Procedure for Defining the Auditory Area of Hearing Impaired Adolescents with a Severe/Profound Hearing Loss II: Loudness Discomfort Levels

Procédure de définition du champ auditif des adolescents malentendants atteints de pertes auditives sévères/profondes II : Les niveaux sonores inconfortables

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Abstract

The intra-subject variability associated with loudness discomfort levels (LDLs) obtained with a modified Pascoe procedure was evaluated. Nine adolescents with a severe/profound hearing loss took part in the investigation. LDLs were measured on 10 occasions over a period of 12 weeks. In more than 50% of the cases, LDLs could not be recorded because the subjects' LDL exceeded the maximum power output of the sound delivery system at the test frequency. Results obtained from six different subjects who provided measurable LDLs on 10 consecutive sessions, for at least one test frequency, suggest that the within session intra-subject variability did not change systematically as a function of repeated testing. The results of five subjects who displayed measurable LDLs during the initial three test sessions (at 500 or 2000 Hz) were compared to similar data obtained from the same subjects who participated in an experiment that investigated intra-subject variability associated with detection thresholds. No systematic differences in either within or across session intra-subject variability were apparent between the detection threshold and LDL measures.

Résumé

On a évalué la variabilité intra-sujet associée aux niveaux sonores inconfortables (NSI) obtenus à l'aide de la méthode Pascoe modifiée. Neuf adolescents atteints d'hypoacousie sévère à profonde ont participé à l'enquête. Les NSI ont été mesurés à dix reprises sur une période de douze semaines. Dans plus de la moitié des cas, les NSI des participants n'ont pu être consignés parce qu'ils dépassaient la sortie maximale du système d'envoi de sons à la fréquence des essais. Toutefois, les résultats obtenus de six sujets différents qui ont fourni des NSI mesurables pendant dix séances consécutives, pour au moins une fréquence d'essai, laissaient croire que la variabilité intra-sujet à l'intérieur d'une séance n'avaient pas changé systématiquement comme fonction d'essai répété. En outre, les résultats obtenus pour cinq sujets qui ont montré des NSI mesurables pendant les trois premières séances d'essai (à 500 ou 2000 Hz) ont été comparés à des données analogues obtenues des mêmes participants dans le cadre d'une expérience d'enquête sur la variabilité intra-sujet associée aux seuils de détection (Gagné, Seewald, Zelisko, et Hudson, 1991). On a noté aucune différence systématique dans la variabilité intra-sujet pendant la séance et entre les séances entre les mesures des seuils de détection et des NSI.

The loudness discomfort level (LDL) may be defined as: "the intensity at which an auditory signal elicits an unfavorable subjective response" (Hawkins, 1980, p. 3). LDLs are used to select the Saturation Sound Pressure Level (SSPL) of an amplification system for hearing impaired individuals (Hawkins, 1980; Hawkins, Beck, Bratt, Fabry, Mueller, & Stelmachowicz, 1991; Hawkins, Walden, Montgomery, & Prosek, 1987; Kawell, Kopun, & Stelmachowicz, 1988; Skinner, 1988). Ideally, the SSPL of an amplification system should be adjusted to some level below an individual's LDLs. Otherwise, amplified sounds from an amplification system may cause an individual some discomfort (Cox, 1981; Hawkins et al., 1987; Walker, Dillon, Byrne, & Christen, 1984). In fact, SSPLs that exceed the listener's LDLs have been reported to be the major reason for hearing aid rejection among hearing impaired individuals (Walker et al., 1984). On the other hand, amplification systems with an SSPL set too far below LDLs may severely restrict the dynamic range of amplified sound available to the hearing impaired individual (Walker et al., 1984). Hence, reliable and valid measurements of LDLs constitute an important component of the hearing aid selection process.

Several variables have been reported to influence the LDLs obtained from a listener (Gagné, Seewald, Zelisko, & Hudson, 1991; Hawkins, 1980; Skinner, 1988). Among them is the psychophysical procedure used to measure LDLs. Psychophysical procedures most often used to measure LDLs include: (1) ascending and/or descending meth-

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ods of limits, (2) methods of constant stimuli, (3) adaptive psychophysical procedures, and (4) methods of adjustment (e.g., Bekesy audiometry). Reviews of the psychophysical procedures that have been used to measure LDLs have been provided by Hawkins (1980) and Skinner (1988).

