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Using Trainable Hearing Aids to Examine Real-World Preferred Gain

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Abstract

Background: While there have been many studies of real-world preferred hearing aid gain, few data are available from participants using hearing aids with today's special features activated. Moreover, only limited data have been collected regarding preferred gain for individuals using trainable hearing aids.

Purpose: To determine whether real-world preferred hearing aid gain with trainable modern hearing aids is in agreement with previous work in this area, and to determine whether the starting programmed gain setting influences preferred gain outcome.

Research Design: An experimental crossover study. Participants were randomly assigned to one of two treatment groups. Following initial treatment, each subject crossed to the opposite group and experienced that treatment.

Study Sample: Twenty-two adults with downward sloping sensorineural hearing loss served as participants (mean age 64.5; 16 males, 6 females). All were experienced users of bilateral amplification.

Intervention: Using a crossover design, participants were fitted to two different prescriptive gain conditions: VC (volume control) start-up 6 dB above NAL-NL1 (National Acoustic Laboratories—Non-linear 1) target or VC start-up 6 dB below NAL-NL1 target. The hearing aids were used in a 10 to 14 day field trial for each condition, and using the VC, the participants could "train" the overall hearing aid gain to their preferred level. During the field trial, daily hearing aid use was logged, as well as the listening situations experienced by the listeners based on the hearing instrument's acoustic scene analysis. The participants completed a questionnaire at the start and end of each field trial in which they rated loudness perceptions and their satisfaction with aided loudness levels.

Results: Because several participants potentially experienced floor or ceiling effects for the range of trainable gain, the majority of the statistical analysis was conducted using 12 of the 22 participants. For both VC-start conditions, the trained preferred gain differed significantly from the NAL-NL1 prescriptive targets. More importantly, the initial start-up gain significantly influenced the trained gain; the mean preferred gain for the +6 dB start condition was approximately 9 dB higher than the preferred gain for the −6 dB start condition, and this difference was statistically significant ($p < .001$). Partial eta squared (η^2) = 0.919, which is a large effect size.

Deviation from the NAL-NL1 target was not significantly influenced by the time spent in different listening environments, amount of hearing aid use during the trial period, or amount of hearing loss. Questionnaire data showed more appropriate ratings for loudness and higher satisfaction with loudness for the 6 dB below target VC-start condition.

Conclusions: When trainable hearing aids are used, the initial programmed gain of hearing instruments can influence preferred gain in the real world.

Key Words: Hearing aids, NAL-NL1, preferred gain, trainable

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Abbreviations: AGCi = automatic gain control-input; AGCo = automatic gain control-output; DNR = digital noise reduction; DSL*m* [i/o] v5 = desired sensation level multistage [input/output], version 5; LDL = loudness discomfort level; NAL-NL1 = National Acoustic Laboratories—Non-linear 1; NAL-RP = National Acoustic Laboratories—Revised Profound; REIG = real ear insertion gain; VC = volume control; WDRC = wide dynamic range compression

Sumario

Antecedentes: Mientras que han habido muchos estudios sobre ganancia preferida en auxiliares auditivos (HA) en el mundo real, pocos datos existen de participantes usando HA con los dispositivos especiales activados de hoy día. Más aún, sólo datos limitados han sido recogidos en relación con la ganancia preferida para individuos usando HA entrenables.

Propósito: Determinar si las ganancias preferidas para HA en el mundo real con HA modernos entrenables está en acuerdo con trabajos previos en esta área, y determinar si el ajuste de ganancia inicial programado influye en los resultados de la ganancia preferida.

Diseño de la Investigación: Es un estudio experimental de cruzamiento. Los participantes fueron asignados al azar a uno de los dos grupos de estudio. Luego del tratamiento inicial, cada sujeto cambio al grupo opuesto y experimentó ese tratamiento.

Muestra del Estudio: Veintidós adultos con perdidas sensorineurales de pendiente descendente participaron (edad media 64.5 años; 16 hombre, 6 mujeres).Todos eran usuarios experimentados de amplificación binauricular.

Intervención: Utilizando un diseño de cruzamiento, se le adaptó a los participantes dos condiciones diferentes de ganancia de prescripción: el VC (control de volumen) inició a 6 dB por encima de la meta del NAL-NL1 (Laboratorio Nacional de Acústica – No Lineal) o el VC inició a 6 dB por debajo de la meta del NAL-NL1. Los HA se utilizaron durante un ensayo de campo de 10 a 14 días para cada condición, y usando el VC, los participantes podían "entrenar" la ganancia global del audífono a su nivel preferido. Durante el ensayo de campo, el uso diario del HA fue registrado, así como las situaciones de escucha experimentadas por el sujeto basados en el análisis de la escena acústica del instrumento auditivo. Los participantes completaron un cuestionario al inicio y al final de cada ensayo de campo, en donde calificaron las percepciones de sonoridad y su satisfacción con los niveles de sonido amplificado.

Resultados: Dado que varios participantes experimentaron potencialmente efectos de techo o de piso para el rango de ganancia entrenable, la mayoría de los análisis estadísticos se condujeron usando 12 de los 22 participantes. Para ambas condiciones de VC al inicio, la ganancia entrenada de preferencia fue significativamente diferente de la meta de prescripción del NAL-NL1. Más importantemente, la ganancia de inicio influyó significativamente en la ganancia entrenada; la ganancia preferida media para la condición de inicio de +6 dB fue aproximadamente 9 dB mayor que la ganancia preferida para la condición de –6 dB, y esta diferencia fue estadísticamente significativa ($p < .001$). Se dio un eta cuadrado parcial (η^2) = 0.919, que es un efecto grande de tamaño.
La desviación de la meta del NAL-NL1 no fue significativamente influida por el tiempo pasado en diferentes ambientes de escucha, la cantidad de uso de HA durante el periodo de prueba, o la magnitud de la hipoacusia. Los datos del cuestionario mostraron calificaciones más apropiadas para la sonoridad y mayor satisfacción con la sonoridad para la condición de inicio de VC 6 dB por debajo de la meta.

Conclusiones: Cuando se utilizan HA entrenables, la ganancia inicial programada del instrumento auditivo puede influir en la ganancia preferida en el mundo real.

Palabras Clave: Auxiliares auditivos, NAL-NL1, ganancia preferida, entrenable

Abreviaturas: AGCi = control automático de ganancia de ingreso; AGCo = control automático de ganancia de salida; DNR = reducción digital del ruido; DSL*m* [i/o] v5 = nivel deseado de sensación en multi-etapas [input/output] versión 5; LDL = nivel de molestia en la sonoridad; NAL-NL1 = Laboratorios Nacionales de Acústica – No Lineal 1; NAL-RP = Laboratorios Nacionales de Acústica – Revisado Profundo; REIG = ganancia de inserción de oído real; VC = control de volumen; WDRC = compresión de rango dinámico amplio

Many factors must be considered when hearing aid fitting algorithms are developed and validated. Consideration is commonly given to such issues as audibility, loudness, speech intelligibility, and sound quality. The weighting of these different factors can, and usually does, impact the resulting prescriptive method.

Another patient-specific attribute that is often also considered is preferred listening level or preferred gain. That is, if the hearing aid user, rather than the audiologist, is allowed to choose the gain provided by the hearing aids, what would he or she select? Assuming that the patient is provided appropriate real-world listening situations, it could be reasoned that his or her "preferred" gain would be some personal best case composite of audibility, loudness, speech recognition, and quality. Many older prescriptive methods used with linear instruments, such as Berger (Berger et al, 1977), POGO (prescription of gain and output; McCandless and Lyregaard, 1983) and Libby1/3 (Libby, 1985), were based primarily on estimates or measurements of average preferred gain.

Currently two validated prescriptive methods are commonly available for programming hearing aids: the desired sensation level (DSL*m* [i/o] v5) (Scollie et al, 2005) and the National Acoustic Laboratories—Non-Linear 1 (NAL-NL1) (Byrne et al, 2001). While preferred gain was not specifically used to develop either of these methods, it has been used as a metric in validation studies; more so for the NAL method (see Mueller 2005; Keidser and Dillon, 2007, for review). This is partly because the DSL has been used more with infants and children, where preferred gain often is not measurable, or is less reliable. Nonetheless, there have been a number of DSL focused preferred gain studies with adults (Jenstad et al, 2007; Moodie et al, 2007).

As mentioned, the majority of preferred gain studies have been related to the NAL family of prescriptive methods, as this is the most common fitting algorithm used for adults and has been in use for over 30 years. Moreover, the prescriptive targets for average inputs for the NAL method have not changed significantly since 1986 (Dillon, 2006). This allows for a large body of comparative data.

