Comparison of SSPL90 Selection Procedures

David B. Hawkins*
Terry L. Ball*
Horace E. Beasley*
William A. Cooper*

Abstract
Recommended SSPL90 values were determined at 500, 1000, and 2000 Hz for 16 subjects with mild-to-moderate sensorineural hearing losses using six different selection procedures, including an Upper Limit of Comfortable Listening (ULCL) and threshold-based procedure by Cox (1988), a threshold-based procedure by Seewald and Ross (1988), and loudness discomfort procedures by Berger (1988), McCandless and Lyregaard (1983), and Hawkins et al (1987) and Libby (1985). Statistically significant differences were found among the procedures at 500 and 2000 Hz. Analysis of individual data showed that while some subjects obtained similar recommended SSPL90s across the procedures, others showed dramatically different values.

Key Words: Hearing aids, SSPL90, maximum output

In the last 15 years, considerable attention has been directed toward determining the most appropriate gain and frequency response of a hearing aid. A number of studies have compared the various frequency response selection procedures to determine if they result in different recommendations. While it is clear that different values do result, it has not been shown that one procedure results in superior speech understanding ability. A similar approach has not been focused upon the selection of the most appropriate maximum output or saturation sound pressure level (SSPL90). While few would argue that a hearing aid should not produce discomfort for the user, there has been little agreement on how or what should be measured to assist the audiologist in deciding where to limit the output. There are a number of published approaches to the selection of SSPL90, but they have neither been compared nor has the validity of any one approach been substantiated.

Two basic approaches to selecting the SSPL90 have been described in the literature. One approach involves obtaining some supra-threshold measure of loudness perception, such as loudness discomfort levels (LDLs). The SSPL90 is selected based upon this measurement, often being set just below a threshold of discomfort. A second approach employs either pure-tone thresholds or suprathreshold loudness measurements and determines an output limiting value that will prevent typical speech from saturating the hearing aid, thus leaving a prescribed amount of headroom. Since in the second approach loudness discomfort is only assumed not to occur at the selected limiting level, the client is questioned during a trial period to detect any loudness discomfort problems (Cox, 1988).

A number of procedures have been described in the last 10 years for selecting SSPL90, each falling into one of the above two categories. In addition to approaching the problem from different perspectives, the procedures use different stimuli, psychophysical procedures, instructions, and often different transducers. For this study, six published procedures that have recommended a specific method for specifying the SSPL90 of a hearing aid were identified. The purpose of this study was to investigate the question of whether the various procedures recommend different SSPL90 values.

*University of South Carolina, Columbia, South Carolina
Reprint requests: David B. Hawkins, Department of Speech-Language Pathology & Audiology, University of South Carolina, Columbia, SC 29208
METHOD

Subjects

Sixteen adults with mild-to-moderate sensorineural hearing loss served as subjects. The mean audiogram with standard deviations for the test ear is shown in Figure 1. The subjects ranged in age from 39 to 84 years, with a mean age of 64 years. Based upon previous evaluations, each subject was judged by the experimenters as capable of performing suprathreshold loudness judgments. Twelve of the 16 subjects were current hearing aid users.

SSPL90 Selection Procedures

Six procedures designed to select SSPL90 were included and used with each subject. These procedures are briefly summarized below.

Upper Limit of Comfortable Loudness Procedure

Cox (1988) developed the Upper Limit of Comfortable Loudness Procedure (Cox ULCL). A descending approach from near the LDL is used to determine the ULCL or Highest Comfortable Level (HCL) for warble tones presented through standard earphones. The instructions tell the subject to respond when the signal is comfortably loud and suggest the client reference their judgments to television and radio listening. Equations are then used taking into account the peaks of the long-term speech spectrum, 6-cc coupler versus real-ear differences, and 2-cc coupler versus real-ear differences. The recommended SSPL90 is expressed in 2-cc coupler values.

Cox Auditory Threshold Based Procedure

An auditory threshold based procedure was described by Cox (1988) (Cox Threshold). The ULCL is predicted from warble-tone or narrow-band noise thresholds. The predicted ULCLs are then used as described above to select the SSPL90. (Conversions and final values for Cox ULCL and Cox Threshold were obtained via MSU Hearing Aid Prescription Program [revised, Version 3.1].)

