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User Preference and Reliability of Bilateral Hearing Aid Gain Adjustments

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Abstract

The purpose of the current study was to evaluate the consistency and reliability of user adjustments to hearing aid gain and the resulting effects on speech understanding. Sixteen bilaterally aided individuals with hearing loss adjusted their hearing aid gain to optimize listening comfort and speech clarity while listening to speech in quiet and noisy backgrounds. Following these adjustments, participants readjusted their aids to optimize clarity and comfort while listening to speech in quiet. These final gain settings were recorded and compared to those provided by NAL-NL1 prescriptive targets. In addition, speech understanding was tested with the hearing aids set at target and user gain settings. Performance differences between the gain settings were then assessed.

Study results revealed that although some listeners preferred more or less gain than prescribed, on average, user and prescribed gain settings were similar in both ears. Some individuals, however, made gain adjustments between ears resulting in "gain mismatches." These "mismatches" were often inconsistent across trials suggesting that these adjustments were unreliable. Speech testing results, however, showed no significant difference across the different gain settings suggesting that the gain deviations introduced in this study were not large enough to significantly affect speech understanding.

Key Words: Bilateral, gain, hearing aids, hearing loss, prescriptive formula, speech understanding, volume control

Abbreviations: HINT = *Hearing in Noise Test*; NAL-NL1 = National Acoustic Laboratories—Nonlinear; REIG = real ear insertion gain; SNR = signal-to-noise ratio; VC = volume control

Sumario

El propósito del actual estudio fue evaluar la consistencia y la confiabilidad de los ajustes ganancia del auxiliar auditivo por parte del usuario, en cuanto a mejorar la comprensión del lenguaje. Dieciséis individuos hipoacúsicos con amplificación bilateral ajustaron la ganancia de sus auxiliares auditivos para optimizar la comodidad al escuchar y la claridad del lenguaje mientras escuchaban lenguaje en ambientes silenciosos y ruidosos. Después de estos ajustes, los participantes reajustaron sus auxiliares para optimizar la claridad

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y la comodidad al escuchar lenguaje en silencio. Estos ajustes finales de ganancia fueron registrados y comparados a aquellos indicados por las metas de prescripción del NAL-NL1. Además, se evaluó la comprensión del lenguaje con los auxiliares auditivos graduados en el nivel meta y en el nivel escogido por el usuario. Entonces se evaluaron las diferencias de desempeño entre dichos ajustes de ganancia.

El estudio reveló que aunque algunos sujetos prefirieron más o menos ganancia de la prescrita, en promedio, los ajustes de ganancia del usuario y los prescritos fueron similares en ambos oídos. Algunos individuos, sin embargo, realizaron ajustes de ganancia entre sus dos oídos que resultaron en "desajustes de ganancia". Estos "desajustes" fueron a menudo inconsistentes en los diferentes ensayos sugiriendo que eran no confiables. Los resultados de las pruebas de lenguaje, sin embargo, no mostraron diferencias significativas entre los diferentes ajustes de ganancia, sugiriendo que las desviaciones de ganancia introducidas en este estudio no fueron lo suficientemente grandes para afectar significativamente la comprensión del lenguaje.

Palabras Clave: Ganancia bilateral, auxiliares auditivos, hipoacusia, fórmula de prescripción, comprensión del lenguaje, control de volumen

Abreviaturas: HINT = Prueba de Audición en Ruido; NAL-NL1 = Laboratorios Nacionales de Acústica – No lineal; REIG = ganancia de inserción de oído real; SNR = tasa de señal/ruido; VC = control de volumen

The use of wide dynamic range compression can, in theory, reduce the need for user adjustments of hearing aid gain via a volume control (VC) mechanism. For example, Kochkin (1995) reported that a large percentage of completely-in-the-canal (CIC) hearing aid users were satisfied with their hearing aid's volume adjustment, even though the CIC hearing aids that they were using did not have a volume control. In reality, however, many individuals with hearing loss may prefer access to a VC to allow gain adjustments in various environments (Surr et al, 2001; Kochkin, 2003). This is not surprising given that the most comfortable level (MCL) for listening is more accurately described as a most comfortable range (MCR). When listening to speech stimuli, the MCR can be as large as 20–30 dB for persons with hearing loss, depending on the measurement method and degree of hearing loss (Ventry and Johnson, 1978). In addition, preferred listening levels can vary based on the listening conditions, signal-to-noise ratio (SNR), and type of noise (Kuk et al, 1994; Keidser et al, 2005; Smeds et al, 2006a, 2000b). Therefore, although low-threshold compression systems may reduce the need for a VC, compared to a linear aid, in many instances user access to VC adjustments remains quite desirable (Surr et al, 2001; Kochkin, 2003).

When hearing aids are fit bilaterally, as they are in approximately 80% of fittings in the United States (Strom, 2006), an important goal of the bilateral fitting is to adjust the gain of each hearing aid to create a "balanced" perception of loudness between ears and to place amplified conversational speech around the midpoint of the patient's "comfortable" range. To achieve this goal the frequency response and overall gain of the hearing aids are initially set based on some prescriptive rule that takes into account the patient's audiometric thresholds (e.g., National Acoustic Laboratories—Nonlinear 2 (NAL-NL2; Dillon, 2006), Desired Sensation Level Version 5 (DSL 5.0; Scollie et al, 2005), or a manufacturer's first fit algorithm). Overall loudness and loudness balance are then typically verified using subjective methods. Although there is no consensus on how to best verify aided loudness perception for speech, a reasonable approach is to present continuous discourse in the sound field and systematically raise and lower the overall gain until optimal loudness, based on subjective report, is achieved (e.g., Cox and Gray, 2001). Loudness balance can be verified using a similar technique by systematically adjusting the gain of the "louder" or "softer" side until a subjective report of "balance" between ears is obtained.

Given the relatively large range of "comfortable" and the fact that MCL varies with SNR, it is expected that listeners will make gain adjustments as they move from one environment to another. Research has shown that many elderly hearing aid users have difficulty manipulating VC mechanisms on hearing aids (Ward et al, 1979), and for this reason, their adjustments might not be precise. A potential negative consequence of these user gain adjustments is creating a "mismatch" between ears. In other words the carefully balanced gain settings provided during the initial fit may be significantly altered due to user gain adjustments. Depending on the magnitude of this mismatch, there is a potential for speech understanding to be affected in certain environments.

We know that, in many conditions, bilateral listening can result in improved speech understanding in background noise. The magnitude of the bilateral benefit will vary based on several factors including the configuration of the speech and noise and the type of masking noise (Bronkhorst and Plomp, 1989; Gallun et al, 2005). Ricketts (2000) compared bilateral and unilateral aided performance and showed an approximately 2.5 dB improvement in the SNR needed for 50% sentence understanding when listening in a background noise of cafeteria babble that surrounded the listener. Although reducing the gain at one ear does not automatically result in a unilateral condition, at some point, if the mismatch becomes severe enough, the speech understanding would only be representative of the hearing aid (ear) with the most gain, and bilateral benefit would be reduced or absent.

The issue of user gain adjustments also is important when considering hearing aids that have a "linked-gain" adjustment. That is, when gain is turned up or down in one, the same adjustment is applied to the other hearing aid. Moreover, hearing aids are now available that automatically readjust gain based on the users preferred settings. Knowledge about hearing aids users' ability to adjust gain reliably would help determine if this "gain learning" should occur with the hearing aids in a linked or unlinked mode.

Unfortunately, a review of current literature reveals no systematic research evaluating the magnitude of hearing aid gain mismatch or its potential effects on speech understanding. The purpose of this experiment was to (1) quantify the consistency and magnitude of gain adjustments made by hearing aid users and compare these gain settings to their National Acoustic Laboratories—Nonlinear (NAL-NL1) prescribed settings and (2) determine if differences from clinician-adjusted gain, resulting from user adjustments of the hearing aid gain, affect speech understanding.

PROCEDURES

Participants

Participants consisted of sixteen (16) adults (eight male and eight female) with symmetrical, mild-severe sensorineural hearing loss (SNHL). Symmetrical was defined as ≤20 dB difference between ears at any audiometric test frequency. Ninety-six percent (96%) of participant thresholds (138 out of 144 thresholds) were ≤10 dB between ears. All participants' hearing thresholds were between 15 and 75 dB HL at 500 Hz and between 50 and 85 dB HL at 3000 Hz (see Figure 1). Participants with hearing loss ranged in age from 23 to 82 years (median age 75.5 years). Fifteen of the 16 participants were experienced hearing aid users (average of 12.7 years of usage). In addition 14 of 15 users had manual volume controls on their current aids while one participant used an external remote control to adjust the gain of his hearing aids. Additional demographic information regarding the study participants is provided in Table 1.

Hearing Aids

All participants were fitted with bilateral Triano 3P BTE aids. The devices were programmed for omnidirectional mode only. In addition, given that the focus of the project was on user adjustments of gain, all noise reduction (termed "Speech Comfort System™" processing) and feedback suppression algorithms were disabled during fitting and testing. Disabling these features limited the influence of these potentially confounding variables and ensured that overall gain preference, as opposed to potential interactions between gain and feature specific processing,

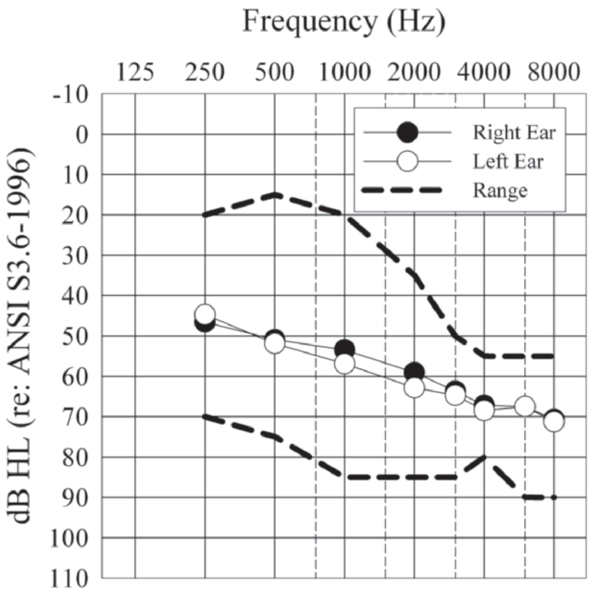

Figure 1. Mean and range of participant audiograms. Filled and open symbols represent the right and left ear, respectively. The dashed lines represent the best and poorest thresholds as a function of frequency across all subjects.

was the primary factor responsible for our results. To allow for substantial gain changes, the VC range, which can be controlled via the manufacturers fitting software, was set to 16 dB (±8 dB from the programmed gain setting). The test hearing aids used a toggle switch, rather than a volume control wheel, to control the aid volume. Holding the toggle switch in a fixed position (up or down) systematically increased or decreased the volume until the toggle switch was released or the maximum change in volume (8 dB) was reached. Pushing the toggle switch up or down and then releasing it increased or decreased the volume in 1 dB steps. An audible beep was heard with each 1 dB change in level. In addition, opening and closing the hearing aid battery door reset the devices to the programmed gain setting.

Participants were fit bilaterally using NAL-NL1 prescriptive real ear insertion gain (REIG) targets. The REIG targets were derived based on the following software choices from NAL-NL1's selection screen options: BTE for hearing aid type, bilateral fitting, and four compression channels. Vent sizes ranged from 3 mm to unvented and were based on degree of hearing loss.