In 2005, Mueller published an evidenced-based review of research centered on use gain or preferred gain using the NAL-RP [National Acoustic Laboratories—Revised Profound] targets (prescription for average inputs) as a reference (Byrne et al, 1990). His review criteria were such that he only included studies in which prescriptive targets had been verified using probe-microphone measures, and the subjects used the hearing aids in real-world conditions. He found that for the majority of the studies that met the criteria, gain similar to the NAL-RP was preferred. When preferred gain findings did not agree with the NAL-RP, a consistent finding was a preference for gain *lower than* the NAL-RP prescription (e.g., Humes et al, 2000; Smeds, 2004).

In a recent laboratory study, Hornsby and Mueller (2008) report findings consistent with the consensus of the Mueller (2005) review. These authors initially fitted participants bilaterally according to the NAL-NL1 prescriptive targets. The participants were then exposed to several unique listening situations that encouraged substantial gain adjustments to either the right or left hearing aid, or both. At the end of each trial the participants were asked to readjust gain for clarity and comfort for a typical listening task (speech at 65 dB SPL from the front). While there was considerable variability among participants, the mean gain setting for both the right and left ears was within 1–2 dB of the NAL-NL1 65 dB SPL input targets.

In another recent paper, Keidser and Dillon (2007) reviewed preferred hearing aid gain research and compared the pooled findings to the prescribed gain of the NAL-NL1. In one portion of the paper, they review the findings of five studies published between 1988 and 2005. The authors report that the across study mean variation from the NAL prescribed gain (for average-level inputs) for these five studies was −4.3 dB. The authors also present more recent data, pooled from five other studies, which resulted in a total sample of 189 adult subjects. Using the NAL-NL1 prescription target (for a 65 dB input) and a ±3 dB tolerance window, they found that 49% of these participants had preferred gain that fell within this 6 dB range; only 5% of the preferred gain values were in excess of NAL-NL1 +3 dB, whereas 46% of the individuals had preferred gain that fell below NAL-NL1 −3 dB. They show, however, that by reducing the prescriptive target by 3 dB and continuing to use the ±3 dB tolerance criterion, 60% of these same participants would then fall within the revised 6 dB window, and 20% of the other preferred gain values would then be evenly divided above and below this criterion. Related to these findings, Dillon (2006) states that the new NAL prescriptive method, NAL-NL2, will have slightly reduced prescriptive targets for average-level inputs.

One problem that exists when using the results of older studies to reach a conclusion regarding average preferred gain is that many of these studies were conducted using hearing aids with analog linear processing. Also, many of these studies did not use hearing aids that employed features that are commonly included with today's modern instruments (e.g., such features as multichannel wide dynamic range compression [WDRC], AGCo [automatic gain control-output], expansion, digital noise reduction [DNR], automatic directional technology, and adaptive feedback control). In some cases, even when features such as DNR or directional technology were available, they were disabled when the subjects used the hearing aids in the real world (e.g., Smeds, 2004). Even in the most recent 2007 Keidser and Dillon report, only a small portion of the 189 subjects had features such as noise reduction, directional technology, or automatic feedback reduction activated (Keidser, pers. comm.). Considering these advanced features, one by one, it would seem that they all have the potential to encourage the use of *more* rather than *less* gain, because in most cases, the feature allows for the limiting of excessive loudness (AGCo), the improved control of loudness (WDRC), the reduction of background noise (directional technology and DNR), or the elimination or reduction of annoyance, such as low level noise (expansion) and acoustic feedback (adaptive feedback control). Research has shown, for example, that activation of features such as DNR and expansion is preferred when listening in background noise (Ricketts and Hornsby, 2005; Plyler et al, 2007). Given that all of these features are available and usually activated for the majority of today's hearing aid fittings, we believed it was important to examine their impact on real-world preferred gain.

Another factor that can influence the findings of real-world preferred gain is the method in which these data are collected. In some previous studies, the preferred gain setting was determined by using multi-memory hearing aids and then programming two or three different algorithms for the different memory settings. The participant then selected the preferred memory during real-world use. The limitation of this approach is that it is not known if the memory selected was the actual "preferred gain" or simply what was closest to preferred gain (e.g., even if the subject selected the memory with the least gain, preferred gain could have been significantly below this amount). A second method commonly used to collect preferred gain data is to fit the subjects with hearing aids with volume controls (VCs). After a real-world listening trial, the patient then returns to the laboratory, and gain is recorded for the VC setting. With this approach, the limitation is that it is not known if the setting of the VC at the moment the subject walked into the laboratory truly represents what the subject was using in the real world. A final data-gathering approach would be to provide the user with a VC for the real-world experience, but upon returning to the laboratory the user is given the opportunity to fine-tune his preferred gain by listening to different stimuli. This approach makes the assumption that laboratory-based preferred gain is the same as what is preferred in the real world, which may not be true (Dillon et al, 2006).

The technology necessary for a "trainable" hearing aid (Dillon et al, 2006; Zakis et al, 2007) has only been available for a few years. While it is possible to train many hearing parameters including WDRC settings and frequency response, the most common commercially available implementation has been to use this technology to train overall hearing aid gain. That is, the hearing aid uses data logging to record VC settings during hearing aid use. In the automatic mode, the hearing aids will then alter start-up gain (whenever the hearing aid is turned on) based on the history of the user's VC changes and preferred VC settings for the preceding hours/days. If automatic changes are not enabled, it is still possible to read out from data logging the VC changes and average preferred gain values reflecting the training that occurred. This technology, therefore, can be used to estimate preferred gain in the real world. The advantages of this approach are that the subject has a wide range of gain settings available, investigators do not have to rely on the subjects' memory of their preferred VC settings, and all data are collected from real-world listening experiences.

While there have been many studies of preferred hearing aid gain, the present research was designed to differ from these previous studies in three areas. First, we used modern hearing aids containing all contemporary special features; all of these features were activated during data collection. Second, the data were collected using trainable hearing aids in the real world that automatically altered start-up gain settings based on the subject's history of VC adjustments and, through data logging, provided a measure of average preferred gain. Finally, using a cross-over design, the start-up gain was programmed both above and below the established NAL-NL1 targets. Specifically, we questioned whether preferred gain using these modern instruments in the real world would be similar to the findings from previous studies, and whether the user's preferred gain would be influenced by the starting point of the programmed gain of the instruments.

MATERIALS AND METHODS

Participants

A total of 22 individuals participated in this study, 16 males and 6 females. Their ages ranged between 24 and 83 years (mean age, 64.5), and they were recruited from the University of Northern Colorado Speech-Language Pathology and Audiology Clinic. Study procedures were approved by the University of Northern Colorado Human Research Internal Review Board. All procedures were explained to the participant, and informed consent was obtained. At the conclusion of the study each participant received $50.00 for his or her participation.

All participants had a bilateral downward sloping mild to moderately severe sensorineural hearing loss with hearing levels no better than 20 dB at 500 Hz and no worse than 80 dB at 3000 Hz. Symmetry between ears was within 15 dB for any given frequency. The mean audiograms for the right and left ears are displayed in Figure 1.

All participants were routine users of bilateral hearing aids and had used hearing aids for at least one year. They were all current users of digital multichannel hearing instruments that employed wide dynamic range compression (WDRC).

Hearing Aids

The hearing aids used in this research were behind-the-ear (BTE) Siemens Centra Model S, with 16-channel AGCi (automatic gain control-input), low-level expansion, and AGCo. Across the 16 channels, the hearing aids had automatic directional technology with adaptive polar

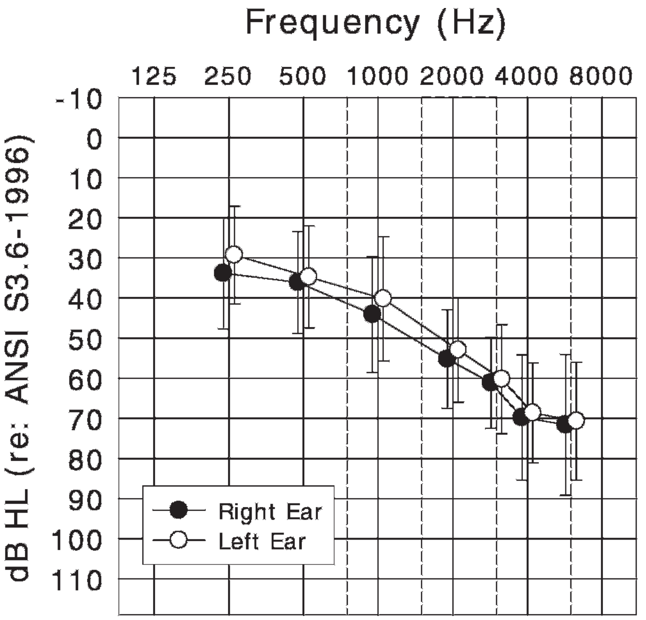

Figure 1. Mean audiogram and standard deviations for the right and left ears of the 22 participants.

patterns and adaptive feedback cancellation. The hearing instruments employed three different types of digital noise reduction (DNR) algorithms, which operate simultaneously and independently in 16 channels. One DNR algorithm is modulation based, an advanced version of the algorithm described by Powers et al (1999) and Mueller et al (2006), with relatively slow onset and offset (onset, ~6–8 sec; offset, ~500 msec). The second DNR algorithm is an adaptive fast-acting noise reduction system, similar in design to Wiener filter technology (see Vaseghi, 2000, for review). The third DNR algorithm is designed to reduce the gain of short duration nonspeech transient sounds (Chalupper and Powers, 2007). Noise reduction strength was set to "medium."

