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Listener Factors Explain Little Variability in Self-Adjusted Hearing Aid Gain

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Abstract

Self-adjustment of hearing aid gain can provide valuable information about the gain preferences of individual listeners, but these preferences are not well understood. Listeners with mild-to-moderate hearing loss used self-adjustment to select amplification gain and compression parameters in real time on a portable touch screen device while listening in quiet and noisy backgrounds. Adjustments to gain prescribed by the National Acoustics Laboratories' non-linear fitting procedure (NAL-NL2) showed large between-subject variability. Known listener characteristics (age, gender, hearing thresholds, hearing aid experience, acceptable noise level, and external ear characteristics) and listener engagement with the self-adjustment software were examined as potential predictors of this variability. Neither listener characteristics nor time spent adjusting gain were robust predictors of gain change from NAL-NL2. Listeners with less than 2 years of hearing aid experience and who also had better hearing thresholds tended to select less gain, relative to NAL-NL2, than experienced hearing aid users who had poorer thresholds. Listener factors explained no more than 10% of the between-subject variance in deviation from NAL-NL2, suggesting that modifying prescriptive fitting formulae based on the factors examined here would be unlikely to result in amplification parameters that are similar to user-customized settings. Self-adjustment typically took less than 3 min, indicating that listeners could use comparable technology without a substantial time commitment.

Keywords

hearing aid fitting, amplification, background noise, acclimatization, hearing loss

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Introduction

Listener satisfaction with hearing aids has not been well predicted and depends on the complexity of the acoustic environment (Kochkin, 2011). Noisy restaurants are among the most challenging environments for people with hearing aids, but it is not clear from existing data how hearing aid fitting could be changed to improve satisfaction in noisy rooms. Hearing aid amplification parameters are typically set according to prescriptive formulae, such as the National Acoustics Laboratories' non-linear fitting procedure (NAL-NL2) (Keidser, Dillon, Flax, Ching, & Brewer, 2011). These formulae are intended to increase speech audibility in quiet for people with hearing loss, sometimes in addition to achieving other goals such as normalizing loudness perception (e.g., Moore, Glasberg, & Stone, 2010). This approach may not always be appropriate for selecting amplification gain for all environments. Noise reduction or beamforming algorithms in modern hearing aids can modestly improve subjective aspects of listening in noise for some hearing aid wearers (Bentler, Wu, Kettel, & Hurtig, 2008; Boymans & Dreschler, 2000), but these algorithms might have side effects that are undesirable, such as reduced speech intelligibility (Brons, Houben, & Dreschler, 2014). Self-adjustment of hearing aid gain (e.g., Keidser et al., 2005) enables listeners to pick amplification settings according to their individual preferences, which could potentially increase listener satisfaction, especially in noise.

The idea of incorporating user feedback or adjustments into the process of fitting hearing aids is not new

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(Neuman, Levitt, Mills, & Schwander, 1987). Although hearing aid wearers sometimes have access to a volume control or may be able to switch between different preprogrammed settings, if hearing aid wearers want substantial changes to the gain and compression characteristics, this typically requires them to ask their audiologist or hearing aid dispenser to fine-tune the hearing aid based on a verbal description of what they want and hope that the resulting changes match their preference (Jenstad, Van Tasell, & Ewert, 2003). This approach is burdensome to both audiologist and client and might not provide the hearing aid wearer with the gain settings they desire, especially in cases where there are communication difficulties between the audiologist and the client or when the desired change in gain is large.

Greater inclusion of the hearing aid wearer into the fitting process was identified as a potential method for accommodating individual differences in preferred gain by allowing the wearers themselves to strike the balance between settings optimized for speech understanding and settings optimized for comfort or other subjective concerns (Kuk & Pape, 1992). Self-adjustment was advocated by Schweitzer, Mortz, and Vaughan (1999), who framed the approach as fitting "not by prescription, but by perception." The feasibility of using self-adjustment to match hearing aid gain to listeners' preferred settings has been explored in the past, such as by Elberling and Hansen (1999) who pointed out potential limitations of audiologist-driven fine tuning and implemented an experimental self-adjustment interface on a PC that enabled control over gain in low-, mid-, and high-frequency regions.

In fact, preferred hearing aid gain has been investigated using a number of techniques, including paired comparisons (Amlani & Schafer, 2009; Byrne, 1986; Keidser, Dillon, & Byrne, 1995; Kuk, Harper, & Doubek, 1994; Moore, Füllgrabe, & Stone, 2011; Preminger, Neuman, Bakke, Walters, & Levitt, 2000; Punch & Howard, 1978), unpaired ratings (e.g., van Buuren, Festen, & Plomp, 1995), observation of the gain-frequency response when the volume control is set to the level the wearer typically uses in daily life (e.g., Humes, Wilson, Barlow, & Garner, 2002; Smeds et al., 2006), self-adjustment of gain characteristics (e.g., Boothroyd & Mackersie, 2017; Dreschler, Keidser, Convery, & Dillon, 2008; Keidser et al., 2005), and trainable hearing aids (Keidser & Alamudi, 2013; Mueller, Hornsby, & Weber, 2008; Zakis, Dillon, & McDermott, 2007). Listener preferences for hearing aid gain have generally been shown to be stable with good within-subject reliability (Dreschler et al., 2008; Elberling & Hansen, 1999; Keidser et al., 2005; Kuk & Pape, 1992; Nelson, Perry, Gregan, & VanTasell, 2018).

Newly available self-adjustment technology, such as Ear Machine©, allows users a wide degree of control over gain and compression characteristics via a visual interface implemented on a smartphone or similar portable touch screen device. This approach allows users to make quick and potentially substantial adjustments to the function of their hearing aid based on their needs and preferences in real time. Although gain preferences and self-adjustment have been studied in the past, a more recent and direct investigation of a modern self-adjustment method and technology that is available to the general public is warranted.

To that end, we completed a study of self-adjustment of amplification parameters using an example of such portable, real-time technology and reported on the range of gains selected by participants with mild-to-moderate sensorineural hearing loss (Nelson et al., 2018). That report describes the reliability of listeners' selections over repeated self-adjustments, the influence of noise on the amount of gain selected, and the impact of self-adjusted gain on speech recognition performance. Participants were seated in a sound-treated room and used the Ear Machine algorithm to adjust gain and compression characteristics while listening to speech presented either in a quiet background or in simulated restaurant noise environments that were created from recordings made in restaurants. The level of the noise and the restaurant environment were varied to assess how the signal-to-noise ratio (SNR) and listening background influenced the self-adjustments made by the participants.

Participants demonstrated good within-subject reliability, and the insertion gains that resulted from self-adjustment were most strongly affected by the SNR, with listeners selecting less gain as the noise level increased. Gain adjustments made in the various noise environments differed by a small but statistically significant amount; spectral differences among noise environments appeared to have a greater influence on gain adjustment than temporal fluctuations in noise energy. Notably, a wide range of selected gains was observed across participants, spanning about 40 dB. Some listeners opted to give themselves 10 to 15 dB more gain than their audiologist-fit settings, while others chose to reduce the gain by 20 to 25 dB. Despite this large range between listeners, speech recognition did not systematically differ between audiologist gain settings and self-adjusted gain settings.

The amount of variability observed in the previous findings was striking. The present report investigates that variability further and describes the between-listener variability of the listeners' engagement with the self-adjustment technology. The finding of large variability between listeners in preferred gain has important clinical implications for hearing aid adoption and satisfaction. Listeners whose first fits are far from their desired gain characteristics are likely to reject hearing aids. Despite the need to match gain to individual preferences rather than the average preference, in much of the prior literature on self-adjustment of amplification, between-listener variability in selected gain is presented in only a limited fashion. If between-listener variability in gain preference can be predicted from listener characteristics that are readily available to audiologists (factors such as age, hearing thresholds, or prior experience using hearing aids), then fitting methods could be updated to provide more desirable listening levels for hearing aid users. To that end, the NAL-NL2 fitting formula includes options for adjusting fitting targets based on several listener characteristics (Keidser, Dillon, Carter, & O'Brien, 2012). A primary goal of the present study is to determine whether there are any meaningful relationships between listener characteristics and self-adjusted gain when listeners use a modern, commercially available user interface to adjust the gain and compression characteristics in real time.

The degree to which gain preferences vary between listeners depends, in part, upon the range of possible gain-frequency responses listeners are able to choose from. Possible relationships between listener characteristics and self-adjusted gain may be weakened if the listeners' desired gain settings are outside the limited number of gain-frequency responses offered to them by the adjustment method. In previous studies, the range of gain-frequency responses was sometimes narrow. Mueller et al. (2008) reported results of gain adjustments made by listeners using a range of 16 dB centered around two baseline levels and noted that many listeners reached the limits of the range during self-adjustment. Dreschler et al. (2008) used technology allowing self-adjustments within a 32-dB range and also noted that some people reached the limit during adjustment. Keidser, O'Brien, Carter, McLelland, and Yeend (2008) observed a range of gain preferences (relative to gain prescribed by an earlier version of the National Acoustics Laboratories' non-linear gain fitting procedure, NAL-NL1) that spanned a range of about 20 dB. Participants in a study by Hornsby and Mueller (2008) made gain adjustments in the entire 16 dB range available to them. One impetus for revisiting the issue of variability between listeners is that the range of gain-frequency responses available to participants in the current study was wider than in many previous studies, and the range in which participants selected gain was wider as well (about 40 dB). This wider range of variability may better capture the influence of listener characteristics and deserves closer inspection.

Listener Characteristics and Preferred Amplification

Hearing aid experience, or adaptation to amplification, has previously been investigated as an explanation for variation in preferred gain among hearing aid users. Although some reports indicate no statistically significant difference in preferred gain between experienced and new hearing aid users (Cox & Alexander, 1992; Horwitz & Turner, 1997; Humes et al., 2002), other evidence supports the hypothesis that new hearing aid users prefer less gain than experienced users (Boymans & Dreschler, 2012; Keidser et al., 2008; Marriage, Moore, & Alcántara, 2004). NAL-NL2 includes an adjustment on the basis of hearing aid experience that is also dependent on hearing thresholds (Keidser et al., 2012). Based on the clear clinical and theoretical questions raised by adaptation to amplification, hearing aid experience was included as a listener characteristic of interest in the current study to examine this relationship using a methodology that gives listeners more direct control over the gain-frequency response of the hearing aid across a wider range.

A common principle of hearing aid fitting is that the gain provided by the aid ought to increase the audibility of speech in the frequency region(s) of the hearing loss. Modern fitting methods for hearing aids incorporate information about the user's pure tone thresholds, but it is not clear whether the difference in gain between self-adjusted fits and prescribed fits is related to hearing thresholds. Mueller et al. (2008) reported no correlation between pure tone average and deviation of self-adjusted gain from prescribed gain, but this finding could have been influenced by ceiling/floor effects based on the limited range of gain in which participants made adjustments (as noted earlier). Keidser et al. (2005) presented evidence that the shape of the gain-frequency response selected by participants with hearing loss was related, in part, to the configuration of their hearing loss, which suggests that listeners were guided by their hearing thresholds as they adjusted gain. Keidser et al. (2008) found that after user selection of a preferred gain-frequency response and volume control setting, gain deviation from prescribed fit was moderately related to hearing thresholds only for the participants who were new users of hearing aids, which indicates that among new hearing aid users, people who have more severe losses prefer gain that is similar to what people with less severe losses prefer.

To understand the behavior of listeners when self-adjusting gain, two relationships involving hearing thresholds were investigated in the current study. First, the relationship between hearing thresholds and insertion gain was examined to understand if listeners select gain settings that would improve speech audibility in the frequency region(s) of their hearing loss. If it is the case that hearing thresholds have only a weak relationship with the insertion gain from self-adjusted fits, this would suggest that listeners are primarily using criteria other than audibility to guide their selection of gain, contrary to a primary principle of modern prescriptive formulae. Second, the relationship between hearing thresholds and the deviation of the self-adjusted gain from NAL-NL2 fitted gain was investigated to determine the potential utility of modifying a prescriptive formula based on listener thresholds to better match desired gain.

Toward the goal of supplying sufficient gain to overcome the listener's hearing loss, part of the amplification from a hearing aid compensates for the loss of the resonant energy of the external ear (real-ear unaided gain or REUG) that occurs when the hearing aid is inserted into the ear canal (Upfold & Byrne, 1988). There is substantial variability in the REUG between individuals, and this variability could affect the perceived sound quality of the hearing aid, particularly if there is a meaningful mismatch between the characteristics of the listener's REUG (such as the peak frequency of the resonant energy) and the gain applied by the hearing aid to compensate for the loss of the REUG (Valente, Valente, & Goebel, 1991). It is possible that some of the variability in self-adjusted gain is due to listeners attempting to bring the gain provided by the device into better agreement with the particular acoustic characteristics of their ears. Based on this hypothesis, real-ear characteristics were included as predictors of interest.

Keidser et al. (2008) reported that female listeners tended to prefer less gain than male listeners. The NAL-NL2 formula includes an option for modifying prescribed gain based on gender. When gender is provided to the algorithm, gain is modified by $+1$ dB for males and -1 dB for females, creating a 2-dB difference in overall gain. The magnitude of this difference reflects the finding that female participants preferred about 2 dB less gain than male participants on average and gives consideration to the trend in the literature for female participants to select lower most comfortable levels (MCL) than male listeners (Keidser et al., 2012). Listener gender was included as a characteristic of interest to evaluate whether further gain modifications based on gender might be appropriate to better match prescribed gain to desired gain.

Although MCL describes the level at which a listener finds speech the most comfortable, acceptable noise level (ANL) describes the maximum level of background noise a listener will tolerate when listening to speech at MCL (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006; Nabelek, Tampas, & Burchfield, 2004). ANL is, in essence, an SNR computed by subtracting the highest level of background noise a listener can accept (in dB) from the MCL. Tolerance of noise as quantified by ANL could potentially explain variability in hearing aid gain preference in noisy conditions. Even though hearing aids amplify speech and noise equally within a processing channel, the gain affects the absolute level of the noise at the output of the hearing aid. Given previous findings that ANL increases (i.e., listeners tolerate less noise) as the overall presentation level increases (Franklin, Thelin, Nabelek, & Burchfield, 2006; Tampas & Harkrider, 2006), it is possible that by lowering the gain during self-adjustment, listeners are making the noise level more tolerable even if they are not changing the SNR within individual processing channels. Based on this hypothesis, ANL was included as a variable of interest to understand if ANL could be used to better match prescribed gain to desired gain.

However, it is not clear that self-adjustment will relate to ANL, in part because noise tolerance appears to depend on both the overall sound level as well as how that tolerance is measured. Recker and Edwards (2013) assessed tolerance for noise using the typical ANL procedure as well as the minimum acceptable speech level procedure in which listeners adjust the speech level while the noise level is fixed, in contrast to the ANL procedure in which speech is at a fixed level and the noise level is adjusted. They found that the overall presentation level had opposite effects on noise tolerance depending on whether it was the noise or the speech that was adjusted. As presentation level increased, ANL values also increased (representing less tolerance for noise at higher overall levels), but minimum acceptable speech level values decreased (representing more tolerance for noise at higher overall levels). It is an open question whether between-listener variability in ANL could be used to better match prescribed gain to self-adjusted gain. The hypothesis that lower tolerance for noise, as measured by ANL, will lead listeners to reduce gain relative to NAL-NL2 when listening in noisy environments will be examined.

Listener Engagement

Differences in how listeners interact with self-adjustment technology that affords the listener liberal control over the amplification characteristics could also be a potential predictor of variability in self-adjusted gain. The relationship between a listener's engagement with the technology and the resulting gain is not well understood. For example, it is not known whether people who take more time to self-adjust gain or who explore a greater number of alternative gain-frequency responses are more likely to select gain that deviates further from the baseline (which is their NAL-NL2 fit in the present study). Furthermore, listener characteristics might be related to measures of listener engagement, and characterizing these relationships would help to clarify differences in how self-adjustment technology is likely to be used.

Few studies in the literature report details about user interaction with self-adjustment technology, particularly with regard to listener characteristics. In an examination of different controller types for self-adjustment of amplification, Dreschler et al. (2008) noted that participant age, hearing aid experience, or slope of hearing loss were all not statistically significant predictors of the number of key presses needed to reach preferred gain during self-adjustment. In addition, neither age nor hearing aid experience appeared to have systematic effects on test–retest reliability of self-adjustments, suggesting that self-adjustment technology can be used by many listeners to select preferred gain (Boothroyd & Mackersie, 2017; Dreschler et al., 2008). It is not clear that people will interact with any particular implementation of self-adjustment in a similar way to any other particular implementation, and how long it takes users to select their preferred gains could be impacted by the details of the device or algorithm as well as listener factors. Listener engagement will be described and variability in listener engagement will be investigated to understand whether listener characteristics predict how self-adjustment tools might be used by a variety of people, and not just the average user.

Research Aims

In this report, listener age, gender, hearing thresholds, hearing aid experience, real-ear characteristics, ANL, and time taken to complete the self-adjustment session will be evaluated as potential predictors of self-adjusted gain relative to NAL-NL2. In addition, known listener characteristics will be evaluated as potential explanations for differences between listeners in the amount of time taken to complete self-adjustment.

The primary research aims are as follows:

1. Report aspects of listener engagement with the self-adjustment technology, including how listener engagement changes with increasing noise level.
2. Investigate the possibility that known listener characteristics can predict between-subject variability in engagement with the self-adjustment technology.
3. Describe the relationship between hearing thresholds and the insertion gain from self-adjusted fits.
4. Evaluate to what degree known listener characteristics and listener engagement predict how much NAL-NL2 fits differ from self-adjusted fits made in a variety of noise environments and SNRs.

Methods

Subjects

Thirty adults with symmetric sensorineural hearing loss, generally with a sloping configuration and ranging in degree from mild to moderate, participated in the study. Average hearing thresholds of the subjects are shown in Figure 1. Subject ages ranged from 59 to 79 years (mean = 70 years). Thirteen subjects were female. Eighteen subjects had prior hearing aid experience, and of that group, 14 subjects had at least 2 years of experience using hearing aids. For all but 2 subjects, REUG and real-ear-to-coupler difference (RECD) were measured during the same audiological evaluation for inclusion in the study. The use of human subjects was approved by the institutional review board of the University of Minnesota. All subjects provided written informed consent.

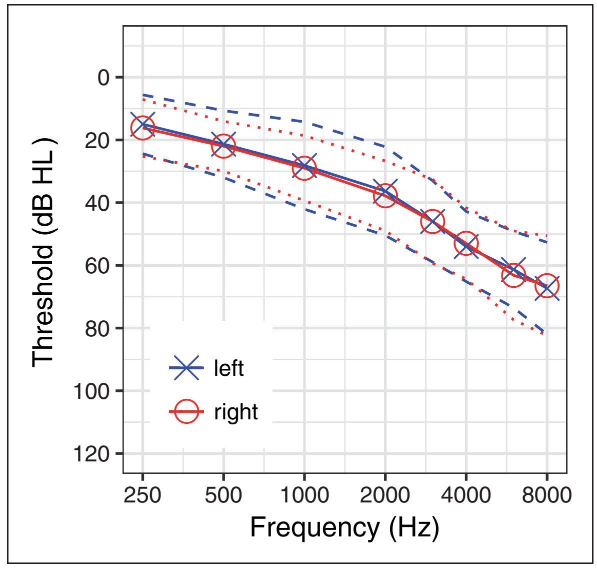

Figure 1. Mean participant audiograms for left and right ears. The dashed blue lines and dotted red lines indicate 1 standard deviation from mean thresholds for left and right ears, respectively.

Equipment

Amplification and self-adjustment of amplification parameters was achieved using an application developed by Ear Machine LLC (www.earmachine.com), running on the Apple iOS platform on an iPod touch (fourth generation). Sound was received by the microphone on the iPod, processed by the Ear Machine algorithm according to user adjustments to two software controllers, and delivered to the listeners' ears using Etymotic ER38-14F foam eartips. The device was designed to simulate a nine-channel multiband wide-dynamic range compressor/limiter with fast attack and slow release times and output limiting. The proprietary signal processing includes a 12-band equalizer and is similar to a commercial hearing aid.

Listeners adjusted the gain using two virtual wheels: one wheel labeled Loudness which changed gain and compression in all 9 compression channels, and one wheel labeled Fine Tuning which changed the overall frequency response in the 12 equalization bands. Movements to the Loudness wheel simultaneously adjusted the gain values, compression ratios, and output limiter thresholds in each of the nine compression bands. The mapping from controller to parameters was designed to approximate the fit-to-prescriptive-target gains for typical hearing losses from mild (lowest wheel position) to severe (highest wheel position). Therefore, as the wheel was moved upward, the gain in the high-frequency bands increased faster than the gain in the low-frequency bands. Movements of the Fine Tuning wheel controlled the degree of spectral tilt by applying an additional adjustment to the gain values in each of the 12 bands, around a pivot point located near 1 kHz. Increases to high-frequency gains therefore also resulted in decreases to low-frequency gains (and vice versa). The positions of the two wheels interacted to produce the final gain-frequency response. The device was capable of producing a wide range of gain-frequency responses, with up to 40 dB of insertion gain in the low frequencies and 50 to 60 dB of insertion gain in the high frequencies, although in practice the achievable gain is be limited by feedback, based on the individual fit of the earphone.

Figure 2 shows calculated insertion gains for a 65-dB sound pressure level (SPL) speech-shaped input at low, mid, and high positions of the Loudness and Fine Tuning wheels. When the Fine tuning wheel is in a neutral position (when no frequency-specific gain changes are being made in addition to the parameters set by the loudness wheel), the gain effects of the Loudness wheel are clear: At the lowest position, the gain is relatively flat as a function of frequency, but at the highest position, the high-frequency gain has increased more relative to the low-frequency gain, reflecting the increase in high-frequency versus low-frequency hearing loss observed on average as hearing loss becomes more severe.

The Ear Machine controllers constitute a self-fitting method that goes beyond a volume control or even a bass, mid-range, and treble fine tuning. The Loudness wheel adjusts all compression parameters simultaneously in all compression bands to achieve prescriptive fits based on commonly observed audiogram shapes, while the Fine Tuning wheel allows additional gain adjustments beyond the initial prescriptive fit.

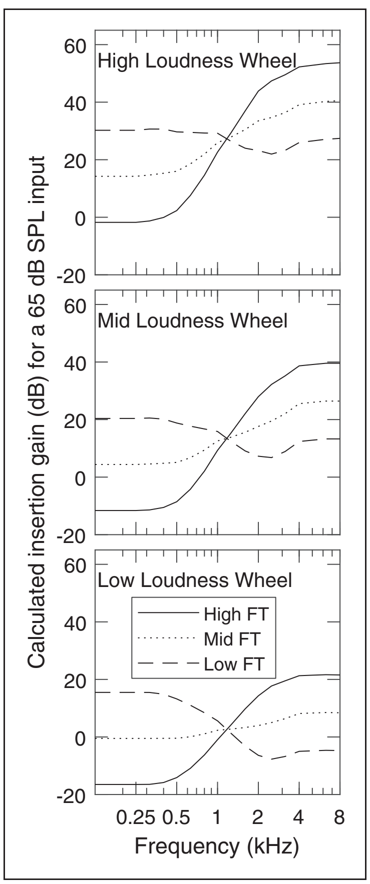

Figure 2. Insertion gains from the research device, calculated for a 65 dB SPL speech-shaped input at several positions of the Loudness and FT wheels.
FT = Fine Tuning; SPL = sound pressure level.

Self-Adjustment Procedure

This study analyzed previously reported gain adjustment data (Nelson et al., 2018), and additional details can be found in that report. Prior to self-adjustment, an audiologist fits the research device to the listener's NAL-NL2 real-ear aided response (REAR) targets (within 5 dB) using an Audioscan Verifit version 3.16, which does not include the NAL-NL2 empirical adjustments for gender and assumes an experienced hearing aid user. This served as the baseline gain-frequency response that the device was reset to before each self-adjustment trial began. Afterward, the participant was seated in the center of a double-walled sound chamber with a 48-speaker array (Anthony Gallo Acoustics—A'Diva ti speakers) driven by 24 Crown XLS 1500 power amplifiers and 3 Lynx Aurora 16 D/A converters and controlled using MATLAB (MathWorks). During each self-adjustment trial, recordings of a female voice speaking 30-second passages from the Connected Speech Test (Cox, Alexander, & Gilmore, 1987) were presented on a loop through a speaker in front of the listener at 65 dBC. Subjects used the Ear Machine© software running on an iPod touch (fourth generation) to adjust hearing aid gain and compression. Subjects held the iPod in front of them, and the microphone on the iPod received the sound from the speaker array, after which it was processed by the Ear Machine software according to the adjustments made by the subject using the software wheels on the iPod's touch screen. The processed sound was delivered to the listeners' ears via Etymotic ER38-14F foam eartips.

Participants were instructed to turn the wheels on the iPod until the female talker's voice (i.e., the Connected Speech Test passages) was as clear as possible. They were asked to adjust the wheels one at a time but were told they could adjust each wheel as much as they wanted and in any order. They were also encouraged to go back and forth and adjust the two wheels until they were satisfied that they had found the best settings. To end a trial and confirm the current settings as their self-adjusted fit, the subjects tapped an icon on the iPod screen.

Self-adjustments were made while listening to the speech in quiet and in four noisy environments (three simulated restaurants and one steady noise with the same average long-term spectrum as one of the restaurants). The long-term spectra of the noise environments were generally similar to that of conversational speech. The level of the noises was varied to evaluate gain adjustment at 4 SNRs: −10, −5, 0, and +5 dB. Self-adjustment in each condition (i.e., each combination of noise type and noise level) was repeated once. The order of conditions was randomized for each subject.

Unaided ANL Procedure

Unaided ANL values were obtained in a separate session following instructions published online by Frye Electronics, Inc. based on the description by Nabelek et al. (2006). The subject was seated in a sound-treated chamber in front of a loudspeaker controlled by an audiometer. The subject was instructed to verbally respond louder or quieter to indicate the direction that the sound level should be changed by the experimenter. A running speech passage was presented using the audiometer. Following the verbal feedback of the subject, the experimenter adjusted the level of running speech in 5-dB steps to reach the levels representing first, too loud, then too soft, and finally the MCL. With the speech passage set at MCL, a noise with the same long-term spectrum as speech was then introduced. The level of the noise was adjusted based on subject feedback until the subject reported that the target voice was incomprehensible. The level was adjusted again until the subject reported that the target voice was clear and easy to hear. Finally, the level was increased up to the point that the subject indicated that it was the most noise that they could put up with while listening for a long period of time. This noise level (in dB) was recorded as the background noise level, and ANL was calculated by subtracting the background noise level from the MCL. Only 21 of the 30 subjects were able to return to the lab for this additional session.

Data Description and Analyses

After completion of each gain adjustment trial, the software delivered information about the trial to a data server. This included information about the amplification characteristics as well as listener engagement: trial duration in seconds, number of movements of the Loudness wheel, and number of movements of the Fine Tuning wheel. Trial duration started at the point in time that the software wheels appeared onscreen and ended when the subject tapped an icon on the touch screen to indicate that they have completed the adjustment. The onset of sound presentation was not linked to the software's demarcation of the start of a trial, so the initial period of the trial duration as recorded by the software could include some time in which the subject was waiting for the sound presentation to begin. A wheel movement indicates a single touch and release of a software wheel on the touch screen of the iPod. During a single wheel movement, the wheel can be turned up or down (or both) by varying amounts so long as the finger remained on the wheel. What the software records as a single wheel movement could, in reality, represent a user exploring many different gain-frequency responses.

The software also saved the gain and compression parameters for the self-adjusted fit. From these parameters, insertion gain was automatically estimated for a 65 dB SPL speech-shaped noise input, assuming average adult REUG and RECD values and using coupler-calibrated values to convert from voltage to sound pressure in dB.

To simplify analysis, the self-adjusted estimated insertion gain for each trial was averaged into a low-frequency band (125, 250, 500, and 1000 Hz) and a high-frequency band (2000, 3000, 4000, 6000, and 8000 Hz). Calculated insertion gain (using the same 65 dB SPL speech-shaped stationary noise as input and assuming the same average adult REUG and RECD values) for each subject's NAL-NL2 fit was also averaged into the same low- and high-frequency bands. A low-frequency pure tone average (LFPTA) and a high-frequency pure tone average (HFPTA) were calculated for each subject using the same division of frequencies, averaged across left and right ears to compare the self-adjusted gain to the listener's thresholds in the same frequency region. As a general summary of hearing thresholds, a four-frequency pure tone average (4FPTA) was calculated from thresholds at 500, 1000, 2000, and 4000 Hz. NAL-NL2 includes an adjustment for hearing aid experience that depends upon the 4FPTA.

To summarize how self-adjusted fits differed from NAL-NL2 fits, deviation of the self-adjusted gain from NAL-NL2 was calculated by subtracting each subject's NAL-NL2-based insertion gain from the self-adjusted insertion gain (in the two frequency bands). A positive deviation from NAL-NL2 indicates more gain than the NAL-NL2 fit, while a negative deviation indicates less gain than the NAL-NL2 fit.

One trial was excluded from analysis. For a single trial in −5 dB SNR noise for subject S12, the digital record indicated that the subject took over 10 min to finish the trial and did not move either the loudness wheel or the wheel, which suggests that the subject was off-task for this trial. This trial was excluded from all statistical analyses. Of the remaining 1,019 included trials across all subjects, every trial was shorter than 4 min, and every trial but one was shorter than 3 min.

Keidser et al. (2012) presented evidence that suggests that the preference for reduced gain seen in new hearing aid users might change over time, such that at 2 years of hearing aid use, hearing aid user's gain preferences had increased to match the NAL-NL1 prescriptive targets. Accordingly, subjects were sorted into groups according to whether they had at least 2 years of hearing aid use. Using this criterion, 14 subjects were experienced users, and 16 subjects were inexperienced users. Of the inexperienced users, 12 had no experience with hearing aids.

ANL values were obtained for 21 of the 30 subjects. The average age of the 21 subjects that completed the ANL procedure was 69.9 years. Twelve were female, and 11 had any prior experience using hearing aids; of those 11 subjects with any hearing aid experience, 8 people had at least 2 years of prior hearing aid experience. Visualizations of the ANL data are restricted to these 21 subjects, and statistical models that include ANL as a variable were restricted to this subset of subjects. Similarly, because real-ear measures were obtained for 28 of the 30 subjects, statistical analysis of the effect of variability in real-ear acoustics excluded the 2 subjects missing real-ear measures. In short, unless the analysis involved ANL or real-ear measures, data from all 30 subjects were included.

Statistics were computed using the R statistical language. The Benjamini–Hochberg method was used to correct p values to control the false discovery rate. The linear mixed models were created using the lme4 package and the restricted maximum likelihood method (Bates, Mächler, Bolker, & Walker, 2015, p. 4; R Core Team, 2016), and then analysis of variance (ANOVA) tables were calculated using the Kenward–Rogers method for estimating degrees of freedom, via the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). Several mixed models were created this way: One model was fit to the trial duration, and nested models were fit to the gain deviation from NAL-NL2 data in the low frequencies and, separately, to the gain deviation from NAL-NL2 data in the high frequencies. Models included within-subjects fixed effects (SNR, noise type, and repetition, and a random intercept for subject as well as a random slope for SNR per subject, included to account for any differences in the effect of SNR between subjects) as well as between-subjects fixed effects.

For the model fit to trial duration, the between-subjects fixed effects were age, gender, 4FPTA, and hearing aid experience group. The models fit to the gain deviation data included these same effects as well as trial duration and the interaction between 4FPTA and hearing aid experience group as effects. To evaluate ANL and real-ear characteristics as predictors of variability, subjects with missing data were excluded, and then, the respective effect(s)—either ANL, or REUG and RECD—were added to the model. After fitting, residuals were inspected to verify that there were no violations of test assumptions, including homoscedasticity and normality.

To quantify the amount of variance in deviation from NAL-NL2 gain that is accounted for by listener characteristics, the marginal R^2_{GLMM} and conditional R^2_{GLMM} were calculated using the MuMIn package in R (Bartoń, 2018; Johnson, 2014; Nakagawa & Schielzeth, 2013). The marginal R^2_{GLMM} describes the percentage of variance accounted for by the fixed effects in the model, while the conditional R^2_{GLMM} describes the total percentage of variance accounted for by the model (i.e., by both fixed and random effects). Because the primary interest is the between-subject variability, two reduced models (one each for the high- and low-frequency gain deviation data) that included the within-subjects fixed effects but excluded the between-subjects fixed effects (trial duration, age, gender, 4FPTA, hearing aid experience group, and the interaction between 4FPTA and hearing aid experience group) were fit to the data. The difference in marginal R^2_{GLMM} between full and reduced models indicates the variance accounted for by the between-subjects fixed effects in the full models.

Results

Listener Characteristics

Six listener characteristics were evaluated as potential predictors of variation in gain adjustment: age, gender, duration of hearing aid use, hearing thresholds (i.e., LFPTA and HFPTA), and ANL. Bivariate correlations were computed between each predictor variable (except gender) and each other predictor variable. To determine the relationship between gender and the other predictors, independent samples t tests were computed between male and female groups for each of the other predictors. Consistent with typical age-related sensorineural hearing loss, age was significantly correlated with HFPTA, $r(28) = .53$, $p = .02$. For this subject sample, years of hearing aid use were significantly correlated with both LFPTA, $r(28) = .64$, $p < .01$, and HFPTA, $r(28) = .51$, $p = .02$. All other correlations were not statistically significant, and no statistically significant differences were observed between male and female subjects on any listener characteristics (all $p > .05$).

Listener Engagement

Listener engagement with the self-adjustment technology was quantified with three metrics: duration of self-adjustment trial (in seconds), number of movements of the Loudness wheel, and number of movement of the Fine Tuning wheel. Figure 3 summarizes the distribution of each metric at different noise levels. With increasing noise level, subjects tended to make more wheel movements and spent more time making adjustments.

The three listener engagement variables were strongly correlated with each other (ranging from $r = .68$ to $r = .86$), which suggests that three metrics were consistent in capturing listener engagement during the self-adjustment process. Due to the collinearity between the listener engagement variables, for further analyses, trial duration was taken as a representative measure of listener engagement with the self-adjustment software.

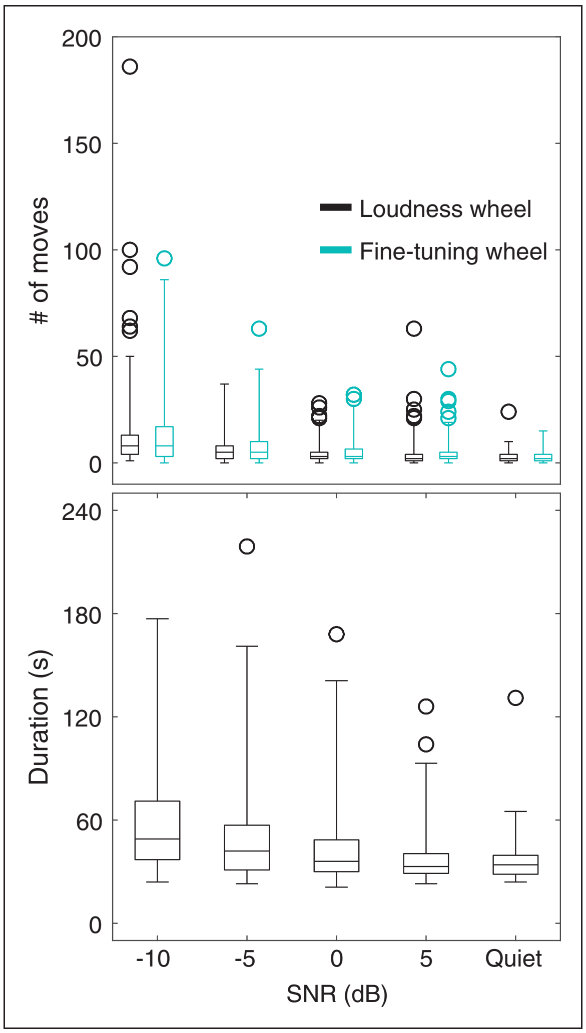

Figure 3. Boxplots showing the duration of self-adjustment trials and number of wheel movements across all included trials for all subjects. Whiskers extend up to 5 times the range between the 25th and 75th percentiles of the data.
SNR = signal-to-noise ratio.

According to the type II sum of squares ANOVA table calculated from the linear mixed model fit to the trial duration data, the only statistically significant fixed effect was SNR, $F(4, 981.0) = 58.19$, $p < .001$; all other $p > .05$. Post hoc tests of contrasts between proximal SNR conditions (i.e., between quiet and +5 dB SNR, between + 5 and 0 dB SNRs, and so on) indicated that trial duration progressively increased as the SNR became poorer ($p < .001$ for all SNR contrasts), consistent with the overall pattern seen in Figure 3. As the listening situation became more difficult, subjects spent more time before making their final selection, suggesting that listener interaction with the technology followed an understandable pattern. However, listener engagement appears not to depend on the listener's age, gender, hearing thresholds, or prior experience with hearing aids—at least within the ranges represented in the current sample of 30 subjects.

Gain Adjustment and Listener Characteristics

Prescriptive gain fitting methods typically prescribe gain based on the user's hearing thresholds. This enables the hearing aid to provide amplification only where it is appropriate for the goals of prescriptive formula (such as increasing speech audibility or normalizing loudness). Therefore, it was of interest whether the insertion gain selected by subjects using self-adjustment would also relate to their hearing thresholds. Figure 4 shows the insertion gain from the self-adjusted fits (averaged across noise environments and trial repetitions) plotted with respect to the LFPTA (for low-frequency insertion gain) and HFPTA (for high-frequency insertion gain) of the subjects. The self-adjusted insertion gain showed statistically significant correlations with the pure tone thresholds in the matching frequency region. For insertion gain and pure tone thresholds in the high frequencies, correlation coefficients ranged from $r = .54$ in the quiet environment to $r = .67$ in the -10 dB SNR condition. For reference, the correlation coefficients between NAL-NL2 gain and pure tone average in this subject sample were $r = .75$ and $r = .60$ for the high and low frequencies, respectively.

The robust correlations between self-adjusted insertion gain and pure tone thresholds indicates that the people who would be prescribed more gain from a hearing aid due to higher thresholds were generally using self-adjustment to achieve more gain than people who had lower thresholds. This indicates that subjects adjusted gain in a meaningful manner that takes into account their hearing thresholds. However, self-adjusted fits showed deviations from NAL-NL2 gain. Explaining the large between-subject variability in deviation from prescribed gain (rather than just the insertion gain of the self-adjusted fit) is a primary goal of the present study.

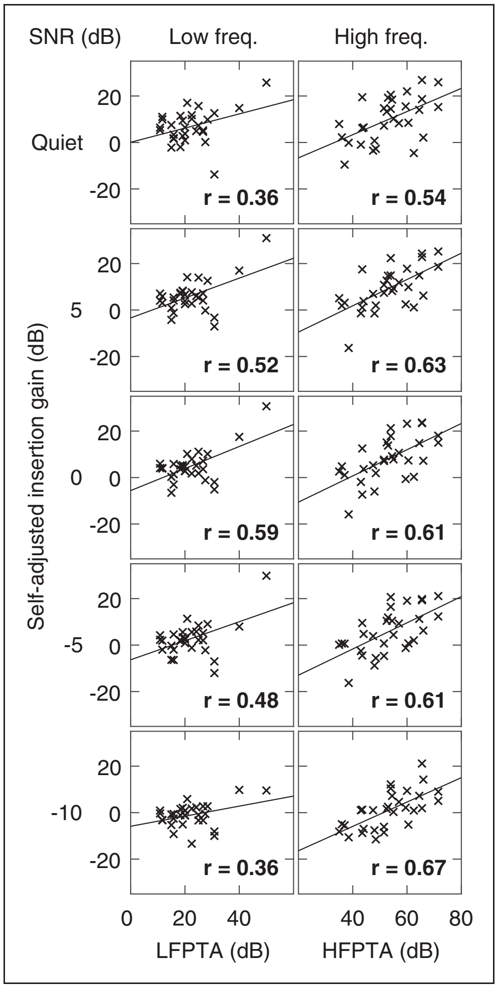

Figure 4. Self-adjusted insertion gain plotted with respect to subjects' hearing thresholds. Insertion gain is averaged across noise types and repetitions. Average low-frequency insertion gain and LFPTA are on the left, while average high-frequency insertion gain and HFPTA are on the right. Rows of plots are labeled along the left side by the SNR in which the adjustments were made. Correlation coefficients for the linear fits are shown at the bottom of each plot (all correlations significant at $p < .05$).
SNR = signal-to-noise ratio; LFPTA = low-frequency pure tone average; HFPTA = high-frequency pure tone average.