All fittings were verified using the steady-state composite noise test signal, presented from a 0° azimuth, on the Frye Systems Fonix 6500 real ear analyzer. The hearing aids were adjusted until a best match to target was obtained. Other than adjustments made to limit feedback, no further "fine-tuning" was performed. For a 65 dB input, measured REIG values were, on average, within 3 dB of prescribed gain values through test frequencies of 2000 Hz and within about 7 dB of target out to 4000 Hz (see Figure 2). While the focus of this research was gain for the 65 dB SPL input signal, the hearing aids used in the study employed WDRC, and compression kneepoints and ratios across the 16 channels were adjusted according to the NAL-NL1 prescription. Hence, hearing aid gain for inputs below 65 dB SPL were also close to NAL-NL1 targets. REIG measures made with a 50 dB

Table 1. Demographic Data of Study Participants

Participant	Age	Years of HL	Wear HAs?	Monaural/ Bilateral	Years of HA use	Years of Education	Volume Control on Current Aid
1	73	12	Yes	Bilateral	5	14.5	No
2	82	28	Yes	Bilateral	18	16	Yes
3	72	12	Yes	Bilateral	8	8	Yes, remote
4	81	7	Yes	Monaural	6	13.5	Yes
5	76	10	No	None	0	17	No
6	23	23	Yes	Bilateral	15	17	Yes
7	71	40	Yes	Bilateral	25	18	Yes
8	79	3	Yes	Monaural	0.5	10	Yes
9	79	14	Yes	Bilateral	12	14	Yes
10	75	8	Yes	Bilateral	6	13	Yes
11	80	3	Yes	Bilateral	1	12	Yes
12	51	51	Yes	Bilateral	48	12	Yes
13	82	8	Yes	Bilateral	4	14	Yes
14	61	11	Yes	Bilateral	11	13	Yes
15	72	11	Yes	Bilateral	10	14	Yes
16	82	40	Yes	Bilateral	34	14	Yes
Average	71.2	17.6			12.7	13.75	

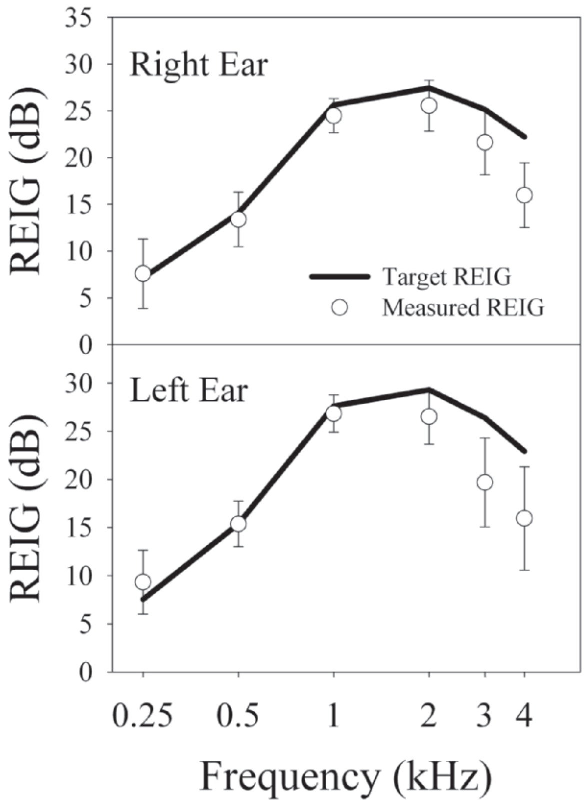

Figure 2. Measured real ear insertion gain using a 65 dB input signal for the right and left ears. NAL-NL1 prescriptive targets are shown for reference. Error bars show 1 standard deviation of the differences between measured and prescribed gain.

SPL input signal were, on average, within 3–4 dB of target values for test frequencies through 3000 Hz (data not shown).

Following real ear verification and adjustment, the hearing aids were removed from the listener, and 2-cc coupler gain measures, using a 65 dB composite noise as an input signal, were made for the right and left hearing aids. A "midfrequency" average gain (MFA; gain at 1, 2, and 3 kHz) measure was used for comparison purposes. This provided us with a "baseline" measure of the clinician fit gain for both hearing aids.

Volume Control Adjustment Procedures

Prior to testing, all participants received training in the use of the hearing aid VC. The training was informal but involved requiring the participants to adjust the gain on the hearing aids to full on (or just prior to feedback) and then reduce gain on the hearing aids to a very low level. Participants were allowed as long as necessary to work with the devices until they felt comfortable making adjustments. This generally required no more than five to ten minutes. If a potential study participant was unable to consistently make VC adjustments they were excluded from the study.

Following the training procedure, the aids were reset to their programmed gain settings by opening and closing the battery doors. Participants were then asked to adjust their hearing aid gain, *if required*, to optimize clarity and comfort while listening to speech in quiet (65 dBA). Participants were instructed to listen first and only make adjustments if required. Following this procedure, the hearing aids were removed, and hearing aid gain was remeasured in a 2-cc coupler, again using a 65 dB composite noise as the input. This allowed us to compare participants' preferred gain with the clinician-prescribed gain.

During the adjustment process, speech materials were presented through a Tannoy System 600™ loudspeaker located approximately 1.25 m from the listener at a 0° azimuth. Practice passages from the Connected Speech Test (CST; Cox et al, 1987) were used as the speech materials. Each passage consists of eight to ten sentences on a specific topic read from a children's encyclopedia by a female talker. Quiet speech was chosen as the test material given NAL-NL1 targets are based on optimizing understanding, clarity, and comfort of speech in quiet (Ching et al, 2001).

After this initial check of each individual's preferred gain settings, participants listened, in a random order, to speech in three simulated environments that were designed to encourage user adjustments of hearing aid gain. These environments (described below) were created by varying the location of the speech and noise loudspeakers, and the type of background noise, in a 3.2 x 3.2 x 3.2 m sound-treated room (Rt_{60} ~450 msec). Speech understanding testing (described later) was also conducted in this same room. In all simulated environments the speech and noise loudspeakers were located 1.25 m from the center of the listener's head.