Hawkins/Libby Approach

A combination of aspects from two published LDL techniques was created to produce the Hawkins/Libby procedure. The instructions and psychophysical procedures were those recommended by Hawkins, Walden, Montgomery, and Prosek (1987). An ascending and bracketing approach to the LDL is used with pure tones or narrow bands of noise. The subject judges each stimulus using the following loudness categories: Very Soft, Soft, Comfortable But Slightly Soft, Comfortable, Comfortable But Slightly Loud, Loud But OK, Uncomfortably Loud, Extremely Uncomfortable, and Painfully Loud. The LDL is defined as the level that yields a judgment of Uncomfortably Loud. An Etymotic ER-3A insert earphone is used as the transducer, as proposed by Libby (1985). The recommended SSPL90, expressed in 2cc coupler values, is 1 dB below the LDL.

Berger Procedure

A procedure was described by Berger (1988) and Berger, Hagberg, and Rane (1988) to determine the maximum permissible SSPL90 (Berger). Ascending pulsed pure tones are presented through standard earphones. The instructions require the client to indicate when the signals "...first become uncomfortably loud. Consider the tones uncomfortable if you could
not listen to them for five minutes or more." The levels of Uncomfortable Loudness (UCL) are converted from dB HL to dB SPL in a 6cc coupler and the SSPL90 is set to this value. At 500 Hz the SSPL90 is set to the UCL (in dB SPL) or 115 dB SPL, whichever is lower.

**Prescription of Gain and Output**

McCandless and Lyregaard (1983) described a UCL component to select SSPL90 as part of their Prescription of Gain and Output (POGO).

This procedure does not specify a psychophysical procedure or specific stimulus. A decision was made to use an ascending and bracketing technique with pure tones. The instructions to the client are to indicate the level that would be "...unacceptably loud to listen to for any length of time." The UCL obtained at each of three test frequencies (500, 1000, and 2000 Hz) is averaged, and 4 dB is added to convert from dB HL to dB SPL in a 2cc coupler. The SSPL90 curve is then set so as not to exceed this averaged value.

**Sewald and Ross Auditory Threshold Based Procedure**

An auditory threshold based procedure was described by Seewald and Ross (1988)(Seewald and Ross). Using pure-tone thresholds, desired sensation levels are determined for the amplified long-term speech spectrum. The levels of the amplified speech spectrum are calculated and a certain amount of "headroom" above these amplified speech levels is determined for setting the real-ear SSPL90. Conversions are applied to the real-ear SSPL90 to determine the 2cc coupler SSPL90 values. (Conversions and final values were obtained via a software program provided by R. Seewald.)

**Procedures**

Each of the above six procedures was carefully administered as described by the authors in the original references. The exact instructions, stimuli, transducers, and psychophysical methods were used. The order of administration of the procedures was randomized for each subject in order to minimize any potential order effects. A brief practice period with each procedure was given to ensure the subjects understood the task. Recommended SSPL90 values were obtained for each procedure at 500, 1000, and 2000 Hz.

**RESULTS AND DISCUSSION**

The mean recommended SSPL90 values and standard deviations for 500, 1000, and 2000 Hz for each of the six procedures are shown in Table 1. The values for POGO in Table 1 are the same at each frequency because the procedure averages the UCLs for the three frequencies and recommends a single SSPL90 number. The mean value of 108 dB SPL for Berger at 500 Hz includes six values of 115 dB SPL. This indicates that six subjects had UCLs above 115 dB SPL because Berger's procedure requires that the SSPL90 not exceed 115 dB SPL at 500 Hz regardless of the actual UCL.

The standard deviations are similar for the four procedures that make suprathreshold loudness judgments (Cox ULCL, Hawkins/Libby, Berger, POGO). The two threshold-based procedures (Cox Threshold and Seewald and Ross) show much smaller standard deviations and reflect more the variability in the audiometric thresholds.

