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# Fit to targets, preferred listening levels, and self-reported outcomes for the DSL v5.0a hearing aid prescription for adults

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## Key Words

Adults
Hearing aids
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Treatment outcome
Questionnaires
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Preferred Listening Level
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Desired Sensation Level

## Abbreviations

BTE: Behind-the-ear
CIC: Completely-in-the-canal
COSI: Client Oriented Scale of Improvement
DSL v5.0a: The Desired Sensation Level Multistage Input/Output Algorithm
ITE: In-the-ear
MHAS: Modernizing of hearing aid services
PLL: Preferred Listening Level
PTA: Pure-tone average
RECD: Real-ear-to-coupler-difference
SPL: Sound pressure level
S-REM: Simulated real-ear measurement

## Abstract

Study objective: This study evaluated how closely the DSL v5.0a prescription could be approximated with hearing aids, its relationship to preferred listening levels (PLLs) of adults with acquired hearing loss, and the self-reported outcomes of the resulting fittings. Participants: Thirty adults with varying degrees and configurations of hearing loss ranging from mild to severe. Methods: Hearing aid output was measured after the initial fitting to DSL v5.0a targets and after determination of the PLL after approximately 90 days. The Client Oriented Scale of Improvement (COSI) was used to evaluate outcome. Results: The 95% confidence interval of fits to target ranged from 5.8 to 8.4 dB across frequency. The DSL v5.0a adult algorithm approximated the PLLs of the participants within 2.6 dB on average. Hearing aid fittings provided positive subjective outcome improvements on the COSI. Conclusions: Findings suggest that the use of DSL v5.0a for the fitting of hearing aids on adults with acquired hearing loss was feasible and provided an appropriate initial fitting.

## *Sumario*

Objetivo del estudio: Este estudio evaluó qué tanto puede satisfacer una prescripción DSL v5.0a con auxiliares auditivos, su relación con los niveles preferidos de escucha (PLLs) en adultos con pérdida auditiva adquirida y los resultados de los auto reportes de las adaptaciones resultantes. Participantes: Treinta adultos con variados grados y configuraciones de pérdidas auditivas, entre leves y severas. Métodos: Se midió la salida del auxiliar auditivo después de la adaptación por metas DSL v5.0a y después de determinar los PLL, al cumplirse aproximadamente 90 días. Para evaluar los resultados, se usó la Escala de Mejoría Orientada hacia el Cliente (COSI). Resultados: 95% de intervalo de confianza de adaptaciones relacionadas con blancos, entre 5.8 a 8.4 dB en todas las frecuencias. El algoritmo en adultos del DSL v5.0a se aproximó a los PLLs de los participantes en un promedio de 2.6 dB. Las adaptaciones de auxiliares auditivos dieron resultados subjetivos positivos con el COSI. Conclusiones: los hallazgos sugieren que el uso de DSL v5.0a para la adaptación de auxiliares auditivos en adultos con pérdidas auditivas adquiridas fue factible y permitió una adaptación inicial apropiada.

The provision of appropriate amplification includes setting hearing aids to provide a given amount of amplification for speech, typically using a prescriptive formula. Appropriateness of fitted gain is one of the main contributors to benefit, and should be selected and fitted in an individualized manner (Cox & Alexander, 1993). According to two large-scale surveys conducted by Kochkin (2005, 2007), benefit is the number one factor for hearing aid user satisfaction, followed by clarity of sound and value (performance of the hearing aid relative to the price). Additionally, lack of benefit from the hearing aids was the most common reason for hearing aid return. Perceived benefit is an important factor in continued use of hearing aids and satisfaction with amplification (Kochkin, 2007). Therefore, initial fitting with an acceptable and beneficial amplified listening level is one element of high quality clinical service for individuals with hearing loss.

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The use of evidence-based prescriptions is considered a recommended practice (American Academy of Audiology, 2006). The Desired Sensation Level (DSL) Method is one such prescription that was originally developed for use with infants and children. The most recent version, however, includes a different (and lower) prescriptive target for use with adults who have acquired hearing losses (Scollie et al., 2005). To date the literature evaluating the DSL v5.0a prescription for adults is sparse. This study was conducted to evaluate this new prescription, in terms of electroacoustic feasibility, as well as clinical efficacy and effectiveness.

When evaluating a prescriptive algorithm, it is important to assess how well the fitting matches the prescription itself (Mueller, 2005). The modernizing of hearing aid services (MHAS) guidelines in the United Kingdom recommends that a fitting to a prescription should be within ± 5 dB at 250, 500, 1000 and 2000 Hz, and ± 8 dB at 3000 and 4000 Hz (Aazh & Moore, 2007). However, the extent to which initial fittings match prescribed targets varies in the literature. Sammeth et al. (1993) fitted linear peak-clipping in-the-ear (ITE) hearing aids using NAL-R, POGO II and MSU formulae. Even though the prescribed gain differed between the formulae, the mean fitting error was less than or equal to 10 dB from 250 to 4000 Hz, regardless of which prescriptive formula was used. Also, there was a trend towards over-fitting the low and mid frequencies while under-fitting the high frequencies compared to targets for all three formulae. This translated to a mean difference between prescribed and obtained modified Speech Transmission Indices of 18.7%, indicating that speech understanding may be negatively affected in at least some of the fittings. However, fitting errors in excess of 10 and 15 dB had to be tolerated in order to accept 50% and 90% of the fittings, respectively. Sammeth et al. (1993) speculated that individualized parameters and multichannel hearing aids would be important for decreasing this fitting error. Swan and Gatehouse (1995) used real-ear measures and changes to the physical properties of the hearing aids to adjust fittings that deviated from the NAL prescription by more than ±10 dB. Following these adjustments, the number of fittings that fell within ±10 dB of the prescribed targets increased from 24% to 62% from 250 to 4000 Hz, and from 43% to 85% if 4000 Hz was excluded. Trine and van Tasell (2002) quantitatively demonstrated that fittings and speech audibility (based on the Articulation Index) do improve with multiple channels, but this improvement plateaus at about four or five channels. Recently, Aazh and Moore (2007) evaluated the initial fittings of digital multichannel hearing aids using manufacturer implementations of the NAL-NL1 algorithm and after adjustments to the frequency responses using real-ear insertion gain (REIG). Only 36% of the manufacturer first fittings came within ±10 dB of the NAL-NL1 targets from 250 to 4000 Hz, which increased to 83% once adjustments were made using real-ear measures. Fitting within ±10 dB was easiest from 500 to 2000 Hz and the most difficult at 3000 Hz. Similar to Trine and van Tasell (2002), hearing aids with fewer channels were less likely to come within the acceptable target range. Therefore, with advances in technology and use of individualized measures, it is feasible to fit the majority of hearing aids to within ±10 dB of prescribed targets from 250 to 4000 Hz.

