric data, time of onset of loss, or past experience with linear or nonlinear amplification. However, data suggested that there may be a nonlinear relationship between preference and average hearing loss in the low frequencies. Whereas data were insufficient to provide an actual prescription, a recommendation for using CRs in the range from linear to 2:1 as appropriate starting points when fitting fast-acting WDRC to clients with severe-to-profound hearing loss was discussed. The participants were generally complicated to fit, and the study demonstrated a need for spending a little extra time with this client group in order to reach a satisfactory outcome.

Acknowledgments. The authors would like to thank Lisa Hartley for her great efforts with recruitment and assistance with data collection, and Gary Gow from GN ReSound Australia for hardware and software support.

NOTES

1. Whereas the sponsor of the study was interested in optimizing the compression ratios with the proprietary prescription of the gain-frequency response shape, NAL was not willing to fit this particular subject group with a response that was very different from NAL-RP without some empirical determination that the proprietary prescription was acceptable to and adequate for the subject.
2. It is more sensible to compare compression ratios using the inverse compression ratio (1/CR) because variations in the 1/CR are directly proportional to variation in the hearing aid's output and, hence, gain. Also, whereas the compression ratio extends over an infinite range of values, the 1/CR is bounded by 0 (limiter, CR = ∞:1) and 1 (linear, CR = 1:1), making it more suitable for arithmetic analyses.

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Appendix 1

Diary form:

Your test situation: Date:

In this test situation

1) How was the performance of Program 1 (one beep):
(Scale from 1 to 10 with 1 labelled Very bad, 5 labelled OK, and 10 labelled Very good)

2) How would you describe the performance of Program 1:

3) How was the performance of Program 2 (two beeps):
(Scale from 1 to 10 with 1 labelled Very bad, 5 labelled OK, and 10 labelled Very good)

4) How would you describe the performance of Program 2:

Exit interview:

1) During this past test period, did you use the hearing aid?
(All the time/ More than 4 hours a day/ 1–4 hours every day/ 3–5 days a week/ Less than 3 days a week)

2) Did you experience any problems with the test device during this test period?
(None at all/ Operational problems [specify]/ Performance problems [specify])

3) Did programs 1 and 2 sound different to you? (Yes/ No)
If yes, was the difference (Distinct/ Moderate/ Slight)

4) How satisfied were you with P1 (ONE BEEP) in quiet situations?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

5) How satisfied were you with P2 (TWO BEEPS) in quiet situations?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

6) How satisfied were you with P1 (ONE BEEP) in loud situations?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

7) How satisfied were you with P2 (TWO BEEPS) in loud situations?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

8) How was the volume of your own voice on P1 (ONE BEEP)?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

9) How was the volume of your own voice on P2 (TWO BEEPS)?
(Scale from 1 to 10 with 1 labelled Not satisfied and 10 labelled Very satisfied)

10) Overall, which program did you prefer? (Program 1 [one beep]/ Program 2 [two beeps])

11) How much better was your preferred program?
(Much Better/ Better/ Hardly any Better/ No difference)

Any comments?

P1:

P2: