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Evidence of Acclimatization in Persons with Severe-to-Profound Hearing Loss

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Abstract

The present study examined the phenomenon of acclimatization in persons with a severe-to-profound hearing loss. A secondary purpose was to examine the efficacy of a digital nonlinear power hearing aid that has a low compression threshold with expansion for this population. Twenty experienced hearing aid users wore the study hearing aids for three months and their performance with the study hearing aids was evaluated at the initial fitting, one month, and three months after the initial fitting. Performance of their current hearing aids was also evaluated at the initial fitting. Speech recognition testing was conducted at input levels of 50 dB SPL and 65 dB SPL in quiet, and 75 dB SPL in noise at a +10 SNR. Questionnaires were used to measure subjective performance at each evaluation interval. The results showed improvement in speech recognition score at the one-month evaluation over the initial evaluation. No significant improvement was seen at the three-month evaluation from the one-month visit. In addition, subjective and objective performance of the study hearing aids was significantly better than the participants' own hearing aids at all evaluation intervals. These results provided evidence of acclimatization in persons with a severe-to-profound hearing loss and reinforced the precaution that any trial of amplification, especially from linear to nonlinear mode, should consider this phenomenon.

Key Words: acclimatization, digital power hearing aid, low compression threshold.

Abbreviations: CT = compression threshold; HLC = high level compression, APHAB = Abbreviated Profile of Hearing Aid Benefit; EC = ease of communication; RV = reverberation; BN = background noise; AV = aversiveness of sounds; SPIN = Speech Perception in Noise Test; FDA = Food and Drug Administration; VC = volume control; HHIE-S = Hearing Handicap Inventory for the Elderly – Screening; ANOVA = Analysis of Variance; PTA = pure-tone average; OSPL90 = Output sound pressure level at 90 dB SPL input; WDRC = wide dynamic range compression

Sumario:

El presente estudio examina el efecto de la climatización en personas con hipoacusia severas a profundas. Un propósito secundario fue examinar la eficacia de un auxiliar auditivo potente, digital, no lineal, con un umbral de compresión bajo, pero con expansión para esta población. Veinte usuarios con experiencia con audífonos utilizaron el auxiliar auditivo del estudio por tres meses y su rendimiento con el audífono del estudio se evaluó en la adaptación inicial, al mes y a los tres meses posteriores a la adaptación. El rendimiento de su auxiliar auditivo original fue evaluado también al inicio. Se condujeron pruebas de reconocimiento del lenguaje a niveles de 50 dB SPL

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y a 65 dB SPL, en silencio, y a 75 dB SPL en ruido, con un SNR de + 10. Se utilizaron cuestionarios para medir el rendimiento subjetivo en cada intervalo de evaluación. Los resultados mostraron una mejoría en los puntajes de reconocimiento del lenguaje en la evaluación del primer mes, comparados con los iniciales. No se observó ninguna mejoría significativa en la evaluación a los tres meses, comparada con la visita del primer mes. Además, el rendimiento subjetivo y objetivo del audífono del estudio fue significativamente mejor que el del propio audífono de los participantes, en todos los intervalos de evaluación. Estos resultados mostraron evidencia de la climatización en personas con hipoacusias severas a profundas, y reafirmó la precaución que debe tenerse en cualquier estudio de amplificación, sobre todo del modo lineal al no lineal, debiendo considerarse este fenómeno.

Palabras Clave: Climatización, auxiliar auditivo potente digital, umbral de compresión bajo.

Abreviaturas: CT = umbral de compresión; HLC = compresión de alto nivel; APHAB = Perfil Abreviado del Beneficio del Auxiliar Auditivo; EL = facilidad de audición; RV = reverberación; BN = ruido de fondo; AV = repulsión al sonido; SPIN = Prueba de Percepción del Lenguaje en Ruido; HHIE-S = Inventario de Impedimentos Auditivos del Anciano – Tamizaje; ANOVA = Análisis de Variancia; PTA = Promedio Tonal Puro; OSPL90 = Nivel de presión sonora de salida a 90 dB SPL de entrada; WCRC = Compresión de rango dinámico amplio.

Auditory acclimatization is the systematic change in auditory performance with time that is not linked to a change in the acoustic information available to the listener. It involves improvement in performance that cannot be attributed purely to task, procedural, or training effects (Arlinger et al., 1996, p.87S). It has become a popular topic since the late 1980s. Palmer et al (1998) provided an excellent review of the literature on acclimatization. The same author (Palmer, 1999) also provided another update on the most recent findings in the area.

Aside from the potential physiological underpinnings of acclimatization (Willot, 1996), the observation of this phenomenon has many ramifications. From a research standpoint, it casts doubts on the validity of studies that did not allow time or did not allow adequate time for acclimatization before an evaluation of hearing aid performance was made. It reinforces, as indicated by the FDA in its guidelines for hearing aid validation studies (FDA, 1994), that sufficient time must be allotted for acclimatization prior to actual evaluation.

The phenomenon of acclimatization has far greater clinical implication, especially in the counseling provided to patients relative to expectations from their new hearing aids. For one thing, patients would need to be counseled that (1) their initial experience with the new hearing aids may not represent their final performance with the hearing aids; and (2) it may take time to fully realize the benefits. Furthermore, it suggests that any validation studies should not be performed at the time of the initial fit. Rather, validation should be done

after the patients have had enough time to acclimatize to the hearing aids.

Despite its potential implications, evidence on acclimatization since Silverman and Silman's (1990) clinical report on two cases is, at best, mixed (Cox and Alexander, 1992; Gatehouse, 1992; Saunders and Cienkowski, 1997; Turner et al., 1996). In 1995, a group of clinical researchers met in Eriksholm and concluded that the evidence on acclimatization was confounded by the experimental conditions employed in each study. Issues of audibility, optimal test conditions (stimulus types, test levels and SNR), allowance for gain change over time, and the "right" subject population could have affected the outcome of the evaluation.

The last possibility on the "right" subject population to demonstrate acclimatization is especially of interest. Previously, many of the studies on acclimatization employed participants with relatively mild-to-moderate degrees of hearing loss. These participants, because of their relatively "good" hearing, may have never been deprived of the acoustic signal to demonstrate acclimatization. Consequently, the key to demonstrating such a phenomenon, as summarized by Palmer (1999), is to ensure that the participants "...have enough hearing loss to produce deprivation and yet not so much hearing loss that amplification cannot restore audibility..." Furthermore, the "...outcome measure would have to consist of the same frequencies that were believed to be deprived."

Obviously, there can be many different designs to examine this hypothesis (Palmer, 1999). One possible paradigm to examine the

acclimatization phenomenon is to examine the change in speech recognition scores at low input levels in participants with a severe-to-profound hearing loss (PTA greater than 70 dB HL). This group of participants are typically experienced hearing aid wearers using linear (either peak clipping or compression limiting) hearing aids with a volume control (VC). In theory, while the amount of gain provided by linear hearing aids may be appropriate for speech presented at a conversational level, inputs at a lower level may not be audible unless the wearers constantly adjust the VC on the hearing aids or leave the VC at a higher than desirable setting. In some situations, one can assume that even with this adjustment, there may not be adequate gain/output. That is to say, audibility for soft sounds is not as assured as conversational level sounds for people with a severe-to-profound hearing loss when conventional linear amplification is used. There is a higher likelihood of auditory deprivation in this group of individuals for low-intensity sounds. If one can ensure audibility (as much as one can) or provide more audibility than conventional linear hearing aids to this group of individuals without risking discomfort, one may be able to observe acclimatization more consistently. Unfortunately, commercial hearing aids that meet this requirement were unavailable.

Recently, a digital nonlinear power hearing aid that uses a low compression threshold was introduced. This allows extra gain for low-input sounds without risking discomfort at higher input levels. This hearing aid would appear ideal for use to test the hypothesis of acclimatization. Because the amplification rationale (i.e., nonlinear) used by this hearing aid is significantly different from the conventional linear approach available for persons with a severe-to-profound hearing loss, it may be valuable to compare the efficacy of the study hearing aids to the participants' own linear hearing aids. Thus, the primary purpose of the present study was to examine the presence (or lack thereof) of acclimatization in persons with a severe-to-profound hearing loss. A secondary objective of this study was to compare the efficacy of the study hearing aids with the participants' own hearing aids.

METHOD

Subjects

Twenty adult hearing aid wearers participated in the study. Twelve of the participants

were recruited from the Washington University School of Medicine and eight were recruited from the Northern Illinois University. The age of the participants ranged from 43 years to 92 years with a mean of 55 years (S.D. = 17.3 yrs). All but one participant had a symmetrical (within 5 dB) severe-to-profound sensorineural hearing loss. Figure 1 shows the mean headphone thresholds of the participants. Note that in instances where thresholds were unobtainable within the limits of the audiometer, the maximum dial reading of the audiometer at that frequency was taken instead to compute the average hearing loss. In other words, the "true" average thresholds for the higher frequencies were poorer than those indicated in the figure.

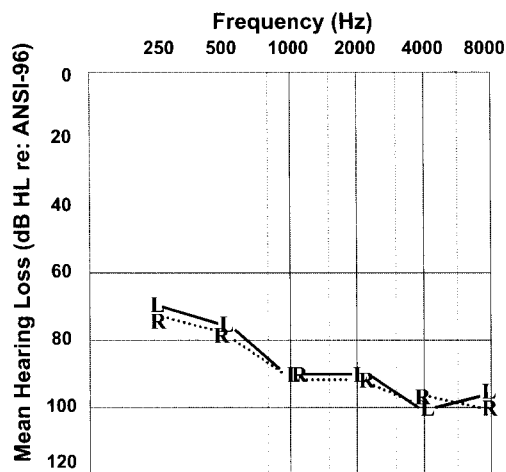


Figure 1. Mean audiometric thresholds measured under headphones (N=20). Maximum dial readings were used to calculate average threshold when "no response" was noted.

All the participants were experienced binaural hearing aid wearers and had been wearing hearing aids for an average of 20 years (S.D. = 13.6 yrs). Their current hearing aids included a variety of power hearing aids from various manufacturers with a typical output saturated sound pressure level (OSPL90) exceeding 135 dB SPL. The average age of their current hearing aids was 4.5 years (S.D. = 3.9 yrs). Participants' hearing aids were dispensed at their respective sites and were judged (via electroacoustic measurement) to be functioning according to specifications at the time of the evaluation. Their hearing aids were mostly linear hearing aids with either peak clipping or compression limiting as the method of output limiting.

Hearing aids

The Widex Senso P38 hearing aid was used in this study. This is a digital 3-channel hearing aid utilizing adaptive, slow-acting compression as the processing algorithm. It has a low compression threshold and high-level compression (i.e., two compression thresholds before saturation). As will be elaborated in the following paragraphs, this unique input-output characteristic made it ideal to study the phenomenon of acclimatization in hearing-impaired subjects. Ringdahl et al (2000) provided a detailed description of the characteristics of this hearing aid.

The study hearing aid has a maximum in-situ gain exceeding 70 dB and a peak OSPL90 of 139 dB SPL. It uses a low compression threshold (CT) at 20 dB HL in all three channels. This translates roughly to 32 dB SPL in the low-frequency and 26 dB SPL in the mid- and high-frequency channels. The advantage of the low CT is to provide greater gain to low input signals that are below the CT (Kuk, 1999). Expansion is used below the CT to minimize the perception of microphone noise and low-level ambient noise. Uniform gain reduction (i.e., compression) starts above the 20 dB HL and continues until a conversational level (second compression threshold - about 53 dB HL in the low-frequency channel, 44 dB HL in the mid-frequency channel, and 39 dB HL in the high-frequency channel) is reached beyond which less gain reduction occurs (high level compression). The advantage of the second segment of compression is to minimize temporal and saturation distortion occurring at high input levels. Gain for conversational input was estimated from the NAL-RP fitting formula (Byrne et al., 1990) modified for the device specific features (e.g., channels, release times etc.) of the study hearing aid (Kuk and Ludvigsen, 1999). "Noise reduction" algorithm was not available on this study hearing aid. Figure 2 compares the input - output curve of a linear hearing aid and the P38 hearing aid matched at a conversational input level. Note the extra output at low input levels and the reduced output above a conversational level provided by the study hearing aid over a conventional linear hearing aid. Because most hearing-impaired participants wear conventional linear hearing aids, one may hypothesize that these individuals are deprived of low-input sounds. By providing them with extra gain for low-input sounds, one may be able to observe the phenomenon of acclimatization more easily.

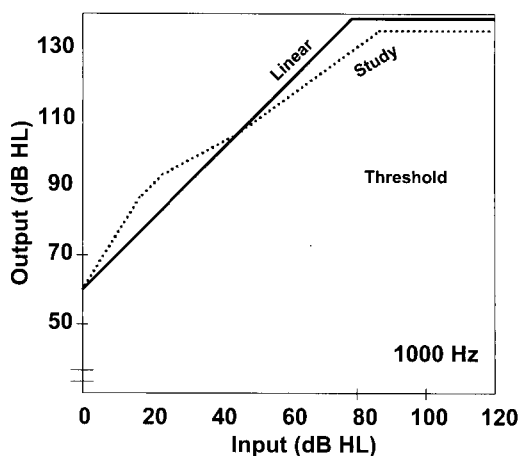


Figure 2. Comparison in input-output curves between the Senso P38 hearing aid and a linear hearing aid matched at a conversational input (about 45 dB HL). A hearing loss of 90 dB HL is assumed.

The manufacturer's fitting software was used to fit the study hearing aids. After the audiogram information was entered into the NOAH audiogram module, the fitting software directly took the audiometric thresholds at specific frequencies as gain entry for each frequency channel. Specifically, the threshold at 500 Hz was used to compute gain for the low-frequency channel; the average threshold at 1000 Hz and 2000 Hz was used for the mid-frequency channel and the threshold at 4000 Hz was used for the high-frequency channel. The filter slope and the cross-over frequency between filters were automatically adjusted based on the magnitude of the entered thresholds.

Following this, an in-situ feedback test was performed on the study hearing aids with the participants wearing the proper earmolds. During the feedback test, gain in each channel was gradually but automatically increased until acoustic feedback was detected at the hearing aid microphone. The maximum gain of the hearing aids was then leveled at 6 dB below the feedback point. This corresponded to the desired gain at an input of 20 dB HL. Because the main objective of this study was to examine acclimatization at low input levels, efforts were made to ensure that the desired gain was available for all channels. However, such was not always achievable especially in the high frequency because of earmold leakage etc. Consequently, a compromised criterion of "-10" (i.e., the actual gain available cannot be 10 dB less than that required to yield

an aided threshold at around 20-30 dB HL) was adopted as the criterion for all but the high-frequency channels. Participants' earmolds were remade if the feedback values did not meet this criterion. It was recognized that even with this criterion one might not ensure full audibility. But it would have provided more audibility for low input sounds than what the participants received from their linear hearing aids.

The input-output curve in Figure 2 suggests the possibility that some participants may initially react negatively to the study hearing aids. Specifically, the additional gain for the low inputs may lead to perception of "noisiness" while the reduced output for the high inputs may lead to perception of "inadequate loudness", "reduced clarity" etc. With time, such perception may disappear and become more acceptable. On the other hand, it is also possible that the same perception may reflect less than optimal gain for the participants. To ensure that the study clinicians did not unnecessarily adjust the study hearing aids and reduce the magnitude of the acclimatization effect, the following instructions were written as a reminder. They were:

- If conversational speech was too loud, the gain setting was lowered in 2.5 dB steps in all channels
- If conversational speech was too soft, the gain setting was raised in 2.5 dB steps in all channels
- If conversational speech was clear and comfortable, but "things are not quite as loud", the recommended settings were maintained
- If conversational speech was clear and comfortable, but participants reported "hearing many soft sounds like sniffing, birds chirping etc", the recommended settings were also maintained
- If conversational speech was loud, but speech was not clear, the mid channel gain was increased by 5 dB and the low channel HTL was decreased by 2.5 dB
- If conversational speech was acceptable, but the occlusion effect was reported, the low-frequency channel gain for high input was lowered in 2-dB steps. To compensate for the loss of loudness, the mid-frequency channel gain was increased by the same amount.

In order to evaluate how the study hearing aids perform in real-life and to minimize any

potential frustrations in their daily use, all participants were given the study hearing aids with the VC option. This allowed gain adjustment of +/- 6 dB relative to the prescribed setting. If participants, upon their return, reported constant use of the VC, then the settings on their hearing aids were fine-tuned in order to meet their preference. This was done before any data collection. It was recognized that this action might alter the amount of gain that participants received during speech recognition testing. However, it would be impractical to force the participants to wear hearing aids that provided unacceptable sound quality even after one month of wear. The settings on the hearing aids at all test sessions were recorded for subsequent verification of gain. As will be shown in the Results section, the majority of participants required less than 3 dB gain adjustment.

Outcome measures

Both objective and subjective outcome measures were used to evaluate participant performance with their own hearing aids and with the study hearing aids over time. These included:

Aided sound-field thresholds

Aided thresholds were obtained with the participants' own hearing aids and the study hearing aids worn binaurally. Aided sound-field thresholds represented the lowest input level that was audible to a listener at a fixed VC set for target gain. Warble tones were presented in an ascending manner to elicit thresholds. Participants sat approximately one meter from a loudspeaker that was placed directly in front of them. No VC adjustment was allowed during any sound-field threshold testing. Participants wore their own hearing aids at the VC setting that they typically used in their daily lives.

Speech recognition test

Sentences from the Speech Perception In Noise (SPIN) test were used to evaluate speech recognition. The noise stimulus was a Widex party noise recorded at the Old Copenhagen Stock Exchange (Valente et al., 1999). This noise was chosen instead of the babble noise that accompanied the SPIN test because of its closer approximation to real-life noise. The speech materials were presented at 0° azimuth, first with the participants' own hearing aids, and then with the study hearing aids at each of

the three intervals of evaluation. The speech materials were presented at 50 dB SPL in quiet, 65 dB SPL in quiet and 75 dB SPL in a 65 dB SPL party noise background. Both speech and noise were presented from the same loudspeaker placed at one meter directly in front of the participants. Order of testing (stimulus levels and word list) was counterbalanced across participants and visits. A practice list was used to familiarize participants to the task.

Abbreviated Profile of Hearing Aid Benefit (APHAB)

The APHAB questionnaire, a benefit measure consisting of 24 items belonging to four categories - Ease of Communication (EC), Reverberation (RV), Background Noise (BN), and Aversiveness of Sounds (AV), was used (Cox and Alexander, 1995). Participants completed the unaided and aided portion of the APHAB questionnaire on their hearing aids at the beginning of the study. The APHAB was not completed on the study hearing aids at initial fit because of participants' lack of experience with the study hearing aids. Instead, participants completed the unaided and aided portions of the APHAB after they have worn the study hearing aids for one month and three months. Because it was realized later that it may be difficult for the participants to estimate their difficulty in the unaided condition on account of their degree of hearing loss, only the aided scores were compared in this study.

Washington University Questionnaire (WUQ)

This relative preference questionnaire was administered at one month and three months after the initial fitting of the study hearing aids. The questionnaire asked for relative preference between the study hearing aids and the participants' own hearing aids in a variety of daily communication situations. Participants chose either their "own aids," the "study aids," "both" or "neither aids" as the response.

Knowles MarkeTrak Questionnaire

The Knowles MarkeTrak questionnaire has been used to evaluate consumer satisfaction (Kochkin, 1996) for hearing aids for several years. Through the use of a rating scale (mostly from 1 to 5, with "1" being very satisfied and "5" being very dissatisfied), hearing aid wearers

indicated their overall satisfaction with the recommended hearing aids, as well as on issues pertaining to their effectiveness in different listening environments, their cost, cosmetic issues, and professionalism of the dispensers. Because of the nature of this study, not all the items on the questionnaire were included. Instead, only the following items were included:

- Overall satisfaction with hearing aids
- Improvement in quality of life with hearing aids
- Satisfaction with "Hearing Aid Features"
- Satisfaction in specific "Listening Situations"

Participants completed the selected items at the beginning of the study on their own hearing aids. They completed the same items at one month and three months after fitting.

Hearing Handicap Inventory for the Elderly - Screening (HHIE-S)

This was a 10-item questionnaire (Ventry and Weinstein, 1982) that addressed the emotional and social difficulty of a hearing-impaired person. Participants answered with a "Yes" (1) "No" (2) or "Sometimes" (3) response to the 10 items. An example of items may be: "Do you have difficulty hearing when someone speaks in a whisper?" "Do you feel handicapped by a hearing problem?" This questionnaire was used at the beginning of the study using participants' own hearing aids as the reference. Participants completed the same questionnaire at one- and three- months post-fitting.

Procedure

Participants were seen for a minimum of 4 sessions. During the first session, the functional status of the participants' own hearing aids was evaluated via electroacoustic measures. Unaided audiometric thresholds and aided sound-field thresholds with the participants' own hearing aids were determined at the wearers' typical VC setting. No attempt was made to match the output of the participants' own hearing aids to the study hearing aids at any input levels. Participants' performance with their own hearing aids on the SPIN test was determined at the three presentation levels (50, 65, and 75 (+10 SNR) dB SPL) at a fixed VC setting. The practice list was used to familiarize participants to the task. Order of testing and SPIN lists were counterbalanced. Participants also completed the unaided and aided portions

of the APHAB questionnaire using their own hearing aids as the criterion. In addition, they also completed the MarkeTrak questionnaire and the HHIE questionnaire.

The appropriateness of the participants' earmolds for the study hearing aids was also evaluated during the first session. New earmolds were ordered if their current earmolds could not maintain the desired gain for soft sounds within a 10 dB margin in the mid- and high-frequency channels. Participants did not wear the study hearing aids until the proper earmolds were available.

Participants returned for the second session (between one and three weeks afterwards) at which time they started wearing the study hearing aids binaurally. The settings on the hearing aids were optimized based on the criteria described in an earlier section. The aided sound-field thresholds with the study hearing aids were determined, along with the SPIN test at the three test conditions presented in a counterbalanced order. Participants were also instructed on the proper use and maintenance of the hearing aids without being disclosed their features. They were also counseled that their perception with the study hearing aids might be different from what they were accustomed to, and they were asked to return with specific comments so that the settings could be modified if necessary.

Participants returned for the third session after they had worn the study hearing aids for one month. The settings on the hearing aids were modified based on the subjective comments whenever necessary. In addition, their speech recognition ability at the three test conditions was again determined. The APHAB, MarkeTrak, HHIE-S, and the Washington University Questionnaire were completed also. Participants completed the same procedure during the three-month follow-up.

RESULTS

Aided sound-field thresholds

A compression hearing aid with a low CT allows more gain for low input sounds. When comparing the aided thresholds of such a hearing aid to a linear hearing aid when both are matched in output to a conversational input, the aid with a lower CT would yield a lower aided threshold (Kuk, 1999). Indeed, in this study, one must meet the requirement of a lower aided threshold before one can even

examine the issue of acclimatization. Figure 3 shows the average aided thresholds between the participants' own hearing aids and the study hearing aids at the initial fitting. The average aided difference between the hearing aids was 4.3 dB at 2000 Hz to 17.5 dB at 250 Hz. These sound-field thresholds were analyzed using a three-way split-plot ANOVA with repeated measures of the two within-subject factors (hearing aids and frequency) and one between-subject factor (site). The results suggested a significant main effect for hearing aid ($F=345.66$; $df=2,323$; $p<.0001$). Post-hoc analyses showed that the average aided thresholds for both hearing aids were significantly lower than the unaided thresholds. In addition, the aided thresholds for the study hearing aids were lower than the participants' own hearing aids at all frequencies. There was also a significant frequency effect ($F=55.88$; $df=5,323$; $p<.0001$). However, no site effect was found ($p > 0.2$).

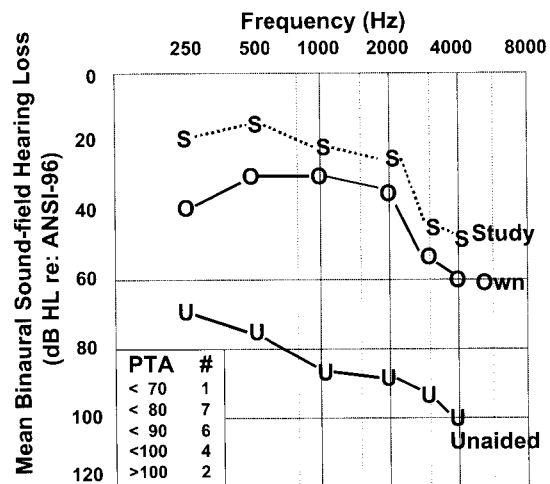


Figure 3. Mean unaided (U) and aided binaural sound-field thresholds for the participants' own hearing aids (O) and the study hearing aids (S). The number of participants with various pure-tone averages (PTA) is listed.

Because the experimenters were allowed to modify settings on the study hearing aids to ensure continued subject participation, it is important to examine these settings in order to ascertain if any change in performance could be attributed to a change in gain/output or to acclimatization. The recorded settings on the study hearing aids for each participant were programmed retroactively on the study hearing

aid and its coupler response was determined with a speech-shaped noise at 50 dB SPL and 80 dB SPL. Of the 20 participants, 10 showed less than 2 dB overall gain change (6 increase and 4 decrease) for both the low- and high-input stimuli. Five participants showed a 3 dB gain increase for the high-level input only and five showed a 3 dB gain decrease for the low-level input. Overall, the average gain was 3 - 4 dB lower in the low-to-mid frequency regions at the three-month follow-up than at the initial fitting for the 50 dB SPL input but 1- 2 dB higher at the three-month follow-up than at the initial visit for the 80 dB SPL input. This is not unexpected from listeners who were accustomed to linear hearing aids. These individuals tended to want more loudness for sounds above a conversational level and less audibility for soft sounds from their new nonlinear hearing aids. Any acclimatization effect seen in this study is possibly not a result of higher gain from the study hearing aids (because it is lower). On the other hand, Horwitz and Turner (1997) showed that inexperienced wearers preferred 2 dB less gain and experienced wearers preferred 2 dB more gain (for conversational input) at the conclusion of the acclimatization period.

Speech recognition scores

SPIN scores were analyzed by three-way split-plot ANOVA with repeated measures of the two within-subject factors (hearing aids and test conditions) and one between-subject factor (site). Because there was not any site effect, the results were combined for reporting.