Following hearing aid fitting, an evaluation of the adequacy of a prescription may consider clinical efficacy, or how well the prescription supports hearing in a controlled task. The PLL is one measure of clinical efficacy of hearing aid fittings. Conceptually, the PLL is a measured listening level that is an optimal compromise between comfort, intelligibility, background noise and distortion (Cox, 1982). The PLL has been defined as "the sound pressure level at the eardrum that the person chooses or prefers for listening to hearing aid-amplified speech" (Cox & Alexander, 1994). Procedurally, the listener simply adjusts the volume control to his or her preference in response to a defined signal. In this way, the acceptability of a prescribed frequency/gain response can be assessed by comparing the PLL to the prescribed target levels for the same signal. Using this approach, Scollie et al. (2000, 2005) found that the children's mean PLLs were, on average, within 2 dB of the target listening levels from the DSL v4.1 prescription. In contrast, experienced adults preferred an average aided listening level of 9 dB below the DSL v4.1 targets and new adult hearing aid users had a mean aided PLL of 11 dB below target (Scollie, et al. 2005). These findings supported the development of a new and lower target listening level for use with adults in the more recently developed DSL v5.0a.

Although the PLL is a measure of hearing aid outcome, it only addresses the issue of efficacy. Real world effectiveness of the hearing aid fittings is also important. One such measure is the Client Oriented Scale of Improvement (COSI) developed by the National Acoustic Laboratories (NAL; Dillon et al., 1997). The COSI is a statistically valid self-report questionnaire (Dillon et al., 1997), in which the patient nominates up to 5 listening situations in which s/he would like to hear better. After a period of wearing the hearing aid(s), the patient rates the degree of perceived change in hearing ability, or reduction in disability, for each nominated situation, as well as final ability in those situations. These quantified measures of self-reported benefit can be compared with available normative data (Dillon et al., 1999). Thus, the COSI is a useful tool for assessing listening needs and the effectiveness of the hearing aid fittings in meeting these needs, as reported by the wearers.

Given the efficacy and effectiveness information provided by the PLL and the COSI, it seems reasonable to use these outcome measures to evaluate the changes made to the DSL algorithm to accommodate the unique listening requirements and preferences of adults with acquired hearing loss. Therefore, the purposes of this study were (1) to measure the range of fit to targets in a clinical environment; (2) to evaluate the preferred listening levels of adults relative to the DSL v5.0a adult prescription; and (3) to measure the self-reported effectiveness of the DSL v5.0a adult prescription for both listening performance and benefit.

## Method

This study was designed as a combined efficacy/effectiveness trial to describe outcomes associated with use of the DSL v5.0a method within routine clinical practice. Clinical effectiveness trials generally use inclusion criteria reflecting clinical practice to ensure broad generalizability and also include outcome-oriented, patient-centered measures (Moore et al., 2009). As such, the procedures used for hearing aid selection and fitting did not deviate significantly from the protocols used by the audiologists in the hearing aid fitting process. Outcome measures were added to these protocols to document the fit to targets, and to measure the preferred listening level and client-oriented evaluation of real world performance and benefit using the COSI questionnaires. Patients were recruited from the normal caseloads of two external collaborating clinical sites, one in Argentina and one in southwestern Ontario, Canada. Procedural and clinical details are described further below.

*Clinicians*

The clinicians in this project routinely used the DSL Method with their pediatric patients, and can therefore be considered experienced DSL 'users'. At the time of data collection, they had little experience with the DSL v5.0a adult prescription. They were aware that an evidence-based approach to developing the adult targets had been taken, and had been trained on how the newer adult targets differed from the pre-existing pediatric prescription. They were also aware that the researchers wished to evaluate whether the new adult prescription would provide initial fittings that closely approximated the Preferred Listening Level. These factors could constitute bias in the clinicians toward fitting the hearing aids closely to target. These fittings, however, were completed for real clinical patients in a private practice environment. Therefore, the clinicians were also aware that an unacceptable fitting could lead to dissatisfaction with the hearing aids, disuse of hearing aids, and/or return of hearing aids. In an effort to create a neutral balance between motivation to fit or not to fit to targets, the experimental protocol explicitly requested the clinicians to make any adjustments required to meet the patient's needs, ranking this outcome as having a higher importance than necessarily fitting to the new prescription.

*Participants*

Fifty patients were invited to participate from the two sites, 25 from a clinic in Argentina and 25 from a clinic in Ontario, Canada. They provided consent to participate under an approved protocol from the Health Sciences Research Ethics Review Board at the University of Western Ontario. Of the 50 participants, 20 from Canada were excluded from the study because they were provided with open-fit hearing aids, which did not meet the inclusion criteria for this study[1]. One participant from Canada withdrew from the study due to discontinued use of the hearing aids. The remaining 30 participants (16 male, 14 female) had a mean age of 67.7 years, ranging from 33.7 to 95.6 years. Based on average pure-tone threshold values, the degree of hearing loss ranged from mild to severe. Figure 1 shows the average and range of hearing losses by frequency across all participants. All participants had acquired, predominantly sensorineural hearing losses and wore digitally programmed multichannel hearing aids. Participants who had worn hearing aids since they were children were not included in this study. Both new (n = 19) and experienced (n = 11) hearing aid users were included. Of the experienced users, the years of experience ranged from 1 to 10 years, with an average of 4.4 years. Most participants were binaural hearing aid users (n = 24), and 20% of participants from each site were monaural users (1 from Canada, 5 from Argentina). Twenty-one of the participants with sensorineural hearing loss were binaural users, and of the five participants with a conductive component to their hearing loss, three were binaural users. A variety of hearing aid styles were used in the study, including BTE hearing aids (n = 24; 22 from Argentina, 2 from Canada), in-the-ear (ITE) hearing aids (n = 22; 18 from Argentina, 4 from Canada), and completely-in-the-canal (CIC) hearing aids (n = 8; 5 from Argentina, 3 from Canada). Participants with open-fit hearing aids were not included in this study. A variety of venting sizes were used in the study, including vents of two mm or greater (n=13), vents between 0.5 and 2 mm (n=25) and unvented fittings (n=25). Not all of the devices used by the participants had datalogging abilities, so logging of use time and user adjustments was not a part of this study.