Recently, Pascoe (1978, 1986, 1988) described a psychophysical procedure that could be applied to the measurement of all aspects of the auditory area and that may be used in the selection and fitting of a hearing aid (i.e., detection thresholds, most comfortable loudness levels, and LDLs). The loudness rating procedure described by Pascoe consists of an ascending method of limits embedded into a one observation interval forced-choice paradigm (Gagné et al., 1991; Pascoe, 1978, 1986, 1988). With this procedure, LDLs were defined as the lowest level at which the listener provided a loudness rating of "too loud" (Pascoe, 1986, 1988). Pascoe (1986, 1988) recommended that several ascending blocks of trials should be completed at each test frequency in order to establish a valid estimate of LDL. He stated that, for blocks of trials succeeding the first ascending trial run, the initial level of the stimulus should be "slightly above the highest comfort level previously chosen" (Pascoe, 1988, p. 132). Pascoe suggested that this procedure served to elevate the LDLs and resulted in a more accurate measurement of the listener's true LDL. One interpretation of this clinical observation is that repeated measurements of LDLs obtained with the Pascoe procedure could result in a large amount of intra-subject variability. The purpose of the present investigation was to investigate the use of a modified Pascoe procedure to measure LDLs among adolescents with a severe/profound sensorineural hearing loss.

Hawkins et al. (1987) investigated the test-retest reliability of LDLs obtained with a modified Pascoe procedure. The most significant modification from the procedure described by Pascoe (1978, 1986) was the instrumentation system used to present test signals. Hawkins et al. (1987) used pure-tones presented to the listener through a hearing aid and custom earmold. The LDLs of one group of nine hearing impaired subjects, obtained with a modified Pascoe procedure were compared to the LDLs obtained with a method of adjustment for another group of eight hearing impaired subjects. All the subjects were tested at two test frequencies (i.e., 1000 and 4000 Hz), on four different days. The results of the investigation revealed that the intra-subject variability associated with the modified Pascoe procedure was considerably less than the intra-subject variability associated with the method of adjustment. LDLs obtained with the modified Pascoe procedure varied by less than 4 dB over the four test sessions (compared to changes that exceeded 20 dB for some subjects tested with the method of adjustment). There were no differences in the intra-subject variability across test frequencies. Also, the authors did not report any systematic changes in the absolute level of an individual's LDL as a function of test session.

Kawell et al. (1988) assessed the applicability of a one observation interval forced-choice loudness rating procedure to measure LDLs in children. Subjects consisted of 20 hearing impaired adults and 20 hearing impaired children. The average hearing loss of both groups was comparable (i.e., moderately-severe sensorineural hearing loss representing diverse audiometric configurations). The children ranged in age from 7 to 14 years. The psychophysical procedure used to measure the LDLs of the adult subjects was similar to the procedure reported by Hawkins et al. (1987). The procedure used to measure the LDLs of the children was modified. Modifications included: (1) simplification of the instructions given to the subjects, (2) reduction in the number of loudness categories (i.e., five loudness categories were used), (3) simplification of the loudness descriptors, and (4) provision of a visual representation of each loudness category (along with a written descriptor). LDLs were obtained at each half-octave frequency between 500 and 4000 Hz. The results of the investigation revealed that, at any given test frequency, there were no significant differences in the mean absolute LDLs obtained from both groups of subjects.

Kawell et al. (1988) also investigated the test-retest reliability of the psychophysical procedure used to measure LDLs among the group of hearing impaired children. LDLs were measured for eight (of the 20) children on three different occasions (over a period of 1 - 3 weeks). The across session intra-subject variability (i.e., standard deviations) ranged from approximately 3.0 dB at 500 Hz to almost 6.0 dB at 3000 Hz. The authors noted that the across session intra-subject variability increased slightly as a function of test frequency. Moreover, the variability in the responses obtained from the children was considerably greater than the variability previously reported by Hawkins et al. (1987) who used a similar procedure to measure LDLs in adults.