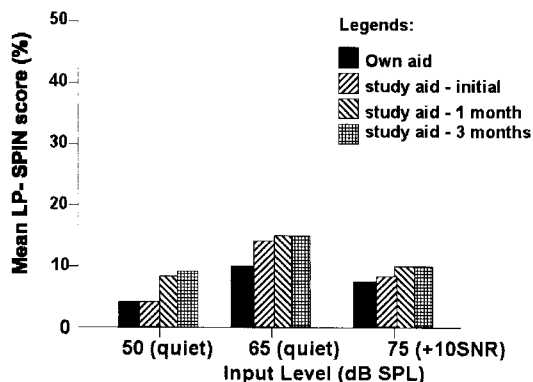


Figure 4. Mean low-probability (LP) SPIN scores for own aids and study hearing aids at different evaluation intervals (initial, one month, and three months) and test conditions (50 dB, 65 dB, and 75 dB SPL (+10 SNR)).

LP-Item Score

Figure 4 summarizes the mean scores for the low probability (LP) items on the SPIN test for all participants (N=20). There was a significant main effect for hearing aids ($F=6.65$; $df=3,209$; $p=.0003$). Bonferroni corrected comparisons of least squares means revealed that the mean performance of the study hearing aids at one-month and three-months was significantly better than the mean performance of the study hearing aids at initial fit ($p = .0252$; $p = .0174$ respectively). Mean differences between the study hearing aids at one- and three-months were not significant. This supports the hypothesis of acclimatization between initial fit and one-month post-fitting. In addition, the mean performance of the study hearing aids at one-month and three-months was significantly better than the mean performance of the participants' own aids ($p=.0004$ and $p=.0002$ respectively). However, the mean difference between the study hearing aids at initial fit and the participants' own aids was not significant. There was a significant test condition effect ($F=35.61$; $df = 2,209$; $p<.0001$) suggesting that performance at the 65 dB SPL test condition was better than the 50 dB SPL ($p < 0.0001$) and the 75 dB SPL (+10 SNR) ($p = .0027$) conditions.

HP-Item Score

Figure 5 summarizes the mean scores for the high probability (HP) items on the SPIN test. There was a significant main effect for hearing aids ($F=10.57$; $df=3,209$; $p<.0001$).

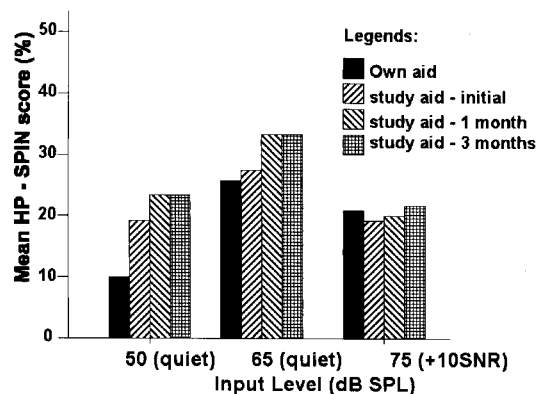


Figure 5. Mean high-probability (HP) SPIN scores for own aids and study hearing aids at different evaluation intervals (initial, one month, and three months) and test conditions (50 dB, 65 dB, and 75 dB SPL (+10 SNR)).

Bonferroni corrected comparisons of least squares means revealed that the mean performance of the study hearing aids at one month ($p = .0248$) and three months ($p = .0029$) was significantly better than their mean performance at initial fit. However, there was no significant difference between performance at one- and three-months post-fitting. This supports the hypothesis of acclimatization between initial fit and one-month post-fitting. In addition, the mean performance of the study hearing aids at initial fit ($p=.0406$), one-month post-fitting ($p=.0004$) and three-months post-fitting ($p<.0001$) was significantly better than the mean performance of the participants' own aids. There was a significant test condition effect ($F=58.50$; $df = 2,209$; $p<.0001$) suggesting that the performance at the 65 dB SPL condition was better than other test conditions ($p < .0001$). The ANOVA revealed a significant two-factor type by condition ($F=3.75$, $d=6,209$; $p=.0014$) interaction.

These results showed significantly better SPIN scores at the one-month and three-month visits than the initial visit, but not between the one-month and three-month visits. This sug-

gests that any acclimatization would have stabilized after using the study hearing aids for one month. In addition, significant differences were also noted between the study hearing aids and the participants' aids at all test intervals for the 50 dB SPL and 65 dB SPL test conditions.

APHAB

Figure 6 reports the mean APHAB aided scores for the participants' own hearing aids and the study hearing aids at one month and three months. Separate two-way (aid by site) ANOVAs were performed for each of the four subscales. For the background noise subscale (BN), there was a significant hearing aid main effect ($F=6.54$; $df=2,36$; $p = .0038$). Bonferroni corrected comparisons revealed that the mean difficulty score for the study hearing aids at three months was significantly lower than the participants' own aids ($p=.0028$). No differences were observed between the participants' own aids and the study hearing aids at one month, or between the study aids at one- and three-months post-fitting. Mean differences reported for the other three subscales were not significant.

Table 1. Frequency of relative preference on the Washington University Questionnaire.

Washington University Hearing Aid Comparison	Current HA		Experiment HA		Both		Neither	
	1 month	3 months	1 month	3 months	1 month	3 months	1 month	3 months
Speech was more...								
Distinct	4	3	8	12*	7	5	1	1
Pleasant	4	3	11**	11*	5	5		1
Natural	4	3	7	11*	7	4		
Comfortably loud	2	3	10*	4	7	12		
Uncomfortably loud		2	5	4			15	14
Performance was better...								
with a close friend 1-on-1	4	4	7	9	9	7		
with a stranger 1-on-1	3	3	8	11*	10	5		
listening to TV with no one else talking		2	10*	8**	7	8	3	2
listening to TV with one or more people talking		3	7*	5	4	7	8	5
listening at a meeting with one speaker	1	4	7*	6	10	6	1	2
listening at a meeting with several speakers	1	3	5	5	7	4	5	6
listening at a family gathering	1	3	6	6	9	9	3	1
listening to the radio in the car	1	2	13*	9*	2	5	2	2
listening to a passenger in car	2	3	13*	11*	4	4		1
listening in an elegant restaurant	1	3	5	7	9	8	2	1
listening in a family restaurant	2	3	9*	6	5	8	3	2
listening in a house of worship	1		11*	8*	3	6*	4	5
listening in a movie theater	2	2	7**	4	3	3	3	5
listening to recorded music	2	1	9*	10*	6	5	2	4
performance was less frustrating	4	5	8	5	5	5	4	5
quiet sounds were more audible	2	1	15*	13*	2	3	1	3
Overall	4	5	11**	12**	4	2	1	1
TOTAL	31	47	151*	135*	99	95	42	45

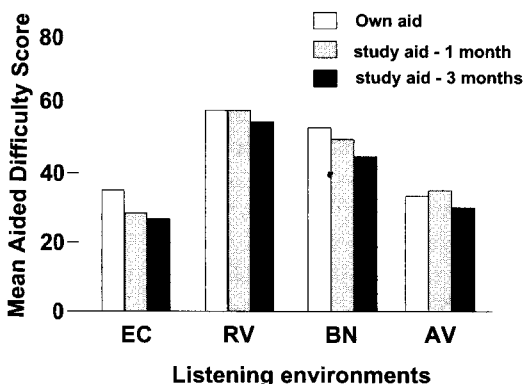


Figure 6. Mean APHAB aided difficulty scores between the participants' own aids and the study hearing aids at one- and three-month follow-up.