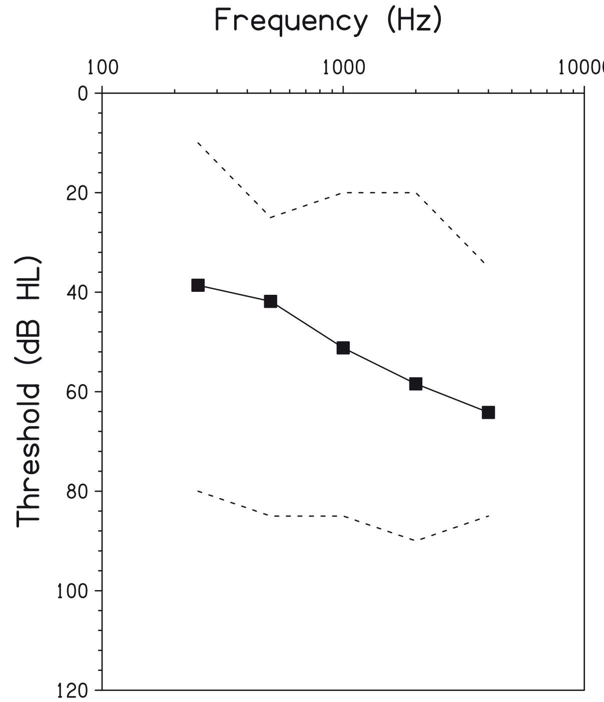


**Figure 1.** Mean, minimum and maximum better ear pure tone thresholds for adults.

*Procedures*

INITIAL VISIT

Participants from both sites were assessed using an audiometric protocol recommended by the College of Audiologists and Speech-Language Pathologists of Ontario (CASLPO, 2008), including otoscopy, tympanometry, and pure tone thresholds for air- and bone-conducted stimuli. Pure-tone thresholds were measured using insert earphones coupled to foam tips. Patients who were considered to be candidates for hearing aid prescription were invited to participate in the study. Real-ear-to-coupler differences (RECDs) were measured to account for individual ear acoustics. Thresholds and RECDs were entered into the Audioscan Verifit software, and calculations converted dB HL thresholds to values in dB SPL using the adult's own RECD values. Targets for hearing aid performance were calculated from the dB SPL thresholds using the adult version of the DSL v5.0a algorithm (Scollie et al., 2005) as embedded within the Verifit VF-1. Conductive and binaural corrections were used, when applicable. The participant then completed Phase I of the Client Oriented Scale of Improvement (COSI; Dillon et al., 1997) by identifying three to five listening situations in which s/he would like to hear better and ranked them in order of importance.

[1]At the time of data collection, the real ear measurement system used did not employ reference microphone settings specifically for open fitting (i.e., a pure substitution calibration approach). Therefore, open fitted devices were excluded from this study because any real ear or simulated real ear measurements may have been affected by sound escaping through the vent, or by the simulated measure's inability to represent vent-transmitted sound.

#### Hearing aid fittings and verification

All hearing aid verification measures were performed in in the test chamber of the Verifit, using simulated real ear measurements (S-REM). The S-REM strategy was selected in order to control for room noise and/or reverberation, to promote test environment consistency between experimental sites and to promote replicable measures across the repeated appointments required by this protocol. The group average error expected from the use of S-REM measurements to predict REM values for adults is 1.4 dB at 4000 Hz. (Scollie et al., 2005). Minimization of error was facilitated by the measurement of an individualized Real Ear to Coupler Difference (RECD) for all participants, and verifying the hearing aid in the HA-1 coupler. This required attachment of the BTE earmold to the HA-1 coupler using putty for some participants.

During verification, each hearing aid was attached to the 2-cc coupler and programmed into the first memory. Hearing aid output was set to match DSL v5.0a targets using a multilevel protocol that included 60 dB SPL speech and 90 dB SPL swept pure-tones. For each test level and signal, the final output (in S-REM) was stored to an external memory device once the clinician judged that an acceptable match to target had been obtained. The university-based collaborators did not supervise or approve the fittings, nor was a numerical criterion of closeness of fit provided to the clinicians. In this way, the clinician's judgement of a maximally close fit to targets could be evaluated.

The hearing aid(s) were then fitted to the participant's ear(s) and changes to the electroacoustic characteristics were made if required to obtain subjective satisfaction for the fitting. No protocol was provided to these experienced clinicians for fine tuning to patient satisfaction. The goal was to ensure that the participant would be willing to wear the hearing aid(s) for their initial 30 day trial. Other hearing aid memories (e.g., noise programs, phone programs) were provided within the hearing aid fitting at the clinician's discretion.

#### Hearing aid follow-up and outcome evaluation

Participants returned to their respective clinics for follow up in approximately 30 days after fitting. During this appointment, fine tuning was completed if necessary to adjust the aid(s) to the participant's preferences. The clinicians were asked to note any issues that the participant reported at the 30 day visit and their resolution for that specific issue. A further 60 days of trial period then began to allow further acclimatization over a total of 90 days.

### *Preferred Listening Level Procedure*

#### Stimuli and routing

The Preferred Listening Level (PLL) was measured while participants listened to running speech at an overall level of 60 dBA in the sound field. The passage used was the Costa Cálida Male Speech Passage, taken from a sample of sounds available from Phonak AG. This passage was chosen because it is available in both English (Canada) and Spanish (Argentina) and therefore could be used at both test sites.

To create a calibrated CD, two white noise signals were digitally filtered in Matlab to have the same spectral shape as the English and Spanish speech passages. Both passages and filtered noise samples were filtered so that the 1/3 octave band levels of each white noise matched the corresponding passage within 0.5 dB across frequencies. The speech passages and filtered noise signals were set at 50% power, placing peaks at least 3 dB down from full-scale deflection to avoid peak clipping. The stimuli were routed from a CD player through a calibrated AD22 Kapmlex (Argentina) or GSI 61 (Canada) audiometer to a loudspeaker positioned in the audiometric sound booth at 60 dB A. This loudspeaker was located 1 m away from the participant at 0° azimuth. Stimulus levels were confirmed prior to the start of the study by using the Manual Control Function in the Audioscan Verifit, and VU meter settings were confirmed daily during data collection. The participant was seated in the calibrated center of head reference point in a double-walled sound treated audiometric booth.

#### Procedure

At the 90 day follow up, and following any fine tuning, the participant was seated in the calibrated reference point in a double-walled sound treated audiometric booth. Participants completed the PLL task in their normally aided condition while listening to the Costa Cálida passage. Specifically, hearing aids were set to the program normally used for hearing speech in quiet, and used monaurally or binaurally, based on their normal use of either a monaural or binaural fitting. The audiologist adjusted the hearing aid(s) while worn on the participant's ear(s) to a minimum volume control/remote setting. The participant was instructed to "adjust the volume control wheel/toggle/remote of your hearing aid(s) to the level where the story sounds best to you." This defined the PLL. After the participant adjusted the hearing aid(s) to the PLL, the hearing aid(s) were carefully removed ensuring that no accidental volume change was made, and placed on the 2-cc coupler within the Verifit test box. The hearing aid was re-verified and these measures at PLL were stored.