The research hearing aids also employed data logging, in which the data from the acoustic scene classification system was categorized into one of five environmental conditions: quiet, speech in quiet, speech in noise, noise, and music. Total hours of use and average daily use also were logged. The hearing aids could be programmed so that the right and left instruments were "linked," and this feature was implemented for the field trial. That is, information sharing takes place between instruments through the use of electromagnetic transmission. When linked the hearing aids have symmetrical steering of the automatic directional systems and the DNR algorithms. Additionally, the input obtained from both instruments is shared, and a single acoustic scene analysis decision is made (consequently, if the hearing aids are always used together, acoustic scene data logging will be identical). Also, when the hearing aids are linked, when a VC change is made to one instrument, the same gain change is applied to the other.

The final special hearing aid feature, an important part of the design of this study, is that the hearing aids had trainable gain. In this product, this training does not alter the maximum or minimum gain of the instruments but, rather, the start-up gain when the hearing aids are first turned on. The physical time constant for learning is defined as the time required by exponential averaging to reach 65% of steady state (optimal gain). This target typically is reached after 17 hours of hearing aid use (see Chalupper and Powers, 2006, for review). Because the hearing aid processing was linked and the hearing aids were used together, the trained gain was the same for both instruments.

Procedures

During the first visit, a complete audiometric evaluation, including immittance testing, was carried out using a Grason Stadler GSI 61 audiometer with ER-3A insert earphones and a Grason Stadler GSI 33 immittance unit. Calibration was in accordance with ANSI 3.6 (American National Standards Institute, 1996). Loudness discomfort levels (LDLs) also were obtained via earphones for 1500 and 3000 Hz pulsed pure-tone signals; the loudness anchors and instructions from the Cox Contour Test were used (Cox, 1995). Ear impressions were obtained, and custom earmolds with #13 standard tubing were ordered; vents, ranging in size from pressure to 2 mm were included based on the participant's hearing loss in the lower frequencies.

At the second visit, participants were fitted with their custom earmolds and bilateral hearing aids. The Siemens CONNEXX version 5.0 software was used for all programming. With only one program activated, the instruments were "First Fit" to the Siemens NAL-NL1 prescriptive method. The volume control range was set at 16 dB with a 50% VC setting (allowing the participant to adjust gain up or down by 8 dB). This 50% point is referred to as "start-up gain," as prior to making any VC adjustments, this is what the user will experience when the hearing aids are turned on. User notification "beeps" were disabled so that the participants did not have a specific reference for gain adjustment or for the boundaries of the gain range.

Compression kneepoints were set at 50 dB SPL in all 16 AGCi channels. The AGCo kneepoint (single channel) was adjusted according to the participant's LDLs (average of 1500 and 3000 Hz; the HL earphone LDLs were converted to 2-cc values using the RETSPLs [reference equivalent thresholds in sound pressure level] for insert earphones).

Probe-microphone measures were obtained utilizing an Audioscan RM 500 SL Speech Mapping System calibrated to the manufacturer's recommendations. Measures to establish real-ear insertion gain (REIG) were conducted following the recommended protocol

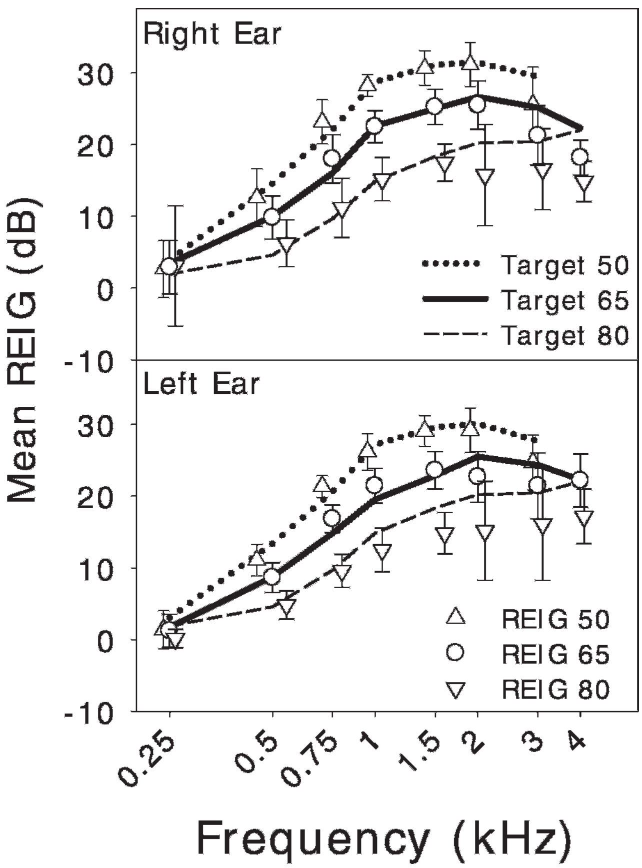

Figure 2. Mean measured REIG compared to NAL-NL1 target REIG for the right and left ears for the inputs of 50, 65, and 80 dB SPL (pink noise stimulus). Error bars represent one standard deviation around the mean REIG.

for this equipment, which included the use of a pink-noise input stimulus and the use of average real-ear unaided gain (REUG) values (Etymotic Design, 2007). REIG was obtained for inputs of 50, 65, and 80 dB SPL. During this verification procedure, gain and compression ratio adjustments were made using the CONNEXX software for each input level to modify the REIG to obtain the best match to the NAL-NL1 REIG targets; compression kneepoints were not altered. When it was not possible to obtain a close match (~3 dB) for all three input levels, priority was given to the 65 dB input level. During this testing, the DNR algorithms and the automatic directional feature were disabled, as the pink-noise stimulus would have been interpreted as noise by the signal classification system. Pilot work conducting probe-microphone measures with these instruments, using real speech as the input stimulus, had shown that gain for speech did not change when these features were enabled.

Figure 2 shows the average REIGs for the right and left ears for the three input levels compared to the respective NAL-NL1 targets. Observe that a close match to target across frequencies was obtained for the 50 and 65 dB inputs (average rms [root mean square] fitting error of 3.9 dB for both input levels across eight key frequencies). For the 80 dB input signal, the match to target was somewhat poorer for the higher frequencies, with the average REIG falling about 5 dB below the prescribed targets. This primarily was because some individuals had relatively low LDLs, which resulted in a low AGCo kneepoint setting, which in turn limited the REAR for the 80 dB input. For these individuals it seemed better to slightly underfit gain for the high frequencies for the 80 dB input rather than to allow the output in this region to exceed the participants' LDLs, which potentially could influence their preferred gain setting.

Once an appropriate match to target had been obtained, the overall gain of the instruments was altered by either +6 or −6 dB; this resulted in an equal gain change for all frequencies. No compression or frequency response parameters were changed. Through a counterbalancing and random assignment procedure, 50% of the participants were provided a midpoint gain setting (start-up gain) of NAL +6 dB (with a ±8 dB window available for training), and the other 50% of participants were provided a mid-point gain setting of NAL −6 dB (also with a ±8 dB window available for training). All special features were activated for the field trial including expansion, DNR, automatic directional technology, and adaptive feedback reduction.

Prior to beginning the field trial, which lasted 10–14 days, all participants were provided with detailed instructions and demonstration on the use of the hearing instruments. They were given written instructions that specifically emphasized that they always use the hearing aids together and use the hearing aids in as many different listening situations as possible. They were also encouraged to make VC changes whenever necessary to obtain the best loudness levels for each listening situation. The participants were given two identical questionnaires to complete during the trial period (see Appendix A). They were instructed to complete one during the first or second day of the trial, and the other at the end of the field trial. The ten questions related to the rating of loudness and loudness satisfaction for five different input signals/levels: soft speech and other soft-level sounds, average speech and other average-level sounds, loud speech and other loud-level sounds, speech in background noise, and background noise.

Because the hearing aids were trainable, and because the participants were not fitted to the NAL-NL1, it was expected that the start-up gain would change during the course of the home trial. For this reason, they were asked to respond to the ten questions based on their listening experience "when you first turn on the hearing aids, before any volume control adjustments." The participants, however, were not informed that the hearing aids were trainable.