To inspect the data for possible relationships between listener characteristics and the degree to which self-adjusted gain changed from the prescribed baseline, deviation from NAL-NL2 gain (averaged across noise types and trial repetitions) was plotted with respect to the listener characteristics of LFPTA, HFPTA, age, years of hearing aid use, trial duration (averaged across noise types and trial repetitions), years of hearing aid use, and gender. Figures 5 and 6 display the resulting scatterplots of listener characteristics and average deviation from NAL-NL2 in the high and low frequencies, respectively. Visually, there appears to be little evidence of relationships between deviation from NAL-NL2 and these listener characteristics.

For the mixed model fit to the high-frequency data, none of the effects of listener characteristics (including the interaction between hearing aid experience and 4FPTA) were statistically significant (all $p > .05$). However, the main effect of trial duration was statistically significant for the low-frequency model, $F(1, 768.66) = 3.88$, $p = .049$. Based on the model coefficient for trial duration, for every additional minute spent using the self-adjustment device, the resulting self-adjusted fit was expected to have 1.2 dB more low-frequency gain than the subject's NAL-NL2 fit, after controlling for the other effects included in the model. The 95% confidence interval, calculated using a percentile bootstrap method, indicates that the true effect of additional time spent adjusting gain could be as little as 0.03 dB to as much as 2.6 dB per minute. Given the large uncertainty about the effect of trial duration, as evidenced by the confidence interval that spans several orders of magnitude, this finding should be interpreted carefully. Of course, simply sitting with the experimental device in hand will not in itself result in changes to gain—as a reminder, trial duration is used here as a proxy for listener engagement with the device.

According to the statistical models, deviation from NAL-NL2 was not reliably predicted from hearing thresholds and hearing aid experience. However, these two variables are confounded in the subject sample, and these statistical inferences should be interpreted with caution. This is underscored by the fact that when 4FPTA is dropped from the model fit to the high-frequency gain deviation from NAL-NL2, the effect of hearing aid experience is statistically significant, $F(1, 39.27) = 5.54$, $p = .02$, and when hearing aid experience is dropped, the effect of 4FPTA is statistically significant, $F(1, 36.18) = 4.52$, $p = .04$. Briefly setting aside the consideration of statistical controls, inexperienced subjects tended to select less high-frequency gain than experienced subjects. Across all SNRs, including quiet, the average difference in high-frequency gain selected by experienced and inexperienced subjects was about 5 dB. In the + 5 dB SNR condition, average high-frequency deviation from NAL-NL2 was −2.7 dB for experienced users and −9.4 dB for inexperienced users. In the 0 dB SNR condition, these values were −1.3 and −8.4 dB, respectively. Thus, when noise levels were mild or moderate, both experienced and inexperienced users reduced high-frequency gain relative to NAL-NL2, but the inexperienced users reduced the high-frequency gain by an additional 7 dB, on average. However, due to the confound of hearing threshold and hearing aid experience in this subject sample, it is not possible to determine whether these differences could most accurately be attributed to hearing threshold, hearing aid experience, to neither characteristic, or to some combination of the two.

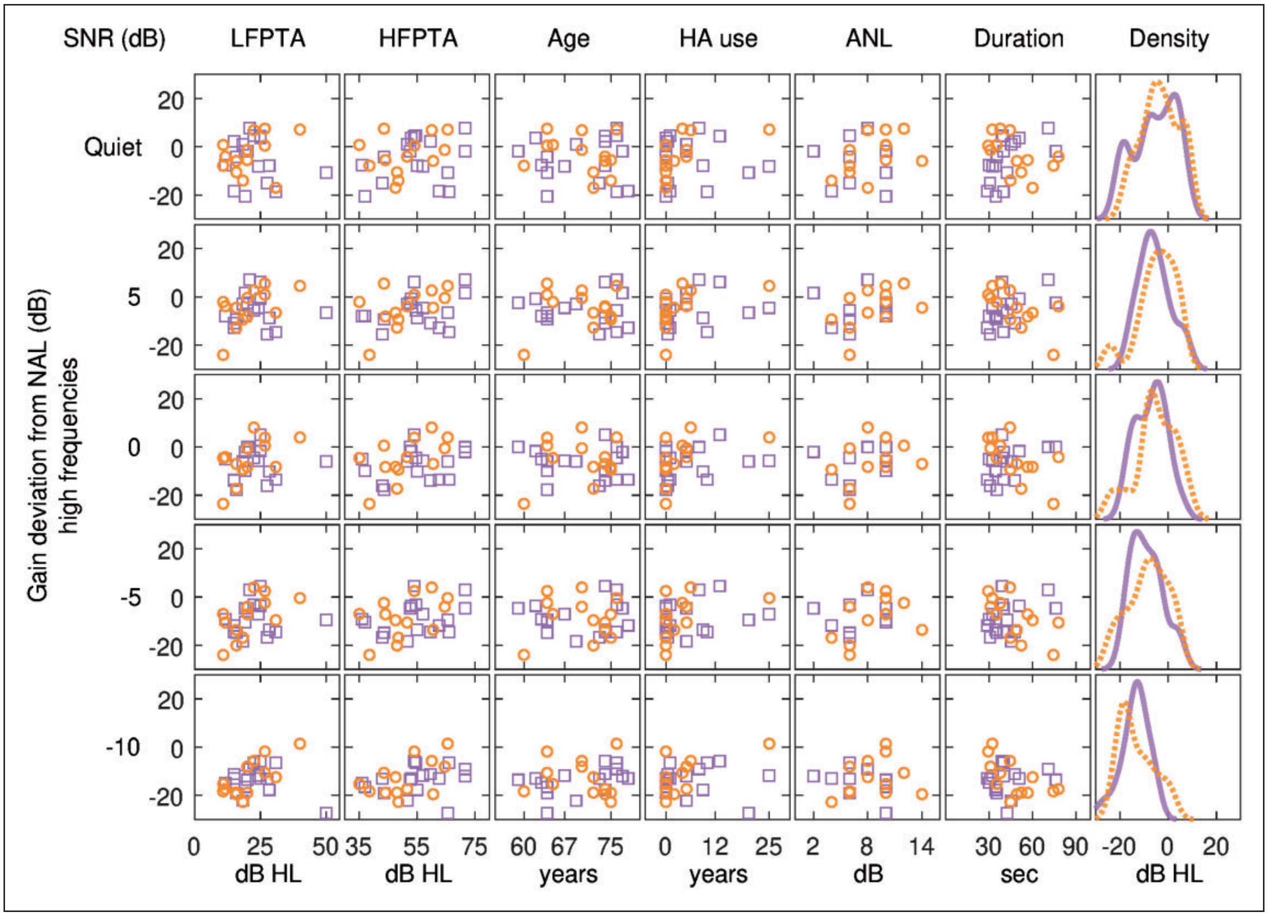

Figure 5. Deviation from NAL-NL2 high-frequency gain. Each row contains data from a different SNR condition, averaged across noise types and repetition. Circles and squares represent female and male subjects, respectively. The rightmost column shows smoothed kernel density estimates for the deviation from NAL-NL2 for male (solid line) and female subjects (dashed line).
ANL = acceptable noise level; HA use = hearing aid use; HFPTA = high-frequency pure tone average; LFPTA = low-frequency pure tone average; SNR = signal-to-noise ratio.

For the high-frequency data, the reduced model's marginal and conditional R^2_{GLMM} were .11 and .55, respectively. The full model's marginal and conditional R^2_{GLMM} were .21 and .56. Thus, the between-subjects fixed effects, when added to the model, accounted for 10% of the variance in deviation from NAL-NL2 for high-frequency gain. For the low-frequency data, the reduced model's marginal and conditional R^2_{GLMM} were .11 and .58, while the full model's marginal and conditional R^2_{GLMM} were .16 and .59, which indicates that the between-subjects fixed effects accounted for 5% of the variance in the low-frequency data. The fact that the conditional R^2_{GLMM} changed very little by the addition of the between-subjects predictors is likely due to the inclusion of subject-related random effects in the reduced model.

ANL and Gain Adjustment

Of the 30 subjects that completed self-adjustments, 21 were able to return for ANL measurement. Figures 5 and 6 show the deviation from NAL-NL2 gain (averaged across noise type and repetition) for these 21 subjects, plotted with respect to their ANL values. As described earlier, two full models, one per frequency band, were fit to the deviation from NAL-NL2 data for these 21 subjects. These models were the same as the full models described previously, with the addition of a fixed effect of ANL. ANOVA tables (type III sum of squares) were calculated in the same manner as before. The main effect of ANL was not statistically significant in either model—high frequency: $F(1, 20.02) < 0.01$, $p = .98$; low frequency: $F(1, 27.93) = 2.96$, $p = .10$. Calculation of marginal R^2_{GLMM} for the models that included ANL and two reduced models excluding ANL indicates that the inclusion of ANL accounted for less than 1% of the variance in either frequency band. After controlling for the other effects in the model, ANL had almost no relationship with the degree to which the self-adjusted gain deviated from the subjects' NAL-NL2 based fits.