#### Client Oriented Scale of Improvement (COSI) outcome evaluation

Following the PLL procedure, the outcome rating stage of the COSI was completed, in which each situation previously identified at the initial visit by the participant was read and the participant was asked (1) if his/her hearing function had changed in each situation, and (2) to rate his/her final hearing ability in each situation with their hearing aids.

## Results

### *Proximity of Initial Fittings to DSL v5.0a Target Levels*

Output levels for a 60 dB SPL speech input at the initial fitting were compared to targets per participant and frequency to evaluate the initial fit to targets. Fit to targets data are plotted in Figure 2 for 250, 500, 1000, 2000 and 4000 Hz. The prescribed versus fitted slopes (computed as level at 4000 – level at 500 Hz) is also displayed in the bottom right corner of Figure 2. The average fit to targets per frequency ranged from .3 to 3.6 dB, and the average fit to slope was 1.4 dB across the 500 to 4000 Hz band, or 0.5 dB per octave. Linear regressions were conducted at each frequency and for the slope, allowing estimation of the 95% confidence intervals of the fits to targets. The regression coefficients, associated $r^2$ values, standard errors, and confidence intervals are provided in Table 1. Results indicate that the fittings were significantly correlated with targets, and that 68% of initial fittings were within 2.9 to 4.2 dB of target and 95% of fittings fell to within 5.8 to 8.4 dB of target across frequencies. Also, the prescribed slope was met within 3.8 dB (or 1.3 dB/octave) in 68%

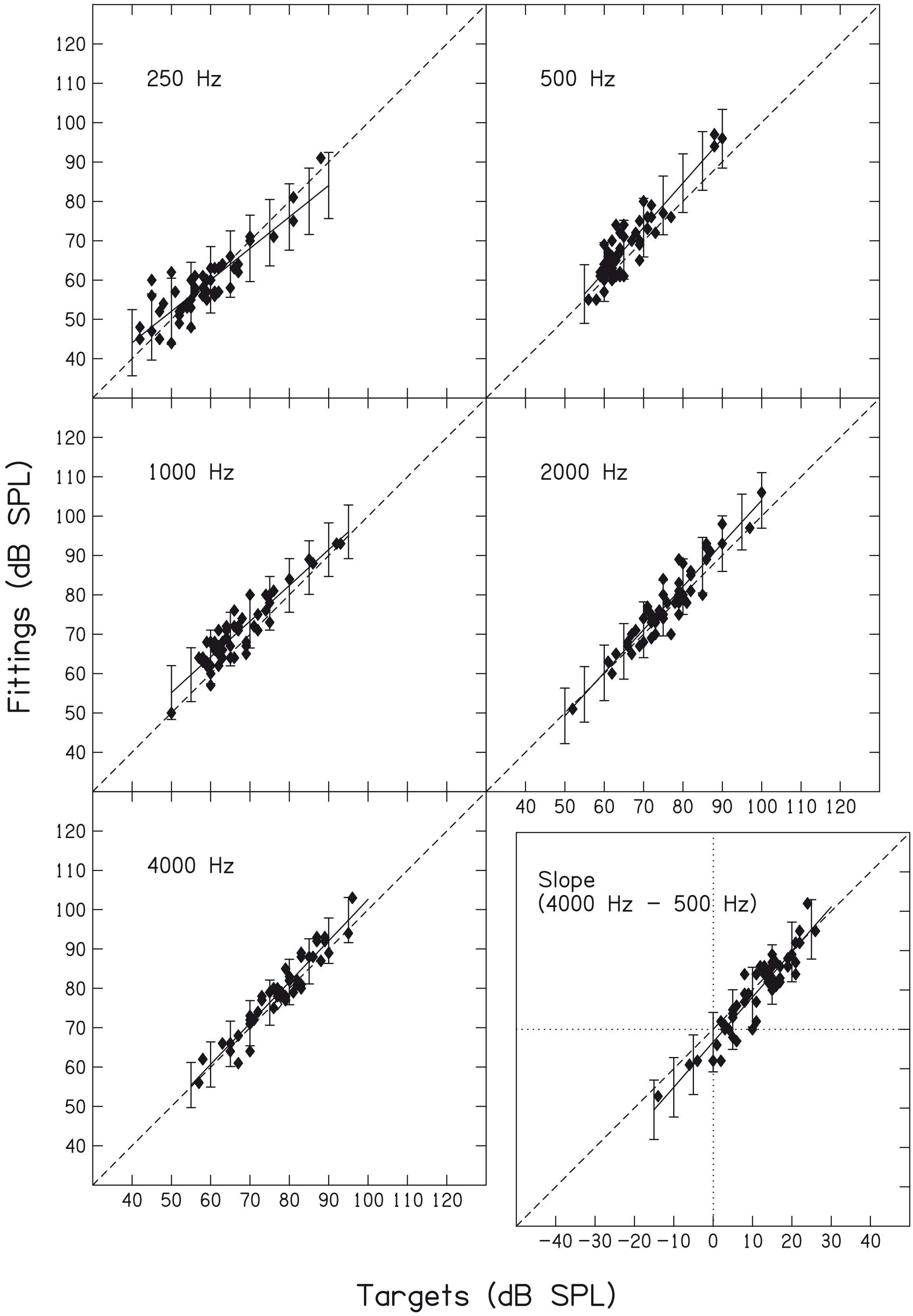


**Figure 2.** Target listening levels from DSL v5.0a, versus aided levels of initial fittings for 60 dB SPL speech, for 53 aided ears of 30 adults who wear hearing aids. Data are shown at five frequencies, and for the target versus fitted slope. Regression lines and 95% CIs of the estimate are shown, along with a dashed diagonal line at target listening levels.