Simulated Environment 1 (SE1)

This condition was designed to simulate a loud bar/restaurant setting and encourage listeners to decrease gain compared to the prescribed settings. Continuous discourse, using the CST practice passages, was presented at a +5 dB SNR from a 0° azimuth. The speech materials were presented at an overall level of 80 dBA. The background noise consisted of five uncorrelated segments of cafeteria babble presented from loudspeakers located at equal intervals around the listener (36°, 108°, 180°, 252°, and 324°). The segments of cafeteria babble were presented through Definitive Technologies loudspeakers (Model BP-2X). These loudspeakers have a bipolar pattern and use two matched driver pairs, which are mounted 150° to either side of the central axis of the loudspeaker resulting in increased sound dispersion within the test environment. The center of both speech and noise loudspeakers were positioned at approximately ear level of the listener (36”). Noise levels from individual speakers were equated, and their overall levels were adjusted to create a combined background noise level of 75 dBA (Larson Davis Model 814 SLM, slow averaging).

Simulated Environment 2 (SE2)

This condition was designed to simulate listening to soft speech or speech at a distance and thus encourage listeners to increase gain compared to the prescribed settings. In this condition, continuous discourse, again CST practice passages, was presented in quiet at an overall level of 45 dBA from the speech speaker (0° azimuth).

Simulated Environment 3 (SE3)

This condition was designed to simulate an asymmetric listening environment in which the noise was presented predominately to one ear and the speech predominately to the other. This setting was included to encourage participants to adjust their VCs to create a “mismatch” between ears. Specifically, this setting was designed in an attempt to encourage the listener to increase gain on the ear near the speech (right ear) and decrease gain on the ear near the noise (left ear). The background noise consisted of traffic noise recorded from an intersection near the Vanderbilt Bill Wilkerson Center. The traffic noise was presented at an overall level of 65 dBA using three BP-2X loudspeakers placed on the left side of listener at azimuths of -45°, -90°, and -135°. The speech materials were presented from a loudspeaker located to the right of the listener (90° azimuth) at an overall level of 65 dBA, resulting in a 0 dB SNR listening condition.

While listening in each environment, subjects were instructed to adjust the gain of their hearing aids to achieve optimal clarity and comfort. No speech testing was conducted in any simulated environment. In addition, we did not record the final VC settings made by the user in these simulated environments. These conditions were included solely to encourage listeners to make substantial (but realistic) gain changes.

After listening in each simulated environment, each participant was asked to readjust the gain of their hearing aids for optimal clarity and comfort while listening to speech in quiet presented at a level of 65 dBA (as they did after the initial fit). With the gain left at this setting (i.e., for speech in quiet) the hearing aids were removed from the listener by the experimenter, and 2-cc coupler gain measures were again obtained and recorded.

To obtain an estimate of gain adjustment consistency, all participants repeated the process of listening and adjusting their hearing aids in the three simulated environments (presented again in a random order) a second time during the study. Following this repetition, participants again listened to speech in quiet (65 dBA) and readjusted hearing aid gain for clarity and comfort a third time (once prior and twice after listening in the simulated environments).

Sentence Understanding Procedures

Speech understanding was assessed using a modified version of the Hearing in Noise Test (HINT; Nilsson et al, 1994). The modifications related to the type and locations of the noise used during testing are described below. Speech test materials were presented through a single Tannoy System 600 loudspeaker positioned at a 0° azimuth. Testing was performed at two noise levels (50 and 65 dBA) and in two noise source configurations. Condition 1 used five-speaker uncorrelated, cafeteria babble with speakers located at equal intervals around the listener (36, 108, 180, 252, and 324°). Condition 2 used a three-speaker noise configuration with all noise sources located on the right side of the listener at 45°, 90°, and 135° (speech still at a 0°

azimuth). This is similar, but on the opposite side, to the noise configuration used in the third simulated environment. The motivation for switching the side of the noise loudspeakers was to create a test condition that would be more likely to be *negatively* affected by user adjustments of volume control gain. During testing, the levels of each noise speaker were equated prior to adjusting their combined overall levels to either 50 or 65 dBA. A lower noise level of 50 dBA was included under the assumption that the effects of "mismatches" in gain adjustments may be more observable at low speech levels.

As per the HINT protocol, speech levels were adaptively varied to determine the SNR required for 50% correct sentence recognition. Performance was assessed using 20 sentences (two 10-sentence lists) per condition. Speech understanding was assessed in a total of eight experimental conditions (two different noise source configurations x two noise levels x two volume control settings [user adjusted and clinician adjusted]). Participants were counterbalanced into groups based on whether speech testing would be performed first with the gain set based on the NAL-NL1 prescriptive fit or the user-adjusted fit. Noise configuration and speech presentation level during speech testing were randomized within each VC setting.

If speech testing was to be done with the user-adjusted gain setting first, then participants listened in the simulated environments (in a random order), made VC adjustments, listened to speech in quiet, readjusted their gain (and settings were then recorded), and then completed speech testing using the HINT materials as described above (two noise configurations x two levels). If speech testing was to be done first with the gain set at the prescribed gain setting, participants listened to speech in quiet (without first listening in the simulated environments) and adjusted their gain as needed. These values were recorded then the gain was reset to the clinician-programmed gain (by opening and closing the battery door), and speech testing was performed using the HINT materials as described above (two noise configurations x two levels). For these participants, after speech testing was completed they listened in the three simulated environments, in a random order, and adjusted their hearing aid gain settings as needed. After this they listened again in quiet and readjusted the hearing aid gain as needed. These final gain values were then recorded. Figure 3 shows a block diagram of the study procedures.