Stuart, Durieux-Smith, and Stenstrom (1991) measured the within session intra-subject variability in LDLs obtained from hearing impaired children. The psychophysical procedure used was similar to the one previously described by Kawell et al. (1988). However, the authors used a different signal delivery and recording system. An insert earphone attached to the subjects' personal earmold was used to present the test stimuli, which consisted of pulsed tones between 500 and 4000 Hz (at octave frequencies). Absolute LDLs were recorded with a probe-tube microphone inserted in the occluded ear canal of the subject. Twenty hearing impaired children ranging in age from 7 to 14 took part in the investigation. The pure tone average hearing loss of the subjects ranged from moderate to severe. Three estimates of LDLs were obtained at each test frequency during one test

session. Once inserted, the earphone and the probe-tube microphone remained in place throughout the test session. The within session intra-subject standard deviation in LDLs for this group of children ranged from 3.35 to 4.85 dB.

Clinical observations (Pascoe, 1978, 1986, 1988) as well as experimental data (Hawkins et al., 1987) suggest that the Pascoe procedure could be developed into a standardized procedure to measure LDLs for the purpose of hearing aid selection among adults. Moreover, the results of Kawell et al. (1988) and Stuart et al. (1991) suggest that a modified Pascoe procedure could be developed to measure LDLs among hearing impaired children. One appealing aspect of the Pascoe approach is that the same basic procedures can be used to measure all components of the auditory area. Moreover, this psychophysical procedure is time efficient, easy to administer (for the clinician), and simple to perform (for the client). The procedure can be easily implemented in many clinical settings (Gagné et al., 1991). However, the reliability and validity of any clinical procedure should be firmly established before it can be recommended for use with children.

The present experiment was designed to further investigate the variability of LDLs obtained with a modified Pascoe procedure. First, the use of a modified Pascoe procedure to measure LDLs among adolescents with a severe/profound hearing loss was investigated. Second, the effect of training on reducing the variability in LDLs was examined. Finally, within and across session intra-subject variability in LDLs was compared to estimates of within and across session intra-subject variability in Detection Thresholds (DTs) obtained from the same subjects in a companion investigation (Gagné et al., 1991).

Method

Subjects

Nine hearing impaired adolescents with a severe/profound sensorineural hearing loss participated in the experiment. Eight of these subjects also took part in a companion investigation that evaluated the intra-subject variability and criterion validity of a modified Pascoe procedure to measure DTs (Gagné et al., 1991). A detailed description of the subjects was provided by Gagné et al., (1991). The mean detection thresholds of each subject who took part in the present investigation are presented in Table 1. The detection thresholds were obtained at 250 Hz and at one-half octave intervals between 500 and 6000 Hz, with a calibrated TDH-50 earphone (ANSI S3.6, 1969). A conventional audiometric psychophysical procedure (ASHA, 1978) was used to measure the detection thresholds in 2 dB steps.

Table 1. Detection thresholds (dB HL re: ANSI S3.6, 1969) for the test-ear of individual subjects.

Subjects	Frequency (Hz)								
	250	500	750	1000	1500	2000	3000	4000	6000
1 (JB)	65	75	95	100	115	115	120	NR*	115
2 (SD)	50	70	110	100	90	80	125	NR*	NR**
3 (RL)	60	80	100	105	115	120	120	NR*	NR**
4 (SM)	75	85	100	110	120	120	125	NR*	NR**
5 (JM)	90	90	100	110	115	115	125	NR*	NR**
6 (TM)	85	85	90	90	100	95	90	80	80
7 (JS)	45	70	85	90	100	85	80	95	NR**
8 (PS)	90	95	95	100	105	105	105	105	NR**
9 (KS)	35	65	85	100	115	120	115	NR*	NR**
Mean	66.1	79.4	95.6	100.6	108.3	106.1	111.7	93.3	97.5
Standard deviation	20.3	10.1	8.1	7.3	10.0	15.8	16.6	12.6	24.8

* no response at maximum linear output of earphone (i.e., 120 dB HL)
** no response at maximum linear output of earphone (i.e., 115 dB HL)