**Table 1.** Regression coefficient, $r^2$ values, error of the estimate and 95% confidence intervals for fittings to DSLv5.0a targets across frequency and prescribed slope of output using a speech input stimulus at 60 dB SPL*.

| | *Frequency (Hz)* | | | | | *Slope* |
|---|---|---|---|---|---|---|
| | *250* | *500* | *1000* | *2000* | *4000* | *4000–500 Hz* |
| Slope | 0.80 | 1.13 | 0.91 | 1.10 | 1.05 | 1.15 |
| y-intercept | 12.12 | –5.62 | 9.76 | –5.52 | –2.22 | –3.26 |
| r squared | 0.78 | 0.83 | 0.85 | 0.88 | 0.92 | 0.86 |
| F(1,52) | 178.12 | 254.28 | 281.37 | 385.53 | 579.08 | 324.57 |
| p | .000 | .000 | .000 | .000 | .000 | .000 |
| SE | 4.21 | 3.73 | 3.42 | 3.53 | 2.87 | 3.78 |
| 95% CI | 8.42 | 7.46 | 6.83 | 7.07 | 5.75 | 7.56 |

*Regression results are reported on data from all aided ears of the 30 participants.



of the fittings and within 7.6 dB (or 2.5 dB/octave) in 95% of the fittings. Overall, the root-mean-square (rms) error across frequency ranged from 1 to 7 dB.

In this study, the hearing aids had between 6 and 20 channels. Fitting with fewer channels may have been related to increased fitting error (Table 2). However, we did not experimentally manipulate the number of channels versus fit to targets and hearing level and therefore cannot draw definitive conclusions about the number of channels required to optimize fit to targets.

### *Recommended, Initially Fitted and Preferred Listening Levels*

In order to evaluate the PLL versus either targets or initial fittings, a repeated measures analysis of variance was conducted with measure (targets, fit to targets, and PLL) and frequency (250, 500, 1000, 2000 and 4000 Hz) as within-participant variables. Only one ear was selected for further analysis. Selection of only one ear per participant was done to avoid spurious statistical duplication of participants with binaural fittings on this behavioural outcome measure. Put differently, the PLL was measured one person at a time, unlike the fit to targets data, which was measured one ear at a time. The intent was therefore to represent individuals rather than ears. For binaural wearers, the ear with the larger dynamic range (and therefore likely better suprathreshold hearing) was chosen as follows. The better ear (by PTA) or monaurally aided ear in typical use was chosen. However, if the PTA was the same for both ears, the ear with the flatter audiometric slope was chosen. One ear with poorer sensitivity was used due to missing data in the other ear.

**Table 2.** Crosstabulation of number of channels versus the number of fittings with varying root mean squared (RMS) error of fit to targets from 250 through 4000 Hz.

| *RMS Error* | *Number of Channels* | | |
|---|---|---|---|
| *(dB)* | *6* | *>6* | *All* |
| 0 | 0 | 1 | 1 |
| 1 | 0 | 3 | 3 |
| 2 | 6 | 2 | 8 |
| 3 | 7 | 2 | 9 |
| 4 | 12 | 1 | 13 |
| 5 | 6 | 1 | 7 |
| 6 | 6 | 1 | 7 |
| 7 | 4 | 0 | 4 |
| 8 | 1 | 0 | 1 |
| Total | 42 | 11 | 53 |

Results indicated significant simple main effects for measure and frequency ($F(1.75,50.71)=11.59$, $p<.001$; $F(1.68,48.60)=56.48$, $p<.001$)[2] but no significant two-way interaction between measure and frequency ($F(4.50,130.44)=1.75$, $p=.135$). Post-hoc pairwise comparisons were completed on the mean levels for each measure collapsed across frequency, with a Bonferroni correction to control type II error to a level of .05. Results indicated that the mean PLL and initial fit to targets did not differ significantly; however, there was a small but statistically significant difference between the targets and both the PLL and initial fit to DSL v5.0a targets. When collapsed across frequency, targets were on average 2.6 dB lower than the PLLs and 1.95 dB lower than the initial fitting to targets ($F(2,28)=11.73$, $p<.001$).

### *Accuracy of Predicting the PLL with DSL v5.0a Targets*

To further assess the relation between target and PLL across hearing levels, the frequency response at PLL was compared to participant-specific targets. Linear regressions using the better or monaurally aided ear of all participants were calculated at each frequency (250, 500, 1000, 2000 and 4000 Hz) with the PLL as the dependent variable and the target as the predictor. Results indicated that the DSL v5.0a targets were significantly correlated with the PLL at all frequencies. The regression coefficients and $r^2$ values as well as standard error and 95% confidence intervals of the predicted estimates of PLLs based on targets are found in Table 3. Figure 3 displays the PLLs relative to the DSL v5.0a targets for 250, 500, 1000, 2000, and 4000 Hz. The slope of the frequency response (level at 4000 Hz – level at 500 Hz) is also displayed in the lowest right-hand quadrant of the figure. Overall, results indicate that 68% of PLLs fell within 3.85 to 6.85 dB of the target across frequencies, and 95% of PLLs fell within 7.7 to 13.7 dB across frequencies (Table 3). Slope at PLL fell within 8.9 dB (or 3 dB per octave), in 95% of cases. In

[2]Degrees of freedom adjusted for lack of sphericity using the Greenhouse-Geiser epsilon.

**Table 3.** Regression coefficients, $r^2$ values, error of the estimates and 95% confidence intervals for preferred listening levels across frequency and prescribed slope of output using a speech input stimulus at 60 dB SPL.*

| | *Frequency (Hz)* | | | | | *Slope* |
|---|---|---|---|---|---|---|
| | *250* | *500* | *1000* | *2000* | *4000* | *4000–500 Hz* |
| Slope | 0.74 | 1.03 | 1.06 | 1.14 | 1.12 | 1.02 |
| y-intercept | 17.64 | 0.82 | −0.66 | −7.96 | −7.38 | −1.14 |
| r squared | 0.51 | 0.74 | 0.86 | 0.88 | 0.87 | 0.82 |
| F(1,29) | 28.7 | 81.0 | 164.9 | 208.3 | 191.5 | 124.1 |
| p | .000 | .000 | .000 | .000 | .000 | .000 |
| SE | 6.85 | 4.15 | 3.85 | 3.86 | 3.89 | 4.44 |
| 95% CI | 13.69 | 8.30 | 7.70 | 7.72 | 7.77 | 8.88 |

*Regression results are reported on data for the better ear or monaurally aided ear of all 30 participants.



addition, the 95% CIs of the regression estimates surround the DSL v5.0a target for all output levels. This indicates that the targets and PLLs did not differ significantly across degrees of hearing loss, since higher thresholds are associated with greater target levels. However, a trend exists at 250 Hz for a higher PLL than target at lower output levels, meaning that some users with better low frequency hearing preferred more output than was prescribed.