Following the first home trial period, all participants returned to the clinic, their questionnaires were collected, and the data logging for their instruments was read. The hearing aids were then reprogrammed to original NAL-NL1 target settings (saved in the fitting software). Based on the counterbalance table, the overall gain was then either increased or decreased by 6 dB so that each participant crossed over to the other group (e.g., participants who previously were in the 6 dB *below* NAL-NL1 target group were now programmed to be in the 6 dB *above* NAL-NL1 target group). They were again provided the written instructions and the questionnaires to complete. Following the second trial period, the data logging was again read. At the end of the study, all participants had been fitted with both the +6 dB and −6 dB conditions; data logging of use gain and acoustic scene analysis had been obtained for both conditions; and two questionnaires had been completed for each field trial condition.

RESULTS

The goal of this research was to determine preferred gain for individuals who were using modern hearing aids with all typical special features activated (e.g., DNR, directional microphone technology), and to examine the effects of initially fitting the participants to gain that differed from an established prescriptive method. In addition, preferred gain data were collected in a method different from most previous studies, using data logging information from hearing aids with trainable VC start-up gain.

Given the focus of the study on preferred gain settings, it was important that participants be able to achieve their desired gain. Unfortunately, this may not have been possible for some participants. Specifically, our maximum gain deviation of ±8 dB was inadequate to allow some participants to adjust the VC to their preferred gain setting, if that setting exceeded the baseline setting by ±8 dB. To ensure that ceiling or floor effects did not influence the results, data for statistical analysis were limited to those individuals whose trained preferred gain was within ±6 dB from the baseline gain setting. Using this criterion, data from ten of the 22 participants were excluded. Of these ten individuals, seven may have experienced floor effects. In other words they may have been unable to turn down gain enough to achieve their preferred gain for at least one of the VC starting conditions. Three participants may have experienced ceiling effects, in that they adjusted gain up to the 8 dB maximum in at least one of the VC starting conditions. One participant adjusted gain up 8 dB when starting with the VC 6 dB below NAL-NL1 targets and down 7 dB when starting 6 dB above NAL-NL1 targets. It is possible that this individual preferred a gain setting that approximated NAL-NL1 targets; however, for consistency these data were excluded as well. As previously stated, the start condition for the 22 subjects was counterbalanced. For the subset of 12 subjects, seven started with 6 dB below, and five started 6 dB above. While on the surface these floor and ceiling effects would seem to be problematic, excluding the data from these ten participants had only a minimal effect on our overall results.

A post hoc power analysis utilizing the measured variance between conditions, based on the 12 remaining participants, revealed that differences between conditions of approximately 2.5 dB could be adequately detected (power = 0.8, alpha = 0.05). Following established conventions (e.g., Cohen, 1968), using the pooled variance from the current study (3.84 dB), and assuming a mean difference between groups of 2.5 dB resulted in a medium effect size (see Vacha-Haase and Thompson, 2004, for a discussion of interpreting effect size).

For completeness, whenever individual data are shown, data from the excluded participants are also included on the figure. Unless otherwise noted, however, their data were not included in the statistical analyses.

Because this was a crossover design, an initial analysis was completed to determine if sequence or carryover effects were present. That is, did the starting VC condition (i.e., 6 dB *over* versus 6 dB *under* NAL-NL1 targets) affect our results? The gain values were obtained from the data logging of VC training after each home trial. If the participant had been fitted with NAL-NL1 +6 dB, and the start-up gain "trained" −4 dB (shown in data logging), then it was assumed that the preferred gain was NAL-NL1 +2 dB. These average data are displayed in Figure 3. A single factor between groups ANOVA with order of treatment as the between groups factor and VC starting condition as the within subjects factor was used to examine the significance of these findings. Results showed no significant effect of treatment order ($F_{1,10} = 0.58$, $p = 0.464$) and no interaction between treatment order and VC condition ($F_{1,10} = 0.834$, $p = 0.383$). Similarly, no significant effects were observed when data from all 22 participants were included.

One of the questions of this study was to determine whether the gain prescribed by the NAL-NL1 fitting algorithm corresponded to preferred use gain for individuals using hearing aids with modern features activated. Figure 4 shows the average deviation (in dB) from NAL-NL1 prescribed gain observed at the end of the real-world trial period with the devices, as well as median values and the distribution. Results are shown for conditions where participants started the trial period with a baseline midpoint gain setting either 6 dB above or below NAL-NL1 prescribed targets. The combined data also are displayed. Grey filled circles and squares represent data from the excluded participants in the 6 dB under and 6 dB above starting conditions, respectively.

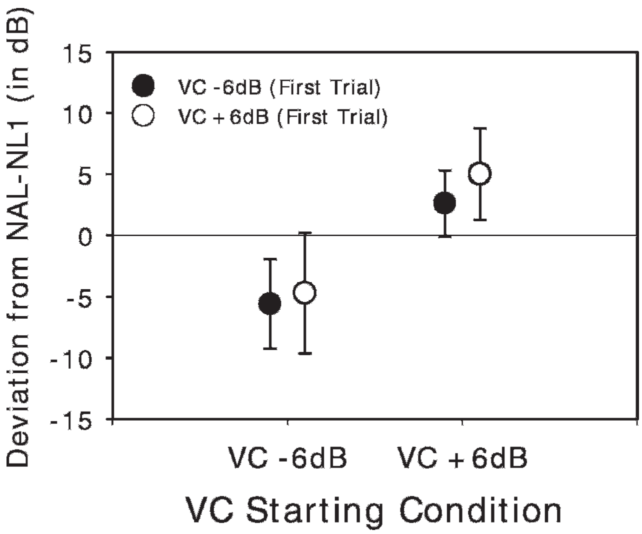

Figure 3. The mean deviation from NAL-NL1 target for each VC-start condition (+6 dB versus −6 dB) as a function of the participants' starting group (+6 dB versus −6 dB) in the crossover design. Error bars represent one standard deviation around the mean.

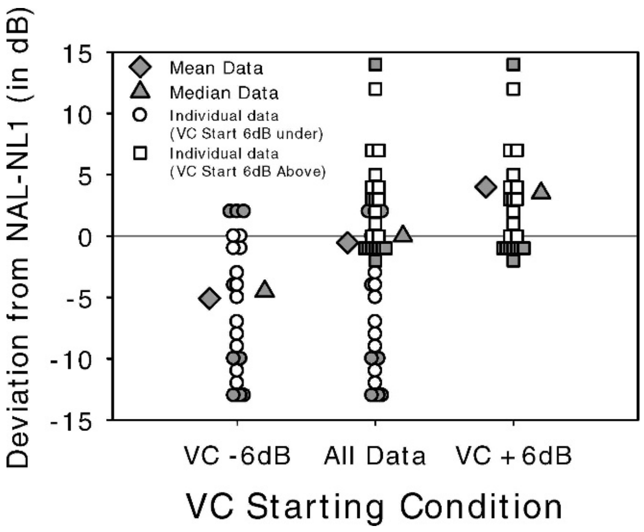

Figure 4. Individual, mean, and median preferred gain results displayed as a function of the VC-start condition (+6 dB versus −6 dB). Pooled data also are shown. Grey circles or squares represent individuals who were eliminated from the statistical analysis because of possible floor or ceiling effects.

An initial, single factor analysis of variance (ANOVA) was performed to examine differences in deviation from NAL-NL1 targets across our two test conditions. The within subjects independent variable was starting VC gain setting (6 dB above target or 6 dB below target), and the dependent variable was the deviation from NAL-NL1 target (in dB) at the end of the trial period. The initial ANOVA showed a significant main effect of starting VC condition ($F_{1,11} = 125.3$, $p < 0.001$). Specifically, the mean deviation from NAL-NL1 target was significantly lower when the starting VC condition was 6 dB below NAL-NL1 targets. The mean difference in final preferred gain settings based on whether the starting VC condition was 6 dB above or below NAL-NL1 targets was approximately 9 dB. An analysis of effect size computed as partial eta squared (η^2) suggests that approximately 92% ($\eta^2 = 0.919$) of the variability in deviations from NAL-NL1 gains was explained by the association of starting VC condition (i.e., whether participant's starting gain was 6 dB above or below NAL-NL1 targets). Together, the ANOVA results and estimates of effect size suggest that starting VC condition plays an important role in final preferred gain settings.

One sample t-tests were used to determine if the deviation from NAL-NL1 targets in each test condition were significantly different from 0 dB (NAL-NL1 target). Results showed that in both the VC starting conditions (6 dB over and 6 dB under NAL-NL1 target) the final average preferred gain was significantly different than NAL-NL1 targets. When the starting condition was 6 dB less than NAL-NL1 the final preferred gain was significantly (~5 dB) less than the prescribed gain ($t = -4.12$, $p = 0.002$). In contrast, when the starting gain setting was 6 dB more than NAL-NL1, the final preferred gain was significantly higher (~4 dB) than target ($t = 4.03$, $p = 0.002$). When all 22 participants were included in the analyses, mean and median results remained stable and were within ~1 dB of values observed with the partial dataset in both VC conditions.