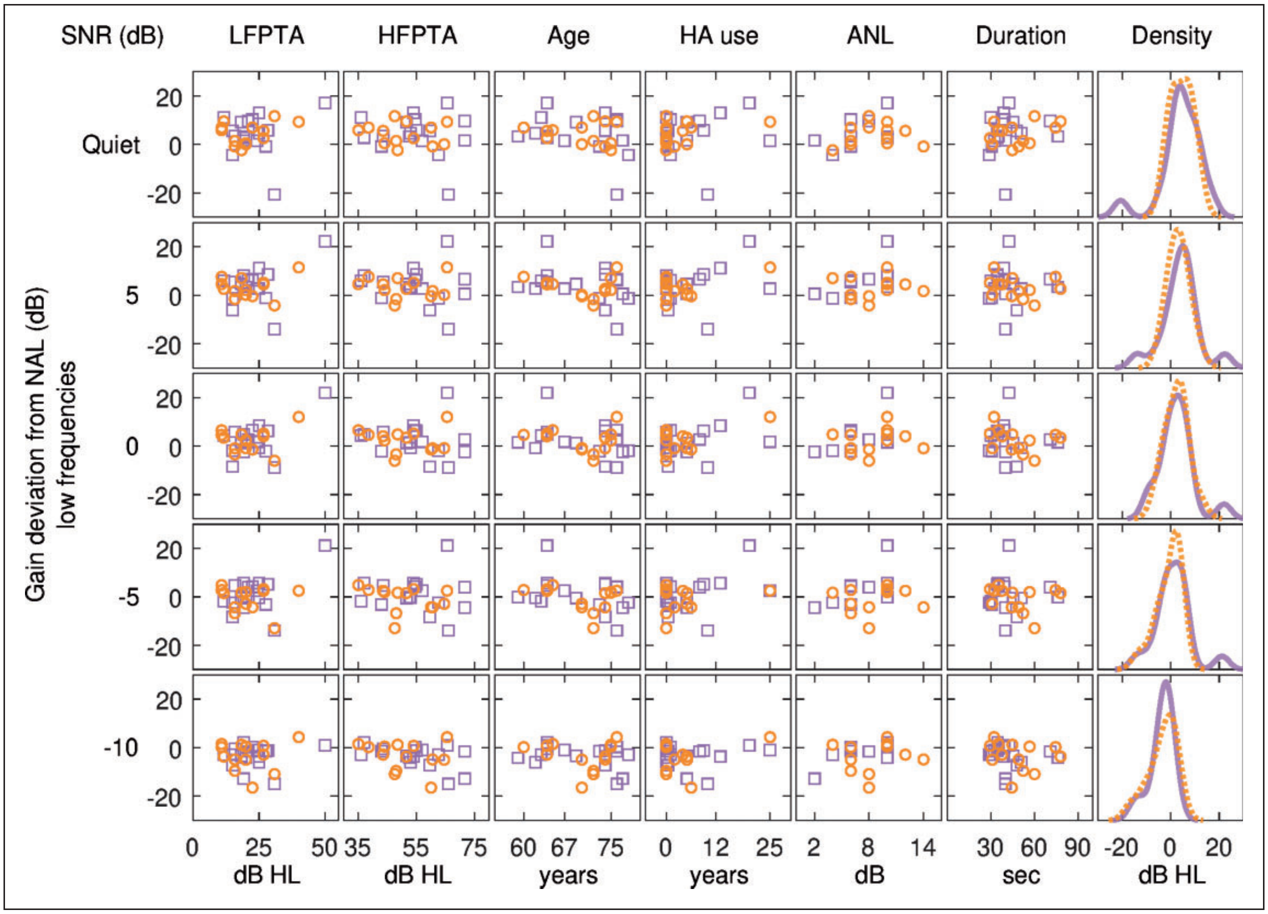

Figure 6. Same as Figure 5, but for deviation from NAL-NL2 gain in the low frequencies.
ANL = acceptable noise level; HA use = hearing aid use; HFPTA = high-frequency pure tone average; LFPTA = low-frequency pure tone average; SNR = signal-to-noise ratio.

Real-Ear Variability

Real-ear measures (REUG and RECD) were obtained for 28 of the 30 subjects. The Ear Machine software assumes an average adult REUG and RECD to estimate insertion gain. Because deviation from NAL-NL2 is a difference measure between two insertion gain values, the REUG and RECD values used in calculating those insertion gains are subtracted out. However, it is still possible that individual variability in real-ear characteristics could have influenced how participants adjusted gain. To evaluate this possibility, the two linear mixed models (one per frequency region) were fit, in the same manner as above, to the deviation from NAL-NL2 data from the 28 subjects for which REUG and RECD were obtained. These models included all the fixed and random effects previously considered except for ANL, as well as two additional between-subjects fixed effects each subject's REUG and RECD, averaged separately within the same high- and low-frequency regions as the gain data. Results of the mixed ANOVAs indicated that, for both models, the main effects of REUG, high frequency: $F(1, 21.21) = 0.61$, $p = .44$; low frequency: $F(1, 20.94) = 0.11$, $p = .74$, and RECD, high frequency: $F(1, 21.21) = 0.29$, $p = .60$; low frequency: $F(1, 21.01) = 0.35$, $p = .55$, were not statistically significant, and variability in real-ear acoustics accounted for less than 1% of the influence on the deviation of self-adjusted gain from NAL-NL2 fits, after controlling for the other included effects.

Discussion

This study analyzed gain self-adjustment data to determine if the large between-subject variability in gain adjustment (about a 40-dB range) could be predicted by known listener characteristics or by listener engagement with the self-adjustment technology. Estimated self-adjusted insertion gain showed strong correlations with listener pure tone thresholds, and self-adjusted insertion gain generally decreased as noise levels increased. In contrast, listener characteristics, including pure tone thresholds, explained little of the between-subject variance in the deviation of self-adjusted gain from

NAL-NL2 based gain. Listener characteristics were estimated to account for 10% of between-subject variance in deviation from NAL-NL2 in the high frequencies (>1000 Hz) and 5% of the variance in low frequencies. Using the self-adjusted gain data and the known listener characteristics examined in this study to modify NAL-NL2 or other similar prescriptive formulae is unlikely to result in the preferred gain in noise for many hearing aid users.

Of the characteristics examined (age, gender, prior hearing aid experience, 4FPTA, duration of self-adjustment, ANL, and real-ear acoustics), none showed strong relationships with deviations from NAL-NL2 gain in the high frequencies, and only trial duration had a statistically significant relationship with deviations from NAL-NL2 gain in the low frequencies. In the current sample, each additional minute with the self-adjustment technology was associated with an increase in low-frequency gain of about 1.2 dB. It is not clear from the data why longer self-adjustment trials would tend to result in more low-frequency gain.

Listeners tended to take more time to adjust gain and made more wheel movements as noise levels increased, demonstrating that listeners spent more time exploring the gain settings when listening conditions were more challenging. These results indicate that subjects used the self-adjustment technology in an understandable manner, taking more time as listening conditions became more difficult. However, the differences between self-adjusted gain and NAL-NL2 based gain were not strongly related to known listener characteristics.

The NAL-NL2 baseline as implemented in the Audioscan Verifit system, which was used to fit NAL-NL2 to subjects in this study, treats all listeners as experienced hearing aid users when calculating REAR targets. When subjects were sorted into two groups based on their years of hearing aid use, as per the findings of Keidser et al. (2012), inexperienced users (<2 years) generally reduced the high-frequency gain further from the NAL-NL2 baseline than the experienced users (⩾2 years) did. However, after controlling for hearing threshold, this difference was not statistically significant, which may be because in the current subject sample, subjects with greater losses also tended to be experienced hearing aid users. Although a finding that inexperienced hearing aid users prefer less gain than those with 2 or more years of hearing aid use would be consistent with other reports (Boymans & Dreschler, 2012; Keidser et al., 2008; Marriage et al., 2004), it was not possible to untangle the effects of hearing aid experience and hearing thresholds in the current subject sample. Furthermore, within-group variability was substantial. Some experienced users preferred 5 dB or more high-frequency gain than NAL-NL2 baseline, while other experienced users preferred substantially less gain than prescribed by the formula (e.g., 15 dB less). Providing a description of this within-group variability, in addition to reporting group averages, is crucial for a full understanding of the influence of hearing aid experience on amplification preferences.