*Subjective Measure of Benefit: COSI*

Subjective measures of benefit and performance were obtained using the COSI (Dillon et al., 1997). The important listening or communication situations self-nominated by the participants were coded into categories described by Dillon et al. (1999). The frequency with which each category was used is listed in Figure 4. The five most commonly nominated categories were: (1) conversation with a group in noise; (2) conversation with a group in quiet; (3) conversation with one or two conversational partners in noise; (4) listening to the television and/or radio; and (5) conversation with one or two conversational partners in quiet. These top five situations replicate the most common situations nominated by the National Acoustic Laboratories (NAL) normative population for the COSI (Dillon et al., 1999). Conversations with a group in noise and in quiet were the most commonly selected situations in our sample of adults, whereas listening to the television and/or radio and conversation with one or two conversational partners in quiet were mentioned more frequently in the NAL population. Otherwise, our sample of adults was similar to the NAL population when nominating problematic areas for which the adults desire the most improvement with their hearing aids.

At the final appointment (approximately 90 days post fitting), the participants rated their real world outcomes for each of the important listening situations they had identified at the initial fitting. The ratings consisting of (1) degree of change, a measure of benefit derived from the hearing aids, and (2) final ability, a measure of hearing aid performance, are shown in Figure 5 in order of situation priority and rating. Higher ratings correspond with greater benefit and/or ability. Some participants chose in-between categories, and scores were designated as such. Most of the improvement scores are either "better" for degree of change or "most of the time" for final ability, and no scores indicate "worse" functioning with the hearing aid fitting or a final ability of less than "half the time." Only one participant rated "no difference" and this was given to the situation designated as 5th in importance by that participant.

In the NAL normative sample, 80% of the population of hearing aid users reported a benefit score of 4 or higher ("better" or "much better"). In the present sample, this outcome was attained for 83% of fittings. For final ability, 90% of the normative population reported hearing 75% of the time (a score of 4) or more ("most of the time" or "almost always"), and this was achieved in 93% of fittings in the present study. Averaged across participants, the outcomes were also similar to average population outcomes for the COSI questionnaire, with average scores exceeding 4 for both change and final ability. Overall, these positive outcomes reported by the hearing aid users indicated effective and clinically acceptable fittings.

## Discussion

The purposes of this study were to determine whether DSL v5.0a targets specifically developed for adults with acquired hearing loss were electroacoustically matched at the initial fitting, similar to the preferred listening levels of adults who wear hearing aids, and clinically acceptable. This was evaluated at two clinical sites with a range of participants with varying audiometric characteristics, types of hearing aids and years of experience wearing hearing aids. The majority of initial fittings to the DSL v5.0a adult prescription were within the ±10 dB range used in the literature (Sammeth et al., 1993; Swan & Gatehouse, 1995; Aazh & Moore, 2007), (Table 4). Furthermore, these fits to target are favourable compared to reported fittings in the literature. Aazh and Moore (2007) reported that 83% of clinician-adjusted fittings were within 10 dB of target at all frequencies, whereas the present sample had 92% within the same criterion. Per frequency, the number of fittings within 10 dB of the target for 250 to 4000 Hz varied from 94 to 100% for both the present sample (Table 4) and the sample from Aazh and Moore (2007). The fittings were also evaluated against the Goodness of Fit calculator Mark IV (GoF-IV, Hostler, 2004). This index evaluates the overall goodness of fit based on gain for moderate-level inputs, and in one study was highly correlated with both the Aided Audibility Index and clinician ratings of goodness of fit (Hostler, 2004). The GoF-IV values range from 0 to 100%, with higher values indicating better fittings. GoF-IV values computed for the fittings in the present study indicated that the fittings were reasonably close to targets: the lowest

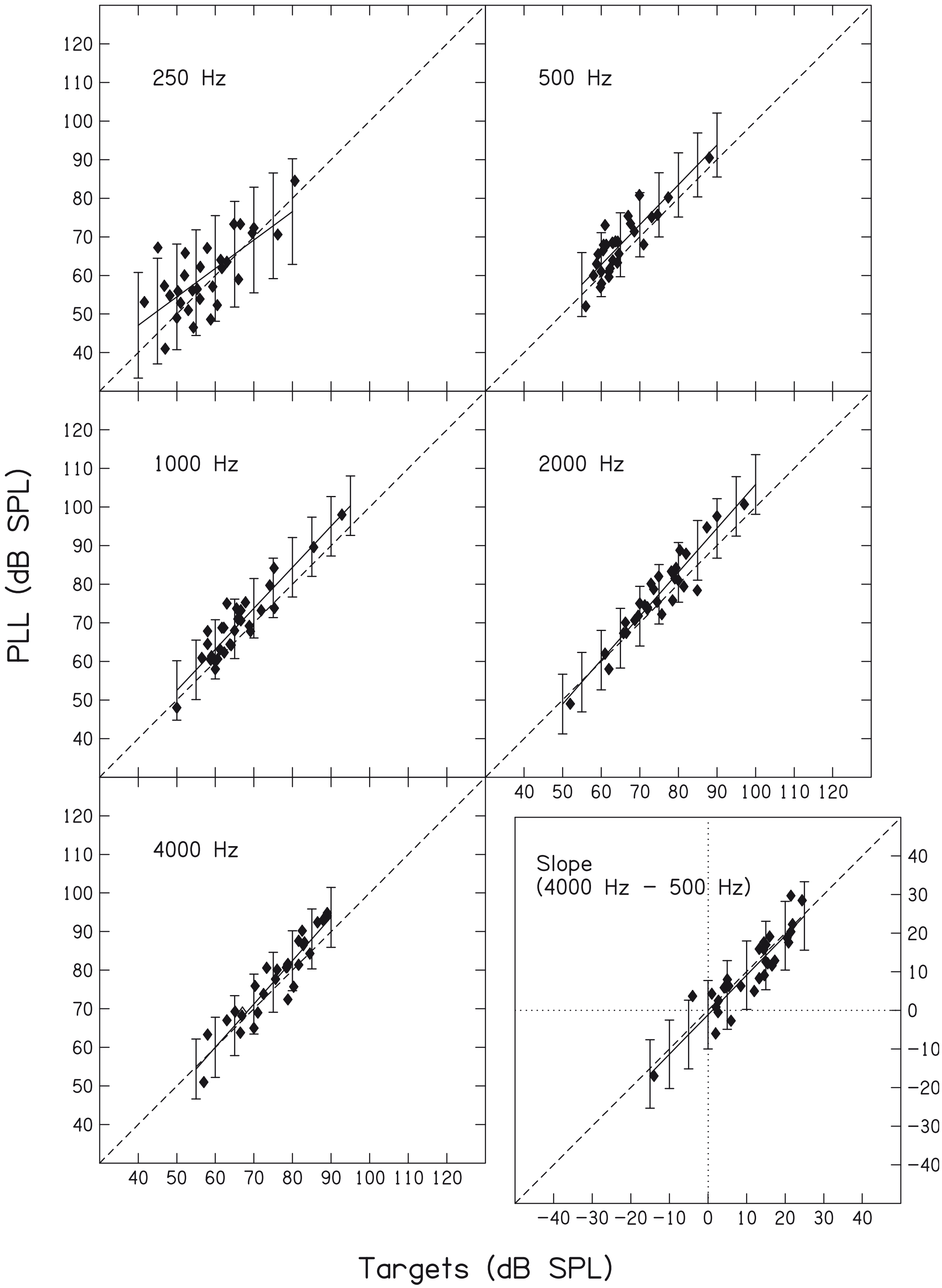


**Figure 3.** Target listening levels from DSL v5.0a, versus preferred listening levels for 60 dB SPL speech. Format follows that of Figure 2. Data are shown for better ears or monaurally aided ears (n=30).