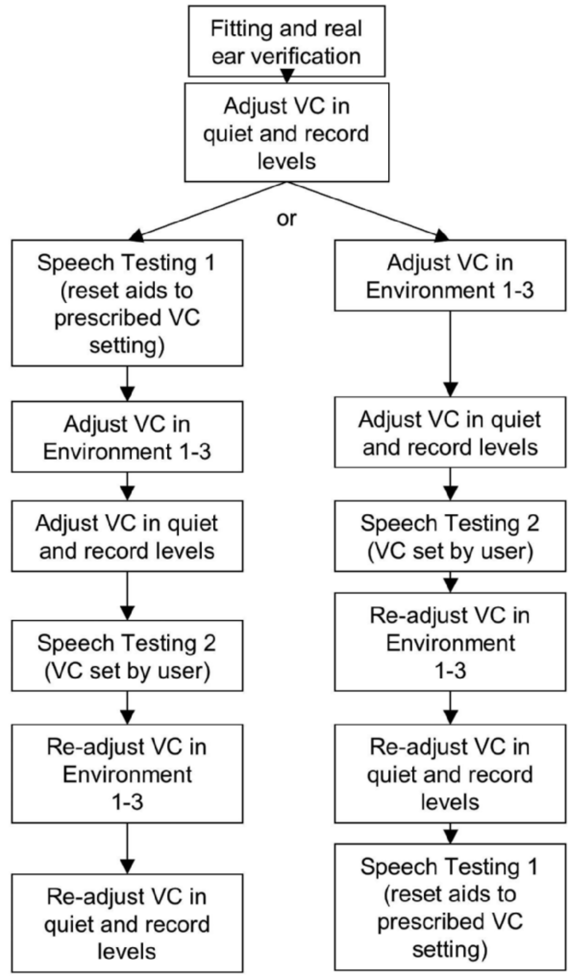

Figure 3. Block diagram of study protocol.

RESULTS

Consistency of User Gain Adjustments

Our first comparison of interest examined the relationship between user adjusted gain settings and the settings programmed by clinicians when fitting to NAL-NL1 targets. Recall that the VCs were programmed to allow a 16 dB range (±8 dB) around the prescribed gain. Although no participants reported an inability to achieve desired gain settings during the study procedures, it is possible that the presence of feedback may have limited upper levels of gain adjustments for some of our listeners. The data shown in Figure 4 were derived by subtracting individual 2-cc coupler midfrequency average gain values (MFA; average at 1, 2, and 3 kHz) for the right and left ears, based on user-adjusted gain settings, from the corresponding right or left ear coupler gain values based on our fit to NAL-NL1 targets. For example, Subject 1's MFA 2-cc NAL-NL1 coupler gain was 38 and 37 dB for the right and left ears, respectively. Following user gain adjustments, after listening to speech in quiet, the hearing aid gain was 39 and 32 dB for the right and left ears, respectively. Thus the deviation from NAL best fit was 1.0 and -5.0 dB for the right and left ears, respectively. Described in this fashion, negative values represent an adjustment resulting in less gain than that given by the clinicians fit to NAL-NL1 targets. These data provide, for each ear, a "deviation from NAL-NL1 best fit," essentially showing how the user adjusted the gain, relative to the programmed NAL-NL1 gain, when listening to speech in quiet.

Figure 4 shows the user gain adjustments immediately following the real ear fitting procedure. Participants' gain settings were preset at the clinician's fit to NAL-NL1 (by turning the hearing aid off and then back on) after which they were instructed to make gain adjustments, if needed, to optimize the comfort and clarity of speech in quiet (65 dBA). The purpose of this was to observe if user-adjusted gain was significantly different than our best fit to NAL-NL1 targets.

Results in Figure 4 show that, *on average*, subjects adjusted the hearing aid gain to slightly less (1–2 dB) than our best fit to the NAL-NL1 targets. Results of a T-test comparing these deviations showed that the differences were not statistically significant ($t = -1.075$, $p = 0.30$ and $t = -1.962$, $p = 0.069$, for the right and left ears, respectively). There was, however, substantial variability across participants. Six of the 16 participants adjusted the hearing aid gain in at least one ear so that it was at least 4 dB different than the programmed gain. Three of the four participants adjusted the gain in both ears than to less than programmed gain while one participant adjusted the gain in both ears to more than programmed gain settings. Two additional participants, discussed below, chose gain values at least 4 dB different than prescribed in one ear only resulting in a "gain mismatch." Gain mismatches due to user adjustments (i.e., differences in the deviation from NAL-NL1 targets between ears) were, *on average*, quite small (~1 dB). Only two of the 16 participants showed gain mismatches >2 dB. These participants showed gain mismatches of ~8 and 11 dB, respectively. Based on further adjustment trials, however, it appears that these mismatches were *not* reflective of a true subjective preference for these VC adjustments. These same partici-

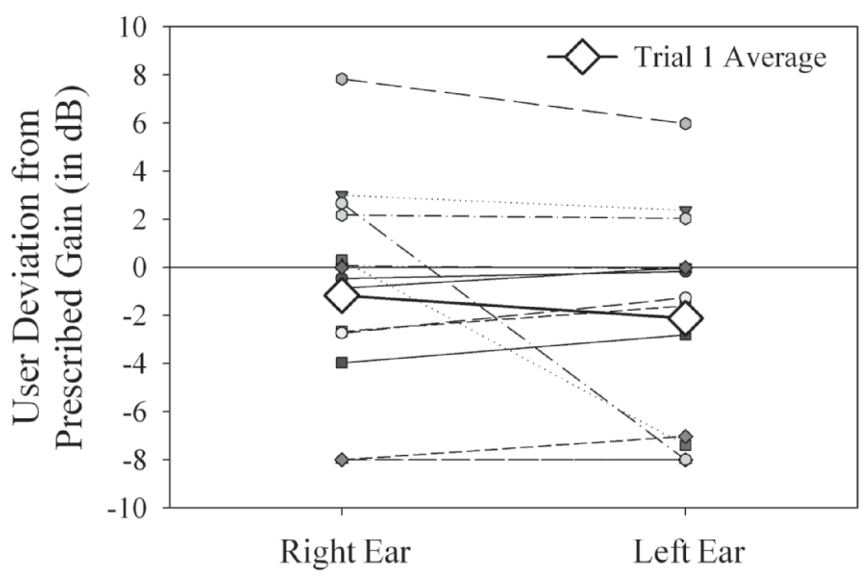

Figure 4. Ear specific deviations, due to user adjustment of the hearing aid gain, from the best fit to prescribed gain settings. These data are from the first trial in which participants *did not* listen in simulated noises prior to making adjustments. The large symbol represents the average results while the small symbols represent individual deviations. Positive values represent user gain adjustments that resulted in more gain than prescribed while negative values reflect adjustments leading to less gain than prescribed.

pants did not maintain a consistent preference for reduced gain in the left ear compared to the right during latter adjustment trials. In fact for both participants the gain mismatch was reversed on at least one of the subsequent trials, suggesting that these individuals were simply unreliable in their ability to make gain adjustments.