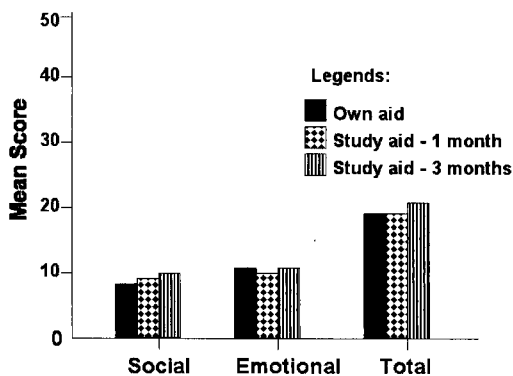


Figure 7. Mean scores on the HHIE-S questionnaire for the participants' own aids and the study hearing aids at one- and three-month intervals.

WU questionnaire

Table 1 summarizes the number of participants who preferred their own "current hearing aids," the "experimental hearing aids," "both hearing aids," and "neither hearing aids" at the one-month and three-month follow-up evaluations. A McNemar's Chi-square test of significance was performed on each item to determine if significant differences were present between related measures. Items showing the study hearing aids to be statistically better than the participants' own hearing aids at the 0.05 level were identified by one asterisk (*) in the cell under the "experimental HA" column. Items that were significant at the $p < 0.1$ level were indicated by two asterisks (**). Table 1 shows that there is an overall preference for the study hearing aids. However, statistical significance was reached on only half of the items. Expectedly, items that were found to be statistically significant related to enhanced audibility (quiet sounds more audible), sound quality (distinct, pleasant, natural, music), and moderate noise and reverberation (car, house of worship, family restaurant). For most items (exception: comfortably loud, one speaker, family restaurant), preference for the study hearing aids at one month post-fitting was also seen at the three month post-fitting interval. This suggests no difference in preference for the study hearing aids between one-month and three-month post-fitting.

HHIE - S

Figure 7 summarizes the mean scores for the social, emotional, and total subscales for the participants' own aids and the study hearing aids at one month and three months on the HHIE-S questionnaire. In general, fewer difficulties were reported with the study hearing aids than the participant's own hearing aids, especially at the three-month evaluation interval ($p = 0.011$). A two-way (aid by site) ANOVA was performed on the Total HHIE-S score. There was a significant hearing aid effect ($F=6.83$; $df=2,36$; $p=.0031$). Bonferroni corrected comparisons revealed that the mean HHIE-S Total score for the study hearing aids at 3 months was significantly better than participants' own aids ($p=.0023$). There was no significant hearing aid by site interaction.

MarkeTrak

Table 2 summarizes the mean satisfaction ratings on selected items of the MarkeTrak questionnaire for the participants' own hearing aids and for the study hearing aids at one and three months post-fitting. Two, 2-way ANOVA were performed – one to compare the ratings for the study hearing aids between one-month and three-month post-fitting; and another to evaluate if the differences in ratings between the participants' own hearing aids and the study hearing

Table 2. Mean satisfaction ratings on selected items on the MarkeTrak.

Items	Own Aid	P38 - one month	P38 - three months
Overall			
Overall satisfaction	2.45	2.05*	2.15*
Improves quality of life	1.4	1.4	1.6
Hearing Aid Features			
Fit/comfort	2.05	2.4*	2.2
Visibility to others	2.25	2.2	2.15
Ease of battery change	1.6	2.1*	2.25*
Battery life	2.25	1.95*	1.85*
Clarity of sounds	2.65	2.4	2.1*
Feedback	3.2	2.65*	2.75*
Volume control ease	2.35	2.55	2.6
Reliability	2.2	1.95	2.05
Improves hearing	1.9	1.95	2.05
Use in noise	3.1	2.7*	3.15
Naturalness	2.4	2.3	2.25
Localization	3.15	2.7*	2.4*
Own voice	2.2	2.3	2.1
Hear soft sounds	3.15	2.35*	2.45*
Comfort loud sounds	2.5	2.3	2.5
Listening situations			
One person	1.6	1.8	1.6
Small group	2.7	2.4	2.25*
Outdoors	2.4	2.35	2.55
Large group	3.8	3.25*	3.25*
Concert	3.68	3.33	3.33
House of worship	3.4	3.03	2.98*
TV	3.1	2.79*	2.7*
Restaurant	3.15	3	3.15
Car	3	2.55*	2.7*
Telephone	3.12	2.95	3
Music	3.25	2.41*	2.3*
Leisure	2.5	2.3	2.35

(1 = very satisfied and 5 = very dissatisfied)

Asterisk (*) within cell indicates that the study hearing aids were rated significantly higher than subjects' own hearing aids ($P < 0.05$)

aids were significant. None of the items showed any significant difference when the comparison was made between the study hearing aids at one month and three months. This suggests no subjective acclimatization occurred between one month and three months post-fitting.

On the other hand, many items on the MarkeTrak questionnaire showed significant difference between the study hearing aids and the participants' own hearing aids (significant differences at the $p < 0.05$ level were indicated with an asterisk). The significant difference was seen at both the one-month and three-month post-fitting. These items included: overall satisfaction, battery life, feedback, localization, hearing soft sounds, large groups, TV, car, and music. Only four items showed a significant change at one time and not the other time of evaluation (fit/comfort, clarity of sounds, small group, house of worship). There was no significant difference in rating for the other items.

DISCUSSION

The present study showed an improvement in SPIN scores when performance was compared between the initial visit and the one-month follow-up with the study hearing aids. No improvement in SPIN scores or in subjective ratings was observed between the one-month and three-month visits. This supports the hypothesis of acclimatization on objective tasks, and further suggests that this phenomenon, if present in subjective rating tasks, takes about a month to plateau. In addition, this study also showed significantly higher SPIN scores for the study hearing aids than the subjects' own hearing aids at the 50 dB SPL and 65 dB SPL test conditions. Results on the subjective questionnaires also supported the advantage of the study hearing aids in situations where the audibility of low level input sounds and perception in noise may be important. This supports the

efficacy of the study hearing aids and suggests that multichannel nonlinear processing as used in the study hearing aids may be preferable to single channel linear processing commonly used by individuals with a severe-to-profound degree of hearing loss.