**Table 4.** Proportion of fits to targets that meet fit to targets within 10 or 5 dB, or within the Modernization of Hearing Aid Services (MHAS) guidelines*.

| | *Frequency (Hz)* | | | | | *Across frequencies* |
|---|---|---|---|---|---|---|
| | *250* | *500* | *1000* | *2000* | *4000* | |
| Within 10 dB | 94% | 98% | 98% | 100% | 100% | 92% |
| Within 5 dB | 81% | 74% | 70% | 81% | 85% | 43% |
| MHAS | 81% | 74% | 70% | 81% | 100% | n/a |

*Within 5 dB from to 2000 Hz and within 8 dB at 4000 Hz (Aazh & Moore, 2007).

value was 75%, and the sample had an average GoF score of 86%. A related guideline from the United Kingdom recommends fitting within 5 dB of target to 2000 Hz, and within 8 dB of target above this (Aazh & Moore, 2007). As shown in Table 4, the majority of fittings achieve these criteria. Taken together, it appears that the sample of hearing aid fittings gathered in this study represents high quality fits to targets.

Results also indicated that the adult targets derived from the DSL v5.0a algorithm closely approximated the PLLs of adults listening to speech at conversational levels, regardless of the degree and configuration of hearing loss. This close approximation of PLL is an improvement from previous results comparing adult preferences with the DSL v4.1 prescription (Scollie et al., 2005). This indicates that the lower listening level prescribed for adults in DSL v5.0a versus v4.1 appears to have moved the target closer to the preferences of adults who use hearing aids. Most PLLs across frequency and hearing level were within 3.8 to 6.8 dB of the targets and prescribed slope. This variation around target may still be within the tolerance for an optimal frequency response. Jenstad et al. (2007) found a 10 dB range in which both consonant identification and loudness ratings were optimized and quality was not compromised. A PLL represents a subjective correlate to these objective measures, since it is a compromise between comfort, intelligibility, background noise and distortion (Cox, 1982). We may, therefore, conclude that

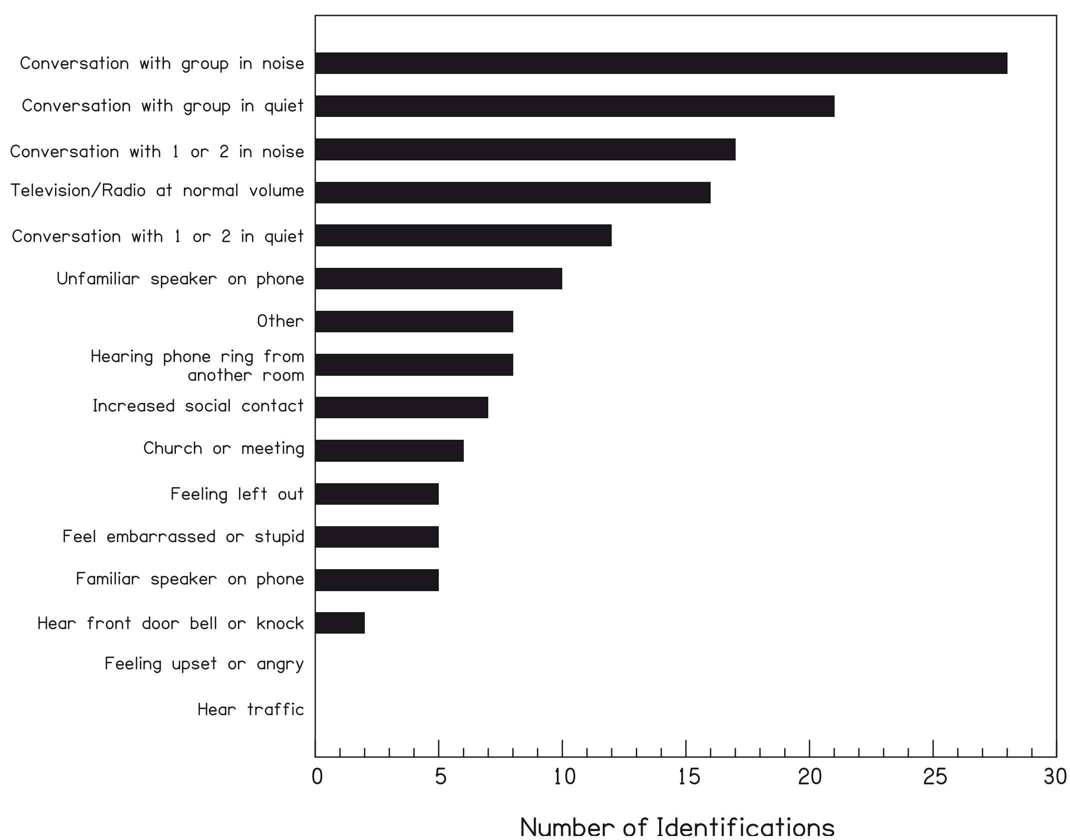


**Figure 4.** Frequency of nomination of listening and communication situations by adult hearing instrument users as priorities for hearing instrument fitting on the Client Oriented Scale of Improvement.