A correlation analysis of the data in Figure 4 (right and left ear deviations) showed a strong and significant ($r = 0.70$, $p < 0.01$) correlation. This suggests that *when starting with the gain set at baseline* (i.e., the clinician's fit), individuals may adjust overall gain up or down, compared to the clinician fit; however, the relative gain between ears remained comparable to that provided by the clinician's fit to NAL-NL1 prescriptive formula.

Figure 5 shows the gain deviations *after* listening in our three divergent simulated environments during two separate trials. Recall that in these conditions participants were encouraged to make gain adjustments. After listening in the divergent settings all participants again listened to speech in quiet (65 dBA) and then reset the hearing aid gain to their preferred settings.

Results shown in Figure 5 show again that, *on average*, deviations in adjusted gain from our clinical fit to NAL-NL1 targets are small and uniform between ears. The "overall average" deviations (i.e., the deviations averaged across both trials) in Figure 5 are near 0 dB for both the right and left ears; however, there was again substantial variability across subjects. In addition, the magnitude of ear "mismatches" was somewhat larger than observed during the first trial (Figure 4) with mismatches up to 16 dB. Baumfield and Dillon (2001) reported that rms differences of 6 dB or more between average prescribed target gain (averaged across 1000, 2000, and 4000 Hz) could affect benefit and satisfaction with an aid. In the 32 trials (16 subjects x two trials), there were only five instances where listeners (four listeners) generated mismatches >6 dB. Only one listener created a mismatch of >6 dB on both trials, and in this case the mismatches were in opposite directions; that is, there was not a consistent preference for a mismatch in one direction.

A correlation analysis continued to show a significant correlation between adjustments made to the right and left ears ($r = 0.534$, $p < 0.01$) for the data combined across the two trials and for each trial individually ($r = 0.536$, $p < 0.05$ and $r = 0.570$, $p < 0.05$ for trials two and three, respectively). This finding also suggests that our study participants were relatively good at readjusting their hearing aids to achieve "balanced" gain between ears even after listening in divergent simulated environments.

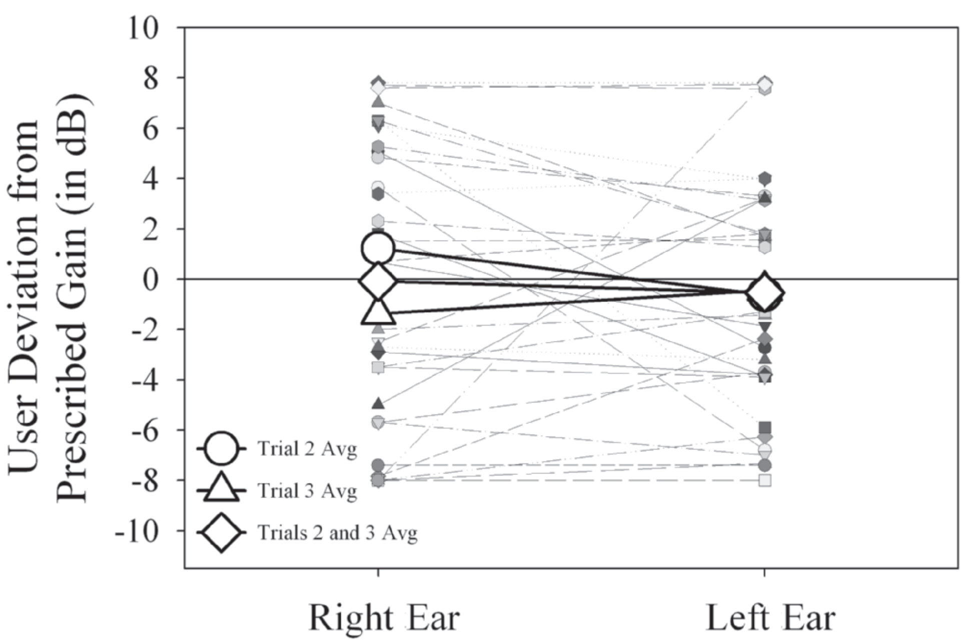

Figure 5. Same as Figure 4 except participants first made gain adjustments while listening in three noise conditions designed to encourage gain adjustments and then listened to speech in quiet (as in Figure 4) and made their final gain adjustments. Deviations reflect final gain adjustments after listening to speech in quiet. Participants were evaluated on two separate trials. Large symbols represent average results while small symbols represent individuals on a given trial.

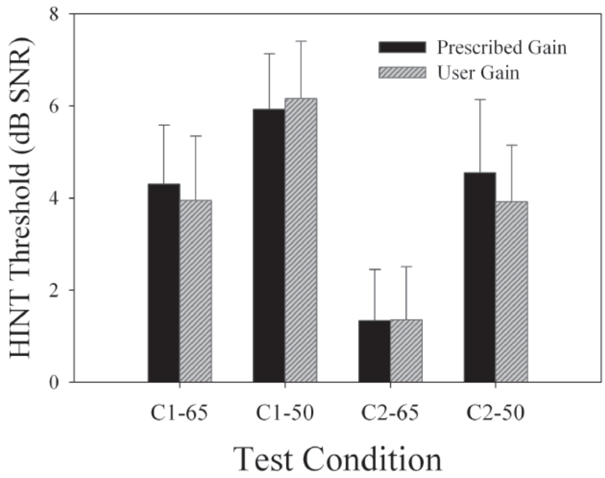

Figure 6. HINT thresholds as a function of Noise Configuration (C1 = Noise Condition 1; Five noise speakers surrounding the listener and C2 = Noise Condition 2; Three noise speakers on the right side of the listener) and Noise level (65 or 50 dBA). Solid and striped bars show data for prescribed and user gain settings, respectively.