Advantage of a lower CT

A key feature of the study hearing aid that prompted this study is its low compression threshold at 20 dB HL in all three channels. Even though not all the participants in this study were able to achieve this low CT because of earmold related feedback issues, the average participant benefited from this low CT nonetheless. This is evidenced in the better aided sound-field thresholds with the study hearing aids, higher SPIN scores at the 50 dB SPL input level at all evaluation intervals, and higher ratings on items in the Washington University Questionnaire and MarkeTrak questionnaire that related to listening at low input levels (soft sounds, localization, hearing at a distance).

The advantages of the low CT may appear at odds with the report of Dillon et al (1998) who showed that adult hearing-impaired people preferred a higher compression threshold (> 65 dB SPL) than a lower one. There are both hearing aid specific issues and criteria issues that made comparisons difficult. In addition to the difference in subject population (moderate versus severe-to-profound hearing loss), Dillon et al (1998) used a single channel fast-acting WDRC hearing aid that employed linear processing below the CT as the main processing strategy. A problem with linear processing below the CT is that same gain is applied to sounds at and below the CT. This gives rise to the possibility that typical ambient noise would be amplified to an audible level (Kuk, 1999). The effect would be exacerbated with the use of short release times because of the more frequent gain fluctuation. On the other hand, the study hearing aids employed a long adaptive release time (from 10 ms to 20 s) with expansion processing below the compression threshold. In contrast to compression, an expansion circuit increases its gain as input level increases. This type of processing allows the desirable gain to be achieved at the target input level (CT) while providing less gain for input levels below the CT. This has the effect of minimizing the perception of circuit noise while maximizing the advantages of a low CT.

These two studies were also different in their objectives. Dillon et al (1998) examined wearer preference for compression threshold. In this study, the experimenters recognized potential objections to a low CT by the participants, but insisted that they try the recommended amplification for at least one month. Such preparation may have neutralized any negative comments on the use of a low CT. Although one may argue that such practice may have positively biased the subjective findings, that could not explain the positive findings on the SPIN test.

Evidence of acclimatization?

The first documented suggestion of acclimatization with hearing aid use was made by Watson and Knudsen (1940) who reported that one of their seventeen subjects showed improved speech scores over time with hearing aid use. Throughout the years, many authors (e.g., Gatehouse, 1992, 1994; Horwitz and Turner, 1997; Silverman and Silman, 1990) reported the same observation. On the other hand, probably an equal number, if not many more questioned the validity of such observations (e.g., Arlinger et al., 1996; Holte et al., 1997; Neuman et al., 1997; Saunder and Cienkowski, 1997). As indicated earlier, such differences in observation could be related to the stimulus test conditions, study protocol, and the choice of the "right" study participants (Palmer et al., 1998).

The results of this study supported the hypothesis of acclimatization in the severe-to-profound hearing loss population. The significant improvement in SPIN scores at the one month follow-up over the initial evaluation attests to this conclusion. Indeed, if one examines Figures 4 and 5 (LP and HP item scores respectively), one can offer the following explanation for the observed findings. With the low CT, more speech information that was previously inaudible (with the linear hearing aids) became audible. If audibility were the only determinant of speech recognition, one would expect an increase in SPIN score (over the participants' own hearing aids) at the initial visit, but no further increase at subsequent visits. This was not the case. Figure 4 shows minimal or no change in LP-item scores between the participants' aids and the test aids at the initial visit at the 50 dB and 75 dB SPL test conditions. However, a small but significant increase was noted for the 65 dB SPL condi-

tion. This suggests that the additional audibility did not fully improve the intelligibility of LP items. The same is not true for the HP items (Figure 5). A difference of 9% in HP-item scores was noted between the study hearing aids and the participants' own aids at the initial visit for the 50 dB SPL condition and 2% for the 65 dB SPL condition. A decrease of 2% was noted at the 75 dB SPL (+10 SNR) condition. The observation that LP item scores were not improved but HP item scores did initially may suggest that overall speech was more audible, but not necessarily those of the target words. Because the identification of the LP items required identification of the target words whereas identification of the HP items may not have such a stringent requirement, the extra audibility yielded higher scores for the HP but not the LP items at the 50 dB SPL test condition. With time and use of the hearing aids, the audible cues that were available at the initial visit became "usable" by the wearers. This may explain the increase in item scores (LP, HP) at the one-month post-fitting interval over the initial fitting. The non-significant difference in item scores between the one-month and three-month post-fitting intervals suggests that most of the acclimatization effect plateaued by about one month.

The phenomenon of acclimatization was observable in all test conditions, although the pattern at the 75 dB SPL (+10 SNR) condition may not be as clear as the 50 dB SPL condition. However, if one examines the word scores at the different test intervals, one would find improvement ranging from 2% to 5% between the initial and three-month evaluation intervals. This improvement, however, was non-significant.

The above-mentioned observations may be explained by the design of the study hearing aids. The low CT accounted for the additional audibility and improved SPIN scores at the initial and one month visits for the low- and medium- presentation levels. At a higher input level (and in noise), the nonlinear characteristics of the study hearing aids (high-level compression) would result in less gain and possibly less distortion than what the participants had previously experienced with their linear hearing aids. One may hypothesize that the loss of loudness and possible loss of distortion (temporal as well as saturation) cues at the initial visit may have accounted for the poorer initial performance with the study hearing aids. Fortunately, this loss of information was not detrimental,

but rather beneficial as evidenced by the gradual improvement in SPIN scores over time as participants acclimatized to the new temporal cues. It would be of interest to examine if such an improvement extends beyond the three-month evaluation. Gatehouse (1992) suggested that 18 weeks (4 1/2 months) may be necessary for acclimatization.

One may question, because of the availability of the VC (+/- 6 dB adjustment) and the allowance for clinician gain adjustment at follow-up visits, that the noted changes may be a function of additional gain desired by the participants and not a better use of existing gain. Clearly, an alternative study design is to prohibit any gain adjustment in the study hearing aids during the study period. This was impossible given our desire to evaluate the real-life efficacy of the study hearing aids in this study as well. However, our choice may not alter the present findings for three reasons. First, Horwitz et al (1997) found that acclimatization was evidenced in subjects regardless of gain adjustment. Secondly, the majority of participants required less than 2 dB gain change with the average participant desiring 2 dB less gain for low- and medium-level sounds and 4 dB more gain for high-level sounds in the mid frequencies. This amount of gain change is possibly too small to result in any measurable difference in speech scores. Furthermore, the direction of gain change is opposite to the direction of the observed improvement in SPIN scores for the 50 dB SPL and 65 dB SPL test conditions. One may argue that acclimatization may have been diminished because of such an adjustment. Lastly, there was not a significant difference in subjective ratings between the one-month and three-month follow-up when gain changes were made.