To evaluate the consistency of gain preference, in relation to NAL-NL1 targets across listeners a correlation analysis comparing the direction and magnitude of gain training as a function of starting VC position was conducted. If listeners were consistent in adjusting the VC to approximate the NAL-NL1 target, then all data points would cluster around 0 dB deviation from target. If an individual's gain preference was consistent, either for more or less gain than prescribed, regardless of starting condition, then the correlation would be significant and positive. For example, if a given participant's true preference was 2 dB below the NAL-NL1, when the starting VC condition was 6 dB under NAL-NL1 targets, his results would show trained gain of +4 dB, and when the starting condition was 6 dB above the prescribed targets, his trained gain would be −8 dB. Results of the correlation analysis did reveal a significant positive correlation ($r = 0.755$, $p < 0.01$) between gain adjustments made with the different starting conditions.

Figure 5 shows the relationship between the changes in VC gain following trial period use as a function of starting VC condition, for each participant. Note that although there is a positive relationship between gain preference across conditions, suggesting that participants had a preferred gain setting, the slope of the regression line is less than 1 (~0.6). This suggests that participants' preferred gain setting was affected to some degree by the starting gain condition.

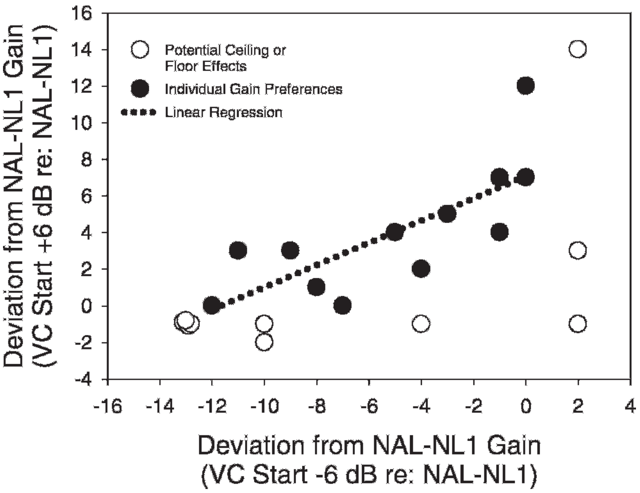

Figure 5. Deviation of trained gain from VC-start position for the +6 dB and −6 dB VC-start conditions. The white circles represent individuals who may have experienced floor or ceiling effects and were not included in the statistical analysis.

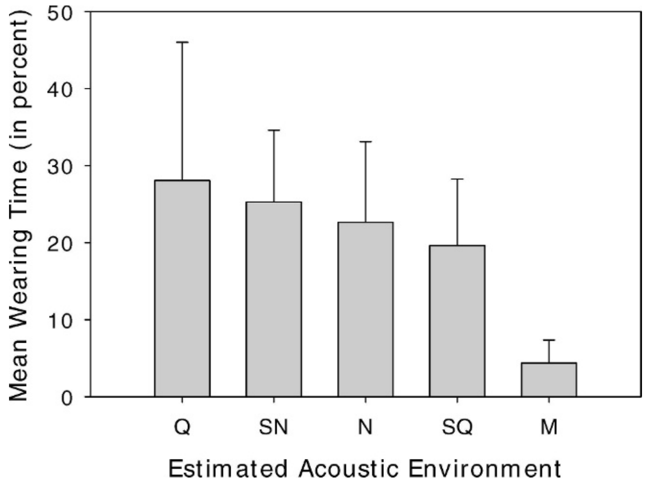

Figure 6. Based on the instruments' acoustic scene analysis, estimates of the mean wearing time during the two trial periods for five different listening conditions: Q = quiet, SN = speech in noise, N = noise, SQ = speech in quiet, M = music. Error bars represent one standard deviation around the mean.

Specifically, and consistent with the data shown in Figure 3, when the starting gain was 6 dB less than prescribed, final preferred gain tended to be less than prescribed by NAL-NL1 (mean ~5 dB, median 4.5 dB). In contrast, when starting gain was 6 dB more than prescribed, final preferred gain was greater (mean ~4 dB, median 3.5 dB) than that prescribed by NAL-NL1. Note that these data reflect deviations from NAL-NL1 target gain, not gain adjustments from baseline gain settings.

Results to this point suggest that when using these hearing aids in everyday settings, participants' average use gain varied based on how the hearing aids were programmed at the initial fitting. In fact, the starting setting (6 dB over versus 6 dB under) resulted in an 8 dB difference in the final median (~9 dB difference in mean) preferred gain setting. One factor that may have influenced these hearing aid adjustments is the amount of time spent in various environmental settings (e.g., quiet versus noise) during the two different trials. Recall that these hearing aids had data logging, in which the acoustic scene analysis resulted in the classification of the input signal into one of five categories.

A series of analyses were made to examine possible relationships between the time spent in specific environments and user VC adjustments. In these analyses, data from all 22 participants were included as the goal here was to examine relationships in relative gain preference and listening conditions, rather than differences in gain preferences across VC starting conditions (which could be influenced by ceiling and floor effects) and listening conditions.

First, listening situations were categorized into one of the following five logged environments: speech in quiet, speech in noise, noise, music, and quiet. These data were obtained during both the starting VC +6 dB and VC −6 dB trial periods. A two-factor repeated measures analysis of variance (ANOVA) was used to ensure that the amount of time spent in the various listening environments across the two trial periods was similar. The within subjects independent variables were starting VC condition (+6 dB or −6 dB) and the type of environment. The dependent variable was the time spent in each listening environment. Results showed no significant difference in time spent in each listening condition as a function of the VC starting condition ($F_{1,21} = 1.00$, $p = 0.328$).

As expected, significant differences were present in terms of time spent in each of the five listening environments ($F_{4,84} = 19.69$, $p < 0.001$). A series of follow-up, single-factor ANOVAs were completed to examine the source of this effect. Time spent in each environment (averaged across VC-start conditions) is shown in Figure 6.

Study participants spent the majority of their time in quiet, speech in noise, and noise alone environments, and time spent in these three environments was not significantly different. Participants spent approximately 19% of their time listening to speech in quiet. This was significantly less than the time spent in quiet alone and spent listening to speech in noise but not between noise alone. The least amount of time was spent in a music environment, which was significantly lower than all other conditions.

A series of correlation analyses, including all 22 participants, were completed to explore potential relationships between time spent in a given environment and deviations from NAL-NL1 targets. That is, did the individuals who spent more time in quiet tend to prefer higher gain? Did individuals who spent more time in noise have lower levels of preferred gain? None of the correlations were significant.

The information from datalogging also provided the number of hours the participants used their hearing aids during the field trial. We questioned if a potential relationship might exist between amount of hearing aid use and hearing aid gain preference. A series of correlation analyses, including all 22 participants, for both the 6 dB under and 6 dB above VC starting conditions were completed to examine these potential relationships. No significant correlations were observed between hearing aid use and the user's gain deviation from NAL-NL1 targets (for either the +6 dB or –6 dB start conditions).

It was also of interest to determine if degree of hearing loss affected a listener's preference for gain relative to NAL-NL1 prescriptive targets. A bilateral pure-tone average (500, 1000, and 2000 Hz) was calculated for all 22 participants. Average bilateral losses ranged from 25 to 63 dB. A correlation analysis, for both the +6 dB and −6 dB VC-start conditions, showed no significant correlation between the pure-tone average and the user's gain deviation from NAL-NL1 targets ($r = -0.32$, $p = 0.146$ for +6 dB start condition; $r = -0.074$, $p = 0.745$ for the −6 dB start condition).

In addition to the objective measures of VC change, subjective measures of loudness and satisfaction for the aided loudness for several conditions were obtained for both VC-start conditions (see Appendix A). Identical questionnaires were completed during the first day or two of the trial and again at the end, for both trial periods; therefore, each participant completed four questionnaires. Given that subjective ratings of, and satisfaction with, aided loudness could be influenced by ceiling or floor effects, only data from the 12 participants not influenced by such effects were included in these analyses.

One question of interest was whether ratings of, or satisfaction with, aided loudness in various conditions varied over time (beginning and end of the trial period), across the five questionnaire items (soft, average, and loud speech/sounds, speech in noise, and noise alone). Figures 7 and 8 show histograms of ratings of, and satisfaction with, loudness combined across both starting gain conditions (VC-start 6 dB under versus 6 dB above target) and including all survey questions. These figures suggest that at least some participants were able, over time, to make gain adjustments that improved their perception of and satisfaction with aided loudness—note the increase in "About Just Right" and "Somewhat Satisfied" ratings. An initial analysis of these data, however, revealed that these trends (collapsed across VC condition) were not statistically significant (Mann-Whitney U test; $Z = -0.53$, $p = 0.60$, and $Z = -0.46$, $p = 0.65$ for loudness and satisfaction, respectively).