Keidser et al. (2012) reported a gender difference of 2.4 dB in preferred gain between male and female subjects. The NAL-NL2 formula prescribes a 2 dB difference in overall gain when gender is specified, with males receiving a 1 dB boost and females a 1 dB cut (although this gain modification is not implemented on the Audioscan Verifit system that was used to fit NAL-NL2 REAR targets in this study). In the present data, males tended to reduce high-frequency gain more than females (1.3 dB average difference across conditions). According to the coefficient for gender in the linear mixed model fit to the high-frequency data from all 30 subjects, after controlling for the other effects included in the model, males were estimated to have selected 1.6 dB less high-frequency gain than females. The coefficients for gender were not statistically significant in either of the models, suggesting that the true effect of gender in the population on deviation from NAL-NL2 could be 0 dB. The male–female difference in this sample is in the opposite direction of the NAL-NL2 gender correction, which was not applied to the NAL-NL2 fits in this study.

ANL ostensibly reflects the least favorable SNR a person is willing to tolerate when listening to speech and was assessed as a potential predictor for gain adjustment variability in noise to determine if preference for gain in noise was related to noise tolerance as measured by ANL. However, ANL was not predictive of variability in gain adjustment. In this sample, only three subjects produced ANL values within the range of SNRs tested (i.e., ANL values of 5 or lower), meaning that even the most favorable SNR condition tested was an unacceptable level of noise to most of the subjects. Although ANL has been reported to improve (i.e., decrease) when the overall presentation level is reduced (Recker & Edwards, 2013), there was no evidence in the present data that individuals with higher ANL values were more likely than those with lower ANL values to reduce the gain to improve the acceptability of the noise.

Listeners were successful overall in using the software interface to quickly adjust gain and compression parameters across frequencies. Out of 1,020 gain adjustments, only 2 took longer than 3 min for the listener to complete (with an average duration of less than 1 min), and the median number of movements of each of the software wheels was 4. Any single wheel movement could represent the exploration of multiple gain-frequency responses so long as the participant did not remove their finger from the touch screen. These results are similar to those reported by Boothroyd and Mackersie (2017), who found an average time for their self-adjustment method of less than 2 min. None of the known listener characteristics robustly predicted how long subjects took to self-adjust gain. These data suggest that people will be able to quickly adjust hearing aid gain and compression parameters using an appropriately designed interface, regardless of hearing thresholds, age, or other personal characteristics (assuming demographic characteristics similar to the current subject sample). Incorporating self-adjustment into the process of fitting a hearing aid is unlikely to be a substantial time investment if the interface is simple and intuitive and allows users to arrive quickly at appropriate settings.

Individuals are relatively stable in their gain adjustments across noise environments, but variability in gain adjustment across listeners is large (Nelson et al., 2018). That is, if a person tends to use self-adjustment to reduce gain in one noise environment, they are likely to also reduce gain in other noise environments. However, it is not currently possible to predict a priori whether any specific individual will tend to prefer more or less gain than what they are prescribed by NAL-NL2. Listener characteristics and interaction with the self-adjustment technology were ineffective at predicting the magnitude of gain adjustments that listeners made. Considering the wide range over which self-adjusted fits deviated from the NAL-NL2 baselines as well as the speed at which self-adjustment is typically completed, self-adjustment may be the most straightforward and effective way to match hearing aid gain with listener's preferred levels, including when listening in noise.

Future Directions

Self-adjustment is a useful tool for investigating preferences for amplification characteristics. In the self-adjustment paradigm, listeners select gain, and their selection is assumed to reflect their preferred gain settings. This assumption will be examined in a future study. Beyond establishing whether listeners prefer their self-adjusted settings to audiologist-fit settings, an important avenue of future research will be to evaluate whether customization of amplification parameters via self-adjustment results in measurable improvements in factors relating to quality of life, such as increased social participation or improved emotional well-being.

Additional work is needed to assess the role of perceived speech intelligibility during self-adjustment and subjective evaluation of hearing aid gain. In the present study, speech was presented at 65 dBC, which represents an average conversational level. For people with mild-to-moderate hearing loss, most of the speech spectrum at this level is above their hearing thresholds, and if noise is present, the audibility of speech is likely to be primarily limited by the level of noise (Plomp, 1986). In such situations, changes to the gain-frequency response are unlikely to have large consequences for speech recognition. While this bolsters the argument that self-adjustment can be used to achieve similar speech recognition outcomes as clinically prescribed gain for conversational-level speech in noise (for people with mild-to-moderate hearing loss), it also means that in the present research, most of the gain-frequency responses available to the subjects through the self-adjustment technology provided similar speech audibility, so speech intelligibility might not have played a large role in the subjects' decisions. Further study of how self-adjustment is used when circumstances permit gain to have a larger influence on speech audibility—such as when speech is at lower levels in quiet—will clarify to what extent people with mild-to-moderate hearing loss are willing to trade speech intelligibility for improved sound quality, comfort, or other subjective factors.

Self-adjustment may one day play an important role in over-the-counter or self-fitting hearing aids, which present a new problem of how to set gain and compression parameters without the direct help of hearing health professionals. Understanding the relationship between gain that is fit according to widely used clinical formulae and gain that is fit using self-adjustment is an important step in understanding the consequences of this new approach. In particular, it will be important to evaluate the many self-adjustment methods (in addition to the Ear Machine method that was used in this study) in terms of their ease of use and effectiveness, because not all self-adjustment methods will produce equivalent results. The present data provide evidence that listeners self-adjust hearing aid gain using the Ear Machine interface according to idiosyncratic preferences that are not easily predicted from known listener characteristics, and it is unlikely that prescriptive formulae can be modified according to demographic information to provide the same degree of personal customization.

Conclusions

The variability in self-selected hearing aid gain that was noted by Nelson et al. (2018) cannot be predicted by known listener factors in this group of 30 subjects. Six listener factors were evaluated as predictors of variation in gain adjustment: age, gender, duration of hearing aid use, hearing thresholds, ANL, and real-ear characteristics. Specifically, we found the following:

1. Listener engagement with the interface was successful in that participants required little time to complete self-adjustment. Subjects took an average of less than 1 min to complete adjustments, and all but 2 adjustments were completed in less than 3 min.
2. Duration of self-adjustment was not related to other known listener characteristics, and while duration

was statistically associated with greater reductions in gain relative to NAL-NL2 in the low frequencies, calculation of the confidence intervals for this effect suggest that this association might not be clinically meaningful.

3. Self-adjusted insertion gain was significantly and strongly correlated with high-frequency hearing thresholds.
4. Listener age was significantly correlated with high-frequency hearing thresholds but explained little between-subject variability in the deviation of self-adjusted gain from NAL-NL2 fitted gain.
5. No statistically significant differences between the gain selected by male and female participants were observed. However, a small trend was noted in the opposite direction of the NAL-NL2 gender corrections in that men tended to reduce the gain further than women, relative to their NAL-NL2 fits.
6. Neither ANL nor between-subject variability in real-ear characteristics (REUG and RECD) predicted gain changes relative to NAL-NL2 in the conditions tested here.
7. Due to the significant correlations between hearing thresholds and years of hearing aid use in the current subject sample, it was not possible to determine with statistical rigor the effects of hearing thresholds and hearing aid experience on deviation of self-adjusted gain from NAL-NL2 fitted gain, but on average, the listeners who had less than 2 years of hearing aid experience (and who also had better pure tone thresholds) reduced the gain more than listeners who had 2 or more years of hearing aid experience (and who had poorer pure tone thresholds).

These findings suggest that, when given the opportunity, individual listeners will choose hearing aid gain characteristics that relate to their hearing thresholds (when starting from a threshold-based prescription) but which may deviate from formula-prescribed gain in ways that are poorly predicted by known factors such as age, gender, hearing loss, or hearing aid experience. This supports the idea that giving people with hearing loss control over hearing aid gain allows them to choose custom parameters that otherwise might not be available when using conventional methods of hearing aid fitting.

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Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Dianne J. Van Tasell is an employee of Bose Corporation, which provided the hardware used in the work reported here.

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