A limitation of the current study design that may have prohibited the full observation of acclimatization is that no subjective data on the study hearing aids were collected during the initial visit. Rather, all the questionnaires were collected one month after wearing the study hearing aids. Such a decision was made because subjective data obtained without any participant experience may be meaningless. On the other hand, the observation of no subjective acclimatization between one-month and three-month visits leaves the question on subjective acclimatization unresolved. Is there no subjective acclimatization at all, or does acclimatization on subjective tasks also plateau before one month? Future studies on subjective acclimatization will need to exam-

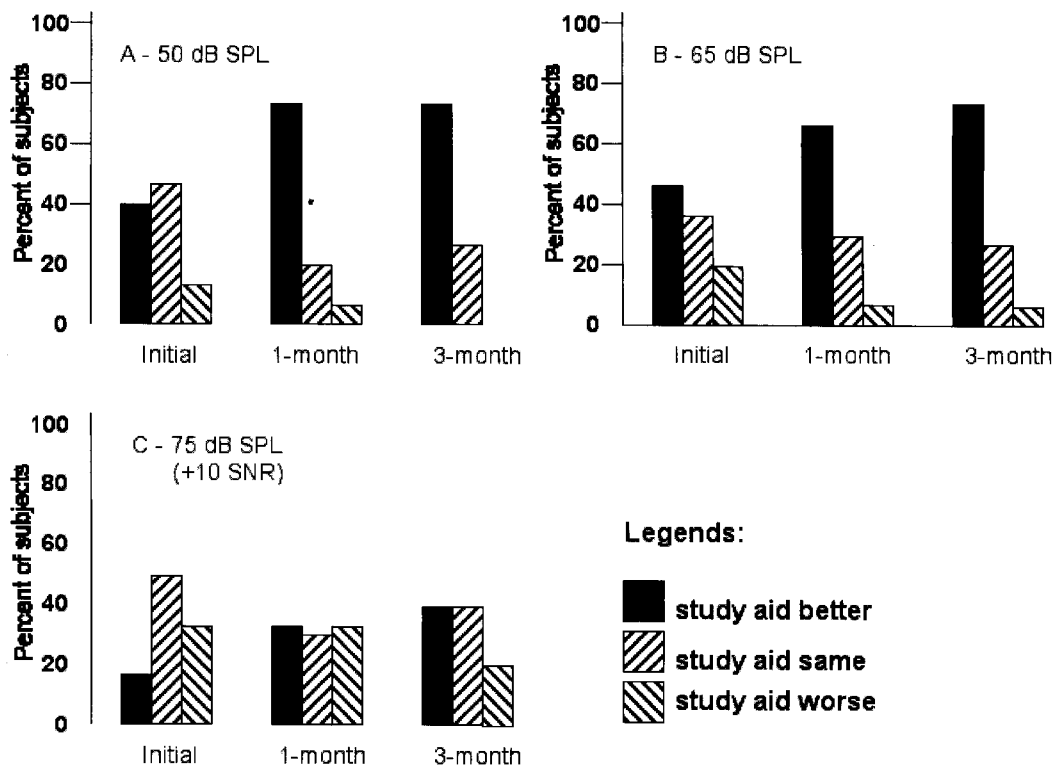


Figure 8. Mean percentage of subjects showing the “Same,” “Better,” and “Worse” total SPIN scores with the study hearing aids re: their own hearing aids at the three evaluation intervals when the stimuli were presented at (A) 50 dB SPL in quiet, (B) 65 dB SPL in quiet, and (C) 75 dB SPL in noise (+10 SNR).

ine subjective performance closer to the initial fit in order to detail the time course of subjective acclimatization.

Implications

There are several clinical implications from the results of the current study. First, the phenomenon of acclimatization is real and its expression is often determined by the test conditions, choice of subjects, evaluation materials, and the type of hearing aid processing used in the evaluation. In general, acclimatization is evidenced when the wearer has been sufficiently deprived of the acoustic stimuli and is given a chance to utilize them. The choice of participants with a severe-to-profound degree of hearing loss and the use of sentence materials with target words of different contextual cues may have optimized this evaluation. The use of multichannel nonlinear processing with a low CT

(and expansion) may be more effective than the use of single channel linear processing to demonstrate this phenomenon in this population also. Participants with a different degree of hearing loss or hearing aid experience may require different evaluation materials or hearing aid processing to demonstrate this phenomenon. Furthermore, because the effect of acclimatization may be subtle, a relatively large sample size may be necessary to allow sufficient statistical power. These factors are important to consider when studying acclimatization or comparing the results of this study to other studies.

Secondly, the time course of acclimatization may be different for different evaluation materials. In this case, it took approximately one month for the participants to acclimatize to the extra audibility cue that affected their SPIN scores in quiet. However, it may take more than three months for the average wearer to improve SPIN scores in noisy background. This suggests that acclimatiza-

tion may not be a uniform and immediate phenomenon. Rather, it may be a process that has different rates of expression for different tasks.

From the clinical perspective, the results of this study highlight the importance of postponing validation measures on hearing aids beyond the initial visit. The authors re-analyzed the SPIN total scores by counting the percentage of participants who achieved a higher, the same, and a lower SPIN score with the study hearing aids than their own hearing aids at the initial, one-month, and three-month evaluation intervals. Based on the within-subject test-retest variability that was observed in a few subjects and from the use of the same test on other occasions, an arbitrary criterion difference of 5% was set for significant differences. The results are summarized in Figure 8 (a, b, and c) for the three test conditions. For the 50 and 65 dB SPL conditions (Figures 8a and 8b respectively), only about 40% of participants showed better performance with the study hearing aids than their own hearing aids at the initial visit. However, at the one-month follow-up, as many as 75% of the participants showed more than 5% improvement with the study hearing aids. If one had made a decision on the appropriateness of the study hearing aids based simply on the initial test results, one would have concluded that two-thirds of the participants would not do better with the study hearing aids. In real-life, the study hearing aids yielded better performance in three-quarters of the participants when they were evaluated at a later time. Similarly, only 15% of the participants performed better with the study hearing aids than their own hearing aids during the initial visit in the 75 dB SPL (+10 SNR) condition. On the other hand, 35% - 40% of them performed better with the study hearing aids at the one-month and three-month visits (Fig 8c). It seems necessary to delay efficacy measures to at least one month post-fitting before one can conclude if the new hearing aids are better than the participants' previous ones.

Along the same line, the results of the current study cast doubt on the appropriateness to fine-tune the recommended settings on hearing aids during initial fittings with the first sign of patient complaint. While such an action may be necessary because the initial estimate may not be optimal, it is also possible that the settings are optimal, but the patients are unaccustomed to the processed sounds. In the later case, adjustment may compromise the benefits offered by the design of the hearing aids. One must understand whether their patients' complaints are expected

reactions or true complaints that originate from a sub-optimal fit. Counseling and proper instructions would be necessary if they are expected reactions. Especially now that digital signal processing is used extensively to achieve different sound processing, it is important that clinicians are fully familiar with their hearing aids to avoid compromises on their fittings.

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