In addition to the overall subjective findings, we examined whether ratings of, or satisfaction with, aided loudness in various conditions were affected by the starting VC condition (6 dB above or below the NAL-NL1 prescriptive target). An initial analysis revealed that loudness ratings, combined across both test times and including all survey questions, were significantly different (Mann-Whitney U test; $Z = -5.63$, $p < 0.001$) between groups. Specifically, when the starting gain position was 6 dB below target, the modal loudness rating was "About Just Right." In contrast, when the starting gain position was 6 dB above target the modal loudness rating was "A Little Too Loud." Similar findings were observed for the satisfaction data. Modal satisfaction ratings were "Somewhat Satisfied" and "Very Dissatisfied" for the 6 dB under and 6 dB above starting conditions, respectively. This finding was also significant ($Z = -2.47$, $p = .013$). Thus, when the starting gain level was 6 dB above target, even though on average participants left their VCs at a higher level (resulting in a better match to the NAL-NL1 prescriptive targets), they were less satisfied with the loudness of the hearing aids overall compared to when the starting VC condition was 6 dB below target.

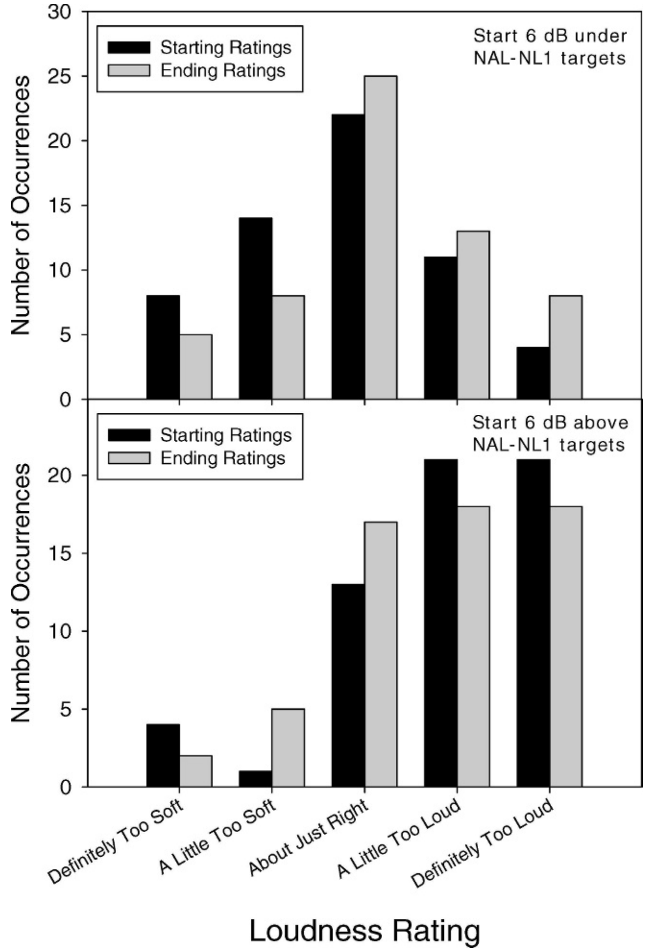

Figure 7. Distribution of the overall loudness ratings from the five questions completed during the field trial (12 subjects, 5 questions, 60 total observations). Results shown for the beginning and ending of the field trial for both the 6 dB under (upper panel) and 6 dB over (lower panel) starting gain conditions.

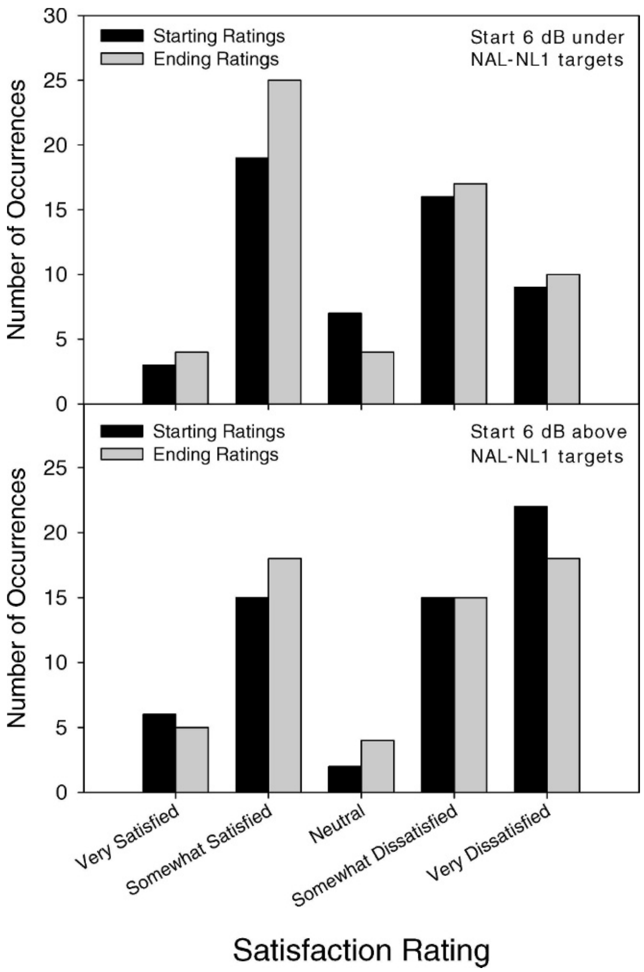

Figure 8. Distribution of the overall satisfaction ratings from the five questions completed during the field trial (12 subjects, 5 questions, 60 total observations). Results shown for the beginning and ending of the field trial for both the 6 dB under (upper panel) and 6 dB over (lower panel) starting gain conditions.

We were also interested in whether ratings of, and satisfaction with, aided loudness varied between the environmental conditions examined in the questionnaire. Figure 9 shows histograms, based on data from the 12 participants included in these analyses, of loudness and satisfaction ratings, combined across both test conditions, for each of the five questionnaire items. Some general trends are apparent in these data. First, for soft and average sounds and speech in noise, loudness ratings were concentrated in the "About Just Right" and "A Little Too Loud" categories. In contrast, loudness ratings of "loud sounds" and "background noise" were concentrated in the "A Little Too Loud" and "Definitely Too Loud" categories.

The satisfaction survey data showed a bimodal distribution. Most participants rated themselves as either "Somewhat Satisfied" or "Somewhat Dissatisfied" with the aided loudness of different sounds. Consistent with the loudness ratings, the most common satisfaction rating for soft and average sounds and speech in noise was "Somewhat Satisfied" while the most common satisfaction rating for background noise was "Very Dissatisfied."

Finally, it also was of interest to examine whether participants' ratings of loudness were significantly related to their VC change during the trial period. That is, it was expected that individuals who rated sounds as too soft would train their hearing aids for more start-up gain. Associations between gain adjustments and loudness ratings in the various settings were examined using the Spearman rank-order correlation coefficient. Given that our interest was in the direction of gain change and loudness ratings rather than absolute gain preferences, data from all 22 participants were included in these analyses. Results are shown in Table 1. A significant negative correlation suggests that individuals with loudness ratings above "About Just Right" turned their VCs down while those with loudness ratings below this rating turned their VCs up. Consistent with this expectation, several significant correlations were observed.

DISCUSSION

In recent years, low-level expansion, digital noise reduction, directional technology, and adaptive feedback reduction have more or less become standard features in hearing aids. One purpose, therefore, of our present research was to determine what effects, if any, these special features might have on preferred hearing aid gain in real-world listening situations. While there already are ample data on preferred real-world gain, little of this has been collected with current hearing aids and with these features activated.