A two-factor repeated measures analysis of variance showed a significant procedure effect (F = 5.30; df = 5.75; p < .001), indicating that

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Cox ULCL</th>
<th>Cox Threshold</th>
<th>Hawkins/Libby</th>
<th>Berger</th>
<th>POGO</th>
<th>Seewald and Ross</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>106 (10.8)</td>
<td>102 (2.4)</td>
<td>112 (7.1)</td>
<td>108 (8.6)</td>
<td>102 (10.8)</td>
<td>107 (4.5)</td>
</tr>
<tr>
<td>1000</td>
<td>105 (11.3)</td>
<td>102 (3.7)</td>
<td>103 (10.8)</td>
<td>109 (12.7)</td>
<td>102 (10.6)</td>
<td>105 (4.2)</td>
</tr>
<tr>
<td>2000</td>
<td>111 (9.8)</td>
<td>104 (3.9)</td>
<td>106 (10.5)</td>
<td>113 (12.4)</td>
<td>102 (10.6)</td>
<td>115 (2.7)</td>
</tr>
</tbody>
</table>

*The standard deviations are in parentheses.
significant differences were present among the procedures in the prescribed SSPL90 values. The mean prescribed SSPL90 for the three frequencies for each of the procedures is shown in Figure 2. The lowest prescribed SSPL90 values were found with POGO and Cox Threshold, and the highest values were found with Berger.

The analysis of variance also revealed a significant frequency by procedure interaction ($F = 9.75; df = 10,150; p < .001$), indicating that differences among the procedures were not constant across the three frequencies. Newman-Keuls Tests were performed on the means at each frequency to determine which of the procedures were significantly different in the prescribed SSPL90. At 500 Hz, the Hawkins/Libby procedure yielded a significantly higher ($p < .05$) SSPL90 than did POGO and the Cox Threshold procedure. The Berger procedure was also significantly higher than the Cox Threshold procedure. No other comparisons reached statistical significance. Since the Hawkins/Libby procedure required foam plugs to be inserted into the ear canal, it is possible that the higher SSPL90 at 500 Hz is partially the result of low-frequency leakage around the plug.

The differences among the procedures at 1000 Hz were less pronounced than at 500 Hz. None of the comparisons among the procedures were statistically significant ($p > .05$). At 2000 Hz, the lowest SSPL90 values were again prescribed by POGO and the Cox Threshold procedure, with Cox ULCL, Berger, and Seewald and Ross recommending the higher values. The Seewald and Ross, Berger, and Cox ULCL procedures recommended SSPL90 values that were significantly higher ($p < .05$) than POGO and Cox Threshold. In addition, Berger and Seewald and Ross were significantly higher than Hawkins/Libby.

In summary, for this rather homogeneous group of hearing-impaired subjects, some significant differences were found among the SSPL90 selection schemes. Several observations seem apparent. First, POGO recommended the lowest SSPL90 values. This is interesting in that POGO tends to recommend the most gain (insertion gain equal to $1/2$ the hearing loss at 1000 Hz and above) among the various frequency response selection procedures. If one is strictly following POGO for both gain and SSPL90, the hearing aid might often be in saturation, making the use of low-distortion output limitation crucial.

Second, there was a significant frequency effect ($F = 13.2; df = 2,30; p < .001$), indicating that recommended SSPL90s vary with frequency. This has implications for the implementation of multiband systems, where optimizing the width of the dynamic range may be possible through more precise output limiting in different frequency regions.

Third, although it might be argued that some of the differences among the procedures are relatively small, analysis of individual subject data often showed substantial differences among the procedures, which would clearly lead to vastly different recommended SSPL90s. For instance, Figure 3 shows the mean prescribed SSPL90 for the three frequencies for Subjects 5 and 8 from each of the six procedures. Depending upon the procedure used, for Subject 5 one might select SSPL90s in the area of 100, 105, 110, 115, or 125 dB SPL. In contrast to Subject 5, similar SSPL90 recommendations occurred across the procedures for some subjects. Also shown in Figure 3 are results from Subject 8, for whom the prescribed SSPL90 values were quite close. All procedures recommended an SSPL90 in the range of 100 to 105 dB SPL.

Variability of the type shown by Subject 5 could be related to subject confusion and an inability to reliably perform suprathreshold loudness judgment tasks. Alternatively, the variability may be related to individual interpretations of different instructional sets, probably the largest source of variability in suprathreshold loudness measurements. Several subjects commented that instructions that included references to time, such as “5 minutes,”
mates of appropriate SSPL90 prove to be equally effective as those derived from suprathreshold loudness judgments, the former would be preferable as they save time and show less variability.

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REFERENCES


Figure 3 Mean prescribed SSPL90 values at 500, 1000, and 2000 Hz for Subjects 5 and 8 for each of the six procedures.