Effect of User Gain Adjustments on Speech Understanding

Of primary interest in this study was the potential effects of user gain adjustments on speech understanding. To examine this we measured HINT sentence thresholds in two noise configurations and at two noise levels with (1) the hearing aid gain set at the NAL-NL1 prescribed setting and (2) the gain set by the user. To obtain the user setting, subjects first listened to speech and made gain adjustments as needed to optimize clarity and comfort in the simulated environments described above. Following this, subjects listened to speech in quiet (at 65 dBA) and *readjusted* their hearing aid gain to optimize clarity and comfort in this setting. Speech understanding was assessed at this gain setting (e.g., with the gain set, by the user, to result in possible mismatches or substantial deviations from the clinician gain settings) and in a separate trial with the aids set at the prescribed gain settings. Mean HINT scores as a function of noise level, noise configuration, and gain condition are shown in Figure 6.

Results show that, *on average*, user adjustment of aid gain had no significant impact on speech understanding. A repeated measures ANOVA was used to examine hearing aid gain effects on speech understanding. The within subjects independent variables were gain condition (NAL-NL1 or user adjusted), noise configuration (five noises surrounding the listener or three noises on the right side), and noise level (65 or 50 dBA). The dependent variable was the HINT score in each gain/noise configuration/noise level condition. Of specific interest in this study, there was no significant effect of gain condition and no significant interaction between gain condition

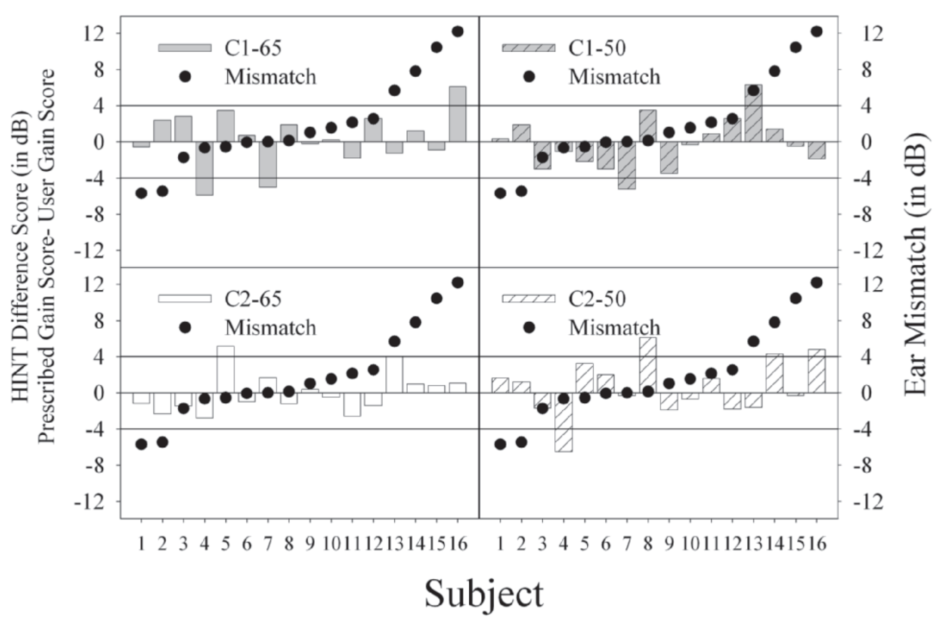

Figure 7. Ear "mismatch" (filled circles) and HINT difference scores (filled bars) plotted separately for each speech in noise test condition and as a function of subject (see text for more details). C1: Noise Condition 1 (Speech at 0° and five noise loudspeakers surrounding the listener). C2: Noise Condition 2 (Speech at 0° and three noise loudspeakers on the right side of the listener). 65 and 50 refer to the overall noise levels of 65 and 50 dBA used during speech testing.

and any other test condition.

Given the substantial variability observed in gain adjustments across users, it was also of interest to see if individual cases of substantial gain mismatches affected speech understanding. Figure 7 shows *differences* in the HINT scores as a function of magnitude of gain mismatch for each of our 16 subjects (each bar represents a HINT difference score for a single subject in a given test condition). Ear mismatch (or gain mismatch between ears) refers to the "difference in the deviations" from the clinician fit for the right and left ear that was present during the portion of the speech testing in which the user-adjusted gain settings were used. These ear mismatches were derived by subtracting the deviation from prescribed target in the left ear from the deviation from prescribed target in the right ear. For example, the participant with the largest mismatch (16, mismatch of 12 dB) achieved this by adjusting the gain in the right aid up (+6 dB) compared to the prescribed gain and adjusting the gain in the left aid down (-6 dB) compared to the prescribed gain. This 6 dB increase in gain in the right ear coupled with a 6 dB decrease in gain in the left ear resulted in a 12 dB "mismatch." The mismatches are shown by the filled symbols on each graph. Subjects are ordered based on the magnitude of their mismatch. The HINT difference scores reflect the change in HINT scores, in each condition, following user adjustments of the gain. A *positive* value means the HINT score was *better* when tested with aid gain set in each ear by the user (rather than at prescribed gain levels). The solid horizontal lines in the figure show a range of ±4 dB around a change score of 0 dB.

There are no normative data for the critical difference in HINT scores between two test conditions, based on the noise type and configurations used in this study. Past research using the HINT and single, steady-state noise sources (placed at 0°, 90°, or 270°) reported a 95% confidence interval of ~2 dB when two 10-sentence lists are used (as was done in our study). Given the variability in the temporal structure of our noise (cafeteria babble), an estimate of a 4 dB 95% confidence interval for our test environment was assumed.

Figure 7 shows that the difference in HINT scores exceeded the ±4 dB criteria in ~15.6% of the cases (10 of 64 instances). Of those cases where the difference exceeded 4 dB, half (5 of the 10) had poorer HINT scores and half had better HINT scores following user adjustment of gain. In addition, *none* of the subjects showed a *consistent* trend toward better or poorer HINT performance following user adjustments. A correlation analysis of user mismatch and change in HINT score also showed no significant relationship between performance on the HINT and user adjustments.