A second purpose of this research was to examine the effects of start-up programmed gain on resulting real-world preferred gain. It seemed reasonable to use the NAL-NL1 prescriptive targets as the reference, as most preferred gain studies have been related to this, or one of the earlier NAL gain-selection methods. We did not want to bias the study in favor of the NAL-NL1 prescription, however, and therefore, rather than fit the participants according to this prescribed gain, they were fitted to either 6 dB above or 6 dB below NAL targets in a crossover design. This initial fitting, however, simply was the 50% point of the VC control (present when the hearing aids were switched on), and during the trial period the participants easily could adjust the hearing aids to approximate the NAL-NL1 target gain using their VC. Given the large body of research supporting the NAL targets (at least the gain-for-average input values), we speculated that the people fitted above target would, on average, adjust the gain downward, and the people fitted under target would adjust their gain upward. We also speculated that if the special features had an impact, they probably would encourage higher

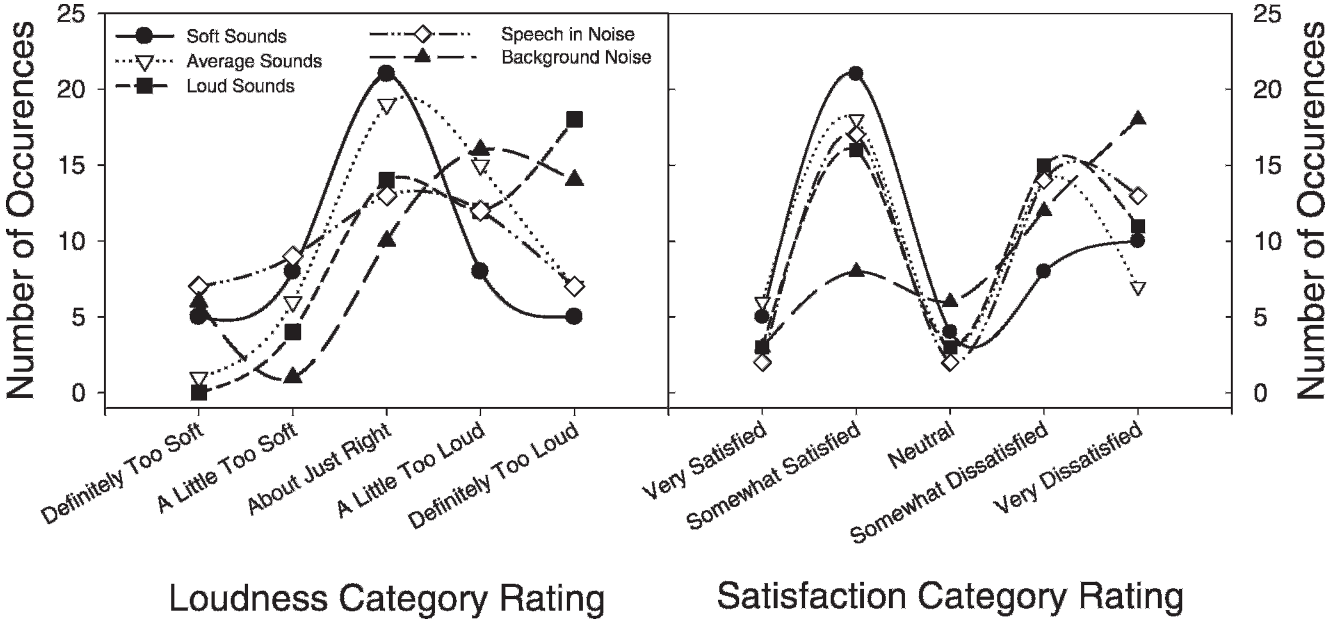

Figure 9. Loudness and satisfaction ratings (combined for both starting-gain conditions) completed during the field trial for the five different input levels/signals.

preferred gain, as in general these features are designed to reduce background noise and annoyance from noise (including acoustic feedback), which in general prompt hearing aid users to use less gain.

As discussed previously, it is possible that many of our participants were unable to reach their true preferred gain, because of the limits of the 16 dB adjustment range, which allowed for ±8 dB of learning. In pilot work, we tried using a 32 dB range with ±16 dB of learning, which was a software option with these hearing aids. While this would have significantly extended our learning range, had we used this fitting option we would not have been able to attain NAL-NL1 targets for the high frequencies for many subjects (i.e., NAL-NL1 target + 16 dB reserve gain exceeded the maximum gain of the instrument). Because of the potential floor and ceiling problems, the majority of the statistical analyses were conducted using the 12 individuals who did not experience these effects. Neither the mean nor the median for either condition, however, changed significantly when all 22 participants were included.

It was surprising to find that the start-up VC setting had such a large impact on the resulting preferred gain—the median for the two conditions varied by 8 dB (see Figure 3). While it is true that preferred gain is a "range" and not a single point, this difference was larger than expected given the ease with which VC changes could have been made. There was a distinct trend present for the +6 dB condition: 18 of the 22 participants trained their hearing aids for less gain. For the −6 condition, however, only 50% of the subjects (11/22) chose to use increased gain. Some individual results were interesting. For example, three participants appeared to have a focused preferred gain region, as their preferred gain settings were within 3 dB for the two conditions, and near the NAL-NL1 target. On the other hand, one participant with a mild-to-moderate hearing loss trained his hearing aids to NAL +3 dB for the +6 dB condition, but the hearing aids were trained to NAL −11 dB for the −6 dB start condition—a 14 dB difference. It was tempting to speculate that perhaps this person did not use his hearing aids very often and that therefore training was

Table 1. Correlation Coefficients for Individual VC Gain Training (louder versus softer) as a Function of The Field Loudness Ratings

Condition	Soft	Average	Loud	Speech in Noise	Noise
Trial Start VC −6 dB	−0.28	−0.49*	−0.58*	−0.30	−0.46*
Trial End VC −6 dB	−0.48*	−0.67*	−0.57*	−0.33	−0.43*
Trial Start VC +6 dB	−0.59*	−0.57*	−0.77*	−0.73*	−0.39
Trial End VC +6 dB	−0.33	−0.35	−0.37	−0.14	−0.18

Note: Results shown for both VC-start conditions and for questionnaire ratings obtained at the start and end of the field trial. A significant negative correlation indicates a downward training of preferred gain when loudness ratings were above (too loud) the target "just about right" loudness anchor (see Appendix 1).
*Correlation was significant at $p < 0.05$.

not complete. This was not the case, however, as he used the hearing aids for 130 hours and 185 hours for the two conditions, respectively.

We are not aware of other research that has examined directly the effects of programmed gain versus preferred gain for real-world listening situations. Usually, in most studies the hearing aids have been programmed according to the NAL prescription and changes in VC settings are observed, or different programs are stored in different memories and the subjects select a preference. Recent research with a trainable hearing aid conducted in the laboratory, however, has shown findings in general agreement with ours. As part of a larger study, Dreschler et al (2008) examined the effects of the baseline overall gain during the training period. They show a reduction in preferred gain of 2.5 dB when the baseline was lowered by 6 dB. Our data show a reduction of 8–9 dB when the baseline was lowered by 12 dB.

Because this was a crossover design, we questioned if the individual's start condition (either +6 dB or −6 dB) might influence the VC adjustments for the second condition. In particular, there was some concern that there might be a carryover effect; the people who started with the +6 dB condition might not adjust their hearing aids down to or below the NAL targets and might then become somewhat accustomed to more gain, which might then prompt them to raise gain when they were fitted with the −6 dB condition. As shown in Figure 3, however, this did not happen; there was not a significant effect for either start condition. It appears that even though on average, preferred gain was quite different for the two trials, this did not influence the participant's VC adjustments when the hearing aids were reprogrammed. This could be partially due to the fact that all participants were experienced hearing aids users. While it is probable that preferred gain is based, at least in part, on previous aided listening experiences, it was not possible to control for the amount of gain that these individuals had been using in the real world prior to experimental participation. While all of them were previous users of bilateral WDRC instruments, and at one time were fitted according to the NAL-NL1 prescriptive method, most had received postfitting adjustments of gain and compression. Moreover, all but two of the subjects had hearing aids with VCs, so their actual use gain may have been quite different from the clinically programmed gain.

Experienced hearing aid users were recruited for this research on the assumption that they could focus on the experimental task (gain adjustment in different listening environments) and not be distracted by other factors that often bother new hearing aid users (e.g., operation, comfort, stigma, etc.). Research suggests, however, that gain preferences would have been similar for new hearing aid users. Convery et al (2005) reviewed the findings of 14 papers on this topic and conducted a pooled analysis for three of these studies (n = 175). They concluded that there is no significant difference between the preferred gain of new versus experienced hearing aid users. Recent research has agreed with this finding, noting small differences between these two groups—new users preferring only 1–2 dB less gain than experienced users (Smeds et al, 2006; Keidser and Dillon, 2007).

One of our research questions was the potential effects that today's special features and algorithms (e.g., DNR, directional technology, feedback reduction) might have on preferred real world gain. The unexpected 8–9 dB effect of VC-start condition makes it difficult to isolate this factor for discussion. The fact that when fitted with NAL-NL1 −6 dB the average participant remained at or near this gain setting, suggests that the special features did not have a strong impact on overall preferred gain judgments, or at least did not encourage the use of more gain as we had predicted.

In our field trial, we used the data logging of the acoustic scene analysis to estimate the amount of time the participants were in different listening conditions. This distribution was based on the algorithms used by the specific hearing aids we selected: the distribution might have been somewhat different if a different brand of hearing aids had been used. Since there are few published data showing average data logging findings for modern instruments, it is difficult to know whether the present group was typical. The findings, however, do seem reasonable based on what is known about the participant sample (most were employed and active). As mentioned earlier, there were no significant correlations between the time spent in a given listening environment and the direction (louder or softer) of the participant's VC training. For example, individuals who spent more time in noise were not significantly more likely to train their hearing aids for less gain. Similarly, those people who spent most of their time in quiet were not more likely to use more gain. It is important to point out, however, that for all of the environmental conditions, the participants tended to be grouped within a relatively small range. In the "noise" condition, for example, the majority of participants were classified as being in noise 10–30% of the time; only 14% (3/22) and 23% (5/22) of the participants were outside of this range for the +6 dB and −6 dB start conditions, respectively. In clinical practice, patients often are fitted with multiple memories, with different programs for listening in quiet versus background noise. They then can apply independent training for each memory. Our participants only had one program to use for all listening environments.