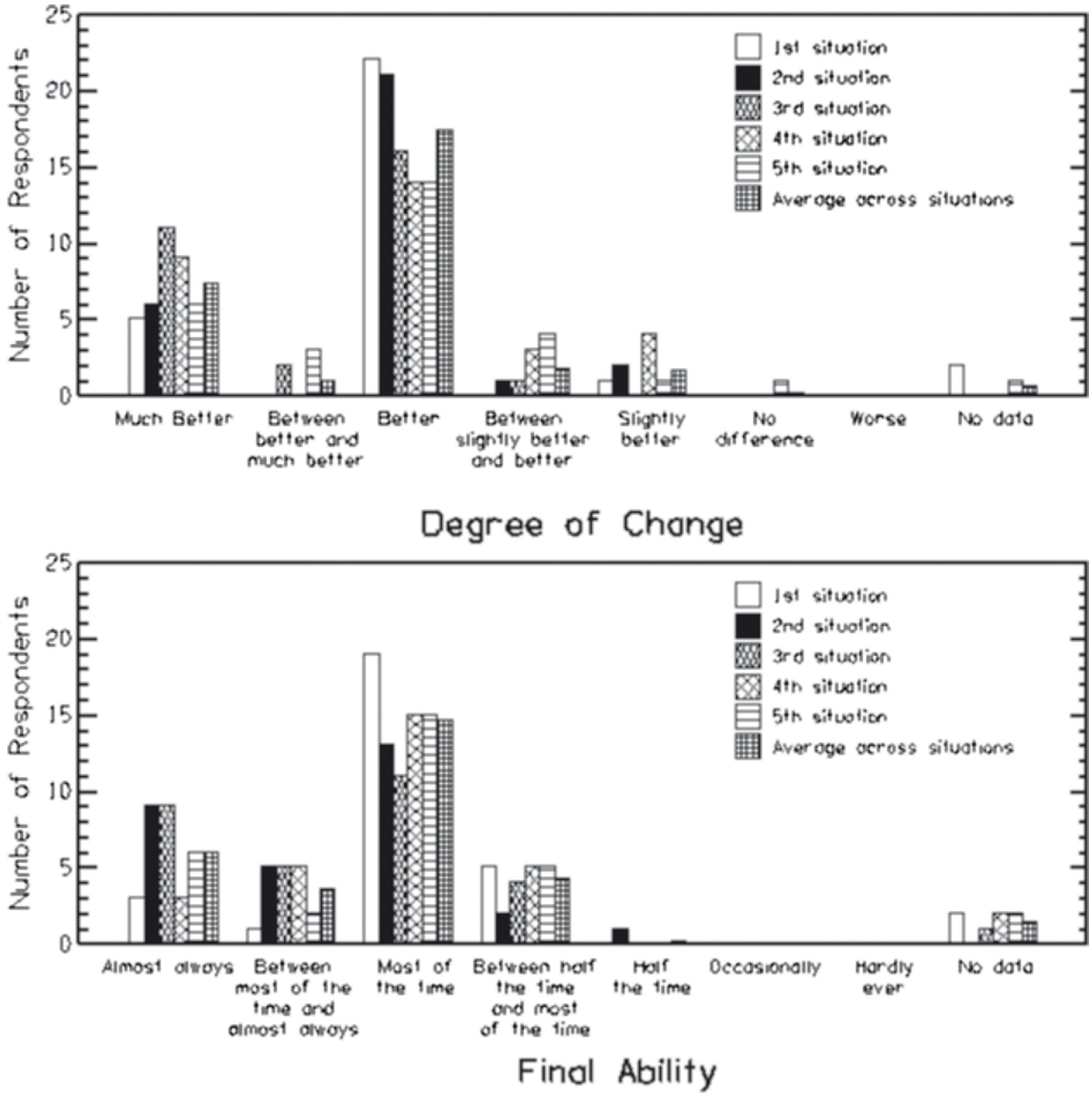


**Figure 5.** Results of the Client Oriented Scale of Improvement for a sample of adult hearing instrument users fitted using the DSL Method v5.0a. Top panel shows Degree of Change scores. Bottom panel shows Final Ability scores. Each bar indicates the number of respondents who provided a given outcome rating. Results are shown for the self-nominated communication situations, in order of situation priority, as well as the average rating across situations for each listener.

the adjustment of less than 7 dB to attain PLL in all of the participants in this study fits well within a 10 dB range of optimal frequency responses. However, further investigation would be required to define the location of these new targets within the optimal range of frequency responses.

More importantly, the hearing aid fittings in this study provided positive outcomes for final hearing ability and benefit on the COSI for the hearing aid users in this study. This suggests that the fittings provided acceptable benefit and communication performance, in the opinions of the participants. The participants identified a wide yet typical range of communication settings in which they wished their hearing aids to provide assistance. The hearing aid memory that was fitted to the DSL target would have been intended for use in some of these situations (e.g., conversation with group in quiet, conversation with one or two in quiet), but not necessarily for others (e.g., conversation with group in noise). Thirteen participants of 30 were provided with memories allocated for use in noisy environments, and one of these thirteen noise programs was automatically accessed by the hearing aid's signal processing algorithm. Therefore, the COSI outcomes noted here were not necessarily obtained using the DSL-fitted memory, and participants also had access to volume control adjustments. Because none of the hearing aids used data logging to track memory or volume control usage, frequency of memory and exact listening levels in various environments are unknown. It is therefore appropriate to interpret the role of the DSLv5.0a target as the base or only program, understanding that many fittings offered additional listening options at the user's discretion. In this context, COSI scores were high and acceptable for those situations in which the DSL-fitted memory would have been recommended for use. Specifically, average benefit scores were 4.6, 4.3, and 4.2 for conversations in quiet, TV/Radio listening, and hearing on the phone, respectively. Final ability scores in these same situations were also high, at 80% or better on average. This provides some evidence that the DSL v5.0a prescriptive target and individualized fitting method is effective when used to fit the base memory of a modern hearing aid fitting. Further research would be needed to understand better the relative effectiveness of using the DSL v5.0a target versus alternative prescriptions for the adult population.

## Summary and Clinical Implications

The purpose of this study was to determine the nature of the relationship between the revised DSL prescriptive targets for adults and the PLLs of adults who use hearing aids. Findings indicate that the DSL v5.0a targets could be closely approximated across frequency with commercial hearing aids, and that the fittings approximated closely the PLLs of adults who wear hearing aids. The relation between PLL and target listening level did not vary significantly across a sample of adults with widely varied hearing losses, using a variety of hearing aid styles and models. This supports the hypothesis that these findings may generalize to other clinical practice settings. In addition, the participants in this study had acceptable hearing aid performance in real world use, hearing better most of the time for most participants. It is possible, however, that participants accessed other memories in the hearing aid for some of their listening situations. These other memories, if used, may have contributed to positive real world outcomes by supporting comfortable listening and/or directional hearing, particularly in noisy environments. The clinical implications of these findings are: (1) use of the DSL v5.0a adult prescription appears to be feasible (i.e., the targets can be met with commercial hearing aids); (2) the DSL v5.0a adult prescription may lead to fittings that provide preferred listening levels for speech in quiet; and (3) these fittings may support an overall successful hearing aid fitting via delivery of acceptable levels of gain when used in combination with modern multimemory fitting strategies.


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