DISCUSSION

The current study had two primary purposes. First we were interested in whether hearing aid users would adjust their hearing aid gain to match prescribed gain settings, particularly after being in situations that encouraged substantial gain adjustments. Our results showed that, *on average*, individuals adjusted their gain to match NAL-NL1 prescribed gain settings in each ear. Although some individuals preferred more or less gain than prescribed, this preference was generally similar between ears (see Figures 4 and 5). There was, however, substantial variability across participants with some listeners introducing relatively large mismatches in gain levels between ears. This was particularly true following listening in our various simulated environments. The introduction of relatively small mismatches by listeners is not unexpected. Although the binaural system in persons with normal hearing is quite sensitive to level differences between ears, the performance of persons with hearing loss is generally poorer and quite variable (Koehnke et al, 1995). Thus some of the mismatches introduced by our listeners may be due to larger than normal interaural level difference (ILD) thresholds. In addition, the task of balancing the level between ears while listening to free field presentation of speech is substantially different than the same/different paradigm used to quantify ILD thresholds under headphones. It is possible that the interaural level difference needed to detect a perceptual "mismatch" while listening to aided speech in the free field is somewhat larger than the threshold for a headphone ILD task.

A second purpose of this study was to determine if gain mismatches affected aided speech perception. The study findings in this area were clear and consistent. For the conditions tested in the study, speech at 0° and noise surrounding the listener or to one side, user adjustment of gain did not significantly affect (negatively or positively) speech understanding compared to performance with the hearing aids set at the prescribed gain settings (see Figure 6). This suggests that the magnitude of the deviations from prescribed gain introduced by users was not large enough to significantly affect speech understanding.

There are several factors that may be responsible for this outcome. A general interpretation of these results is that adult hearing aid users are sensitive to gain changes that could significantly affect speech understanding and are able to prevent changes of that magnitude from occurring. In addition, the lack of a significant effect on speech understanding may be due to the fact that gain deviations were limited to ±8 dB. Allowing larger deviations would have introduced the possibility of larger effects on audibility and thus performance. Another factor that may have limited the effect of user gain adjustments was the speech recognition task we chose. We tested our participants in two fixed levels of background noise (65 and 50 dBA). It is possible that the fixed level of the noise dictated audibility (rather than auditory thresholds) and thus speech recognition performance. That is, with noise levels fixed, adjusting the hearing aid gain changed both the speech and noise levels, leaving the SNR largely unchanged (except in bands where audibility may have been affected by the gain adjustments). We did use a lower noise level (50 dBA) in an attempt to address this issue, but no effect was observed at this level either. It is possible, however, that at even lower noise levels (or with larger VC adjustments) user deviations would affect speech understanding.

Binaural squelch (the improvement in detection and recognition of a signal with binaural versus the better ear monaural listening) is another factor that could have been negatively affected by user gain adjustments. Bronkhorst and Plomp (1992) reported an approximately 3 dB improvement in the SNR needed for 50% sentence recognition, when listening binaurally compared to monaural listening, in a background noise that surrounded the listener, similar to our noise condition 1. The introduction of a large gain mismatch between ears has the potential to change a bilateral fitting into essentially a unilateral one (e.g., turn down the gain such that the signal to one ear is largely inaudible) thus reducing any potential benefit provided by binaural squelch effects. Although there is the potential for user adjustments in gain to affect the benefits of binaural squelch, past research and the experimental conditions used suggest this effect, if present, would be small.

Specifically, the largest gain mismatch introduced during the speech testing portion of the study was approximately 12 dB (one aid turned up 6 dB and the other down 6 dB from target). The binaural system, however, appears to function quite efficiently in the presence of interaural disparities in intensity (level differences between ears) of this magnitude, as long as the SNR between ears remains unchanged. For example, Bronkhorst and Plomp (1989) presented speech and noise to a KEMAR manikin (in an anechoic chamber) and routed the sounds from the KEMAR's ears to listeners. This gave them independent control of the levels at each ear. In one condition a single noise source was used and was presented from a 90° azimuth while the speech was presented from a 0° azimuth. In this condition binaural speech recognition was largely unaffected (only a 0.5 dB decrease in SRT was observed) by a 20 dB decrease in speech and noise levels at the ear near the noise. A larger decrease (approximately 3.5 dB) was observed when the output from the ear opposite the noise was attenuated by 20 dB. In this condition, however, the ear with the better SNR was being attenuated.

Further evidence for the limited effect of user gain adjustments on binaural benefit comes from past research evaluating the effects of interaural differences in level on the masking level difference (MLD). The MLD refers to the improvement in detection or recognition of a signal (speech or nonspeech) when listening in a dichotic (different between ears) versus a monotic or diotic (same to both ears) condition. McFadden (1968) measured MLDs in the NmSm (monaural noise and monaural signal) and N0Sπ (binaural noise in phase between ears and binaural signal 180° out of phase between ears) conditions. In a set of the N0Sπ conditions, the noise level was fixed at one ear while the signal and noise were systematically reduced at the other ear (thus maintaining the SNR at each ear). This is somewhat analogous to the current study in which users were able to adjust the gain of one hearing aid down (decreasing both the signal and noise at one ear). The MLD was quite resistant to changes in interaural level. No effect on the MLD was observed until the level at one ear was reduced more than 10 dB. These findings are consistent with our study results showing no effect of the limited adjustments in gain made by our listeners on speech understanding (Figure 6).

Finally, an important caveat to the current study is that our results represent performance in a laboratory setting with the listeners focused specifically on making consistent and reliable gain adjustments. These results suggest that under these *optimal conditions* older adults with hearing loss can make reliable and reasonable gain adjustments. These results imply that the potential for the introduction, by hearing aid users, of gain mismatches that will negatively affect speech understanding are minimal, and concern over potential negative effects should not be a motivation for not providing a volume control for users. However, recent work by Chalupper and Heuermann (2006) suggests that in real-world settings, other factors, such as time constraints, more rapidly changing environments, and physical constraints (e.g., something in one hand limiting their ability to adjust a given hearing aid) may reduce the reliability and magnitude of user gain adjustments thus increasing the potential for negative effects on speech understanding.

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