The individual data show that the average participant trained the gain by 5 dB (either up or down) for both start conditions. Given that a 5 dB change often alters loudness judgments, it was somewhat surprising that neither loudness ratings nor satisfaction with loudness ratings were improved significantly at the end of the trial compared to the beginning (see Figs. 7 and 8). It may be that the question was somewhat difficult for the participants to understand. Because the effects of the training only applied to start-up gain, the question was worded "when you first turn on the hearing aids, before any volume control adjustments." If the participant turned on the hearing aids in a quiet room by themselves, it is possible the gain change that had occurred over the trial period would not be observable. Also, many participants did have a relatively large dynamic range, and a 5 dB gain change may not have significantly altered everyday loudness perceptions.

Another purpose of having the questionnaires completed at the start and end of the field trials was to determine if the results might differentiate gain preferences for inputs of different intensity levels, and if there might be a particular input level that was driving the gain training. Recall that the users could only change overall gain, not gain for a specific input level (e.g., some form of WDRC training). Gain preferences for different input levels often have been confounding factors when preferred gain has been measured (or inferred) based on real-world hearing aid use, where the subjects are exposed to many different acoustic settings. For example, an individual fitted to a prescriptive target for average-level inputs might find that loud sounds are too loud and routinely reduce the VC simply to make these sounds comfortable (or tolerable). When preferred gain data (the participant's VC setting) is then observed, it might appear that the prescriptive target for average was too high, when in fact the gain for average might have been "just right."

Our participants rated loudness for the five different input signals on a 1 to 5 scale with #3 being about just right, above #3 too loud and below #3 too soft (see Appendix A). As shown in Figure 9, loudness ratings for soft and average sounds follow a reasonable distribution, with the majority of rating in the "About Just Right" category. Observe, however, that for both "loud sounds" and "background noise" the majority of ratings were in the "Definitely Too Loud" category. It is tempting to think that these undesirable ratings of loudness for higher inputs suggests that more aggressive WDRC is needed; that is, the NAL-NL1 prescribed gain for loud inputs relative to average inputs is too high. Recall, however, that on average in the high frequencies we did not meet our REIG NAL-NL1 targets for the 80 dB input signal. Moreover, the AGCo kneepoint was adjusted conservatively: it seems unlikely, therefore, that these signals exceeded the participant's LDL.

Using a more cautious interpretation of these data, it is relevant to consider the thought process of the average participant when completing the questionnaires. At the time of the initial fitting it was explained to the participants that if a loud sound sounded "appropriately loud" then it should be rated "About Just Right." We know, however, that amplified environmental sounds, even those in the 60–70 dB SPL range, often are rated as annoying by hearing aid users (Palmer et al, 2006). Hence, the more unfavorable loudness ratings for the louder inputs simply might have been because the loudness was louder than what the participant preferred, not that the loudness was inappropriate.

Few real-world studies of preferred gain have examined the influence of sounds of different input levels. Two exceptions to this are recent preferred gain studies using the NAL-NL1 as the reference prescription (Smeds et al, 2006, Zakis et al, 2007). These authors found that when fitted with the NAL-NL1 prescription, on average, participants reduced gain more for loud inputs (80 dB SPL) than for average inputs (65 dB SPL), although the difference was quite small (~1.5 dB).

An issue related to the hearing aid training was the amount of time the hearing aids were used during the 10–14 day trial period. Although our previous analysis had already indicated that there was no significant relationship between total use time and preferred gain, we examined initial data and observed that there were five participants who had less than 50 hours of total use time for one of the two conditions. A separate analysis for these participants revealed that their range of learning was no different from the other 17 subjects for either start condition and that neither the mean nor median values were significantly changed if these individuals were removed from the analysis.

From a clinical standpoint, the significant effects that we observed for the VC-start condition must be considered. Most clinicians use the manufacturer's default fitting algorithm, which usually is less gain than prescribed by the NAL-NL1 method, especially for 2000 Hz and above (Keidser et al, 2003; Mueller, 2007). This approach is supported by those who believe that the patient must be given gain that is "acceptable" (*less* usually is considered more acceptable than *more*), and that the gain always can be increased at later patient visits after acclimatization or adaptation has taken place. Our results show, however, that on average, if patients are fitted below NAL-NL1 target, they prefer to stay fitted below target (at least within a two-week trial period; 121 average hours of use). But when they are fitted above NAL target, they do not, on average, train their hearing aids to below target gain, or even to target gain. So what is best? If we believe that for most people, increased audibility leads to increased understanding of speech (at least soft speech), then starting at a gain setting at or near optimum would seem appropriate. On the other hand, when the start gain was 6 dB below NAL-NL1, the loudness ratings were more appropriate, the participants were more satisfied, and about the same number of individuals trained their gain up versus down.

Most of this discussion has focused on average data (mean or median). While our pooled median showed a preferred gain slightly below the NAL-NL1 prescription, individual variations cannot be ignored. For example, in this relatively small group of 22 people, we had one participant who, when fitted in the VC-start +6 dB condition trained his hearing aids to +8–14 dB *above* NAL-NL1, and very possibly could have gone higher if not for the +8 dB gain limit of training. Another participant, when fitted in the VC-start −6 dB condition trained her hearing aids to -8–14 dB *below* NAL-NL1, and very possibly could have gone lower if not for the −8 dB limit of training.

In summary, the present findings show that the baseline gain setting can influence an individual's preferred gain when using hearing aids in the real world. Individuals fitted 6 dB above the NAL-NL1 target tend to train their hearing aids down about 3 dB. The same individuals, when fitted 6 dB below target, tend to leave their gain setting near this lower level. The participant's time spent in different listening environments did not appear to influence training of hearing aid gain. Subjective ratings of loudness and satisfaction with loudness corresponded to the VC-start conditions, with the most favorable findings for the 6 dB *below* target gain setting.

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APPENDIX 1: Real-World Rating of Loudness and Satisfaction with Loudness

1. When you first turn on your hearing aids, before any volume control adjustments, how do you rate the aided loudness levels for soft speech and other soft-level sounds?
☐ Definitely Too Soft
☐ A Little Too Soft
☐ About Just Right
☐ A Little Too Loud
☐ Definitely Too Loud

2. When you first turn on your hearing aids, before any volume control adjustments, how do you rate your satisfaction for the aided loudness for soft speech and other soft sounds?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Neutral
☐ Somewhat Dissatisfied
☐ Very Dissatisfied

3. When you first turn on your hearing aids, before any volume control adjustments, how do you rate the aided loudness levels for average speech and other average-level sounds?
☐ Definitely Too Soft
☐ A Little Too Soft
☐ About Just Right
☐ A Little Too Loud
☐ Definitely Too Loud

4. When you first turn on your hearing aids, before any volume control adjustments, how do you rate your satisfaction for the aided loudness for average speech and other average-level sounds?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Neutral
☐ Somewhat Dissatisfied
☐ Very Dissatisfied

5. When you first turn on your hearing aids, before any volume control adjustments, how do you rate the aided loudness levels for loud speech and other loud sounds?
☐ Definitely Too Soft
☐ A Little Too Soft
☐ About Just Right
☐ A Little Too Loud
☐ Definitely Too Loud

6. When you first turn on your hearing aids, before any volume control adjustments, how do you rate your satisfaction for the aided loudness for loud speech and other loud sounds?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Neutral
☐ Somewhat Dissatisfied
☐ Very Dissatisfied

7. When you first turn on your hearing aids, before any volume control adjustments, how do you rate the aided loudness levels for listening to speech in background noise?
☐ Definitely Too Soft
☐ A Little Too Soft
☐ About Just Right
☐ A Little Too Loud
☐ Definitely Too Loud

8. When you first turn on your hearing aids, before any volume control adjustments, how do you rate your satisfaction for listening to speech in background noise?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Neutral
☐ Somewhat Dissatisfied
☐ Very Dissatisfied

9. When you first turn on your hearing aids, before any volume control adjustments, how do you rate the aided loudness levels for listening to different background noises?
☐ Definitely Too Soft
☐ A Little Too Soft
☐ About Just Right
☐ A Little Too Loud
☐ Definitely Too Loud

10. When you first turn on your hearing aids, before any volume control adjustments, how do you rate your satisfaction for the aided loudness for listening to different background noises?
☐ Very Satisfied
☐ Somewhat Satisfied
☐ Neutral
☐ Somewhat Dissatisfied
☐ Very Dissatisfied