Instrumentation

Equipment used to measure LDLs was similar to the instrumentation system used by Gagné et al. (1991) to measure DTs, and described in detail by Zelisko et al. (1990). Briefly, a stimulus delivery/real-ear measurement system that made it possible to measure the level of the signals (in dB SPL) with a probe-tube microphone inserted into the occluded ear canal of the subjects was used to measure LDLs. The stimuli consisted of pulsed pure tones with a 50% duty cycle of 400 msec. The test frequencies investigated were: 250, 500, 1500, and 2000 Hz. The maximum undistorted output level available from the stimulus delivery/real-ear measurement system was: 123.5 dB, 125.5 dB, 135.5 dB, and 136 dB (SPL, measured in a 2 cm^3 coupler) at 250, 500, 1500, and 2000 Hz, respectively.

Procedure

Subjects were tested individually in a sound-treated audiometric test room. Each subject participated in a total of 10 test sessions over a period of 12 weeks. During each test session LDLs were measured with a modified Pascoe procedure. The stimulus level was increased in 2 dB increments. The starting level of each block of trials was 3 - 6 dB below the expected LDL, based on pre-experiment screening tests (or the LDLs obtained during previous blocks of trials). The selection of a relatively high starting level was required to ensure that all the test stimuli presented within a block of trials would be above the subject's DT at that test frequency. The exact starting level (within this 3 - 6 dB range) was

selected at random prior to each test session. Following each trial, the subject was asked to report the loudness of the stimulus based on a 7-point rating scale (refer to Figure 3 in Gagné et al., 1991). A block of trials was terminated when the subject reported a loudness rating of 6 (i.e., "too loud"). The stimulus level at which this response was obtained was recorded as the LDL for that block of trials. In some cases, a loudness rating of "too loud" was not observed even when the test signal was presented at its maximum (undistorted) level, for that test frequency. In those instances, no measurable LDL was recorded. During each test session a subject completed eight blocks of trials at each test frequency for which LDLs could be measured. The test frequency selected for each block of trials was selected randomly (following the principles of sampling without replacement).

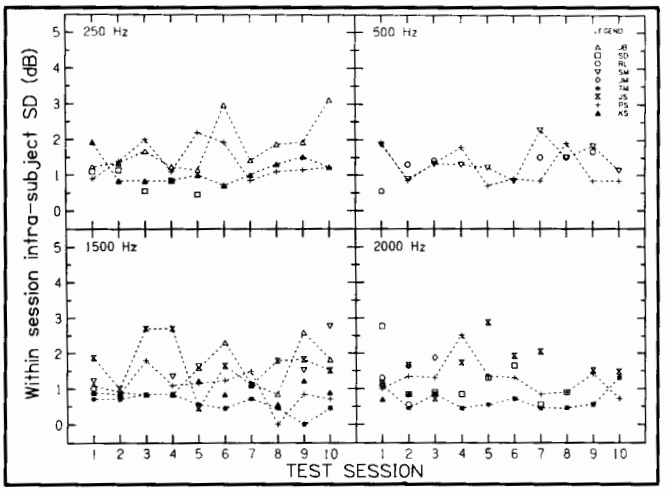
Results and Discussion

Only one subject (PS) provided measurable LDLs for all 10 test sessions, at each of the four test frequencies. Due to the severity of their hearing loss, the LDLs of most subjects exceeded the maximum output level of the stimulus delivery system at one or more of the test frequencies. For many subjects, LDLs were obtained during some, but not all, of the test sessions. The test sessions during which measurable LDLs were obtained for a given subject, at each test frequency, can be extracted from Figure 1. Since the data obtained during the course of the investigation were incomplete, parametric statistical analyses could not be applied. However, subsets of the data were used to examine within and across session intra-subject variability in LDLs. The data selected for these analyses made it possible to compare the intra-subject variability associated with DTs and LDLs directly. The findings reported are preliminary and should be interpreted with caution. Furthermore, the present results are not necessarily comparable to other research findings on this topic. Nor can they be generalized to the hearing impaired population. Nevertheless, the results provide useful insights concerning the potential application of a modified Pascoe procedure to measure the auditory area of hearing impaired individuals.

Within session intra-subject variability

The metric used to examine the within session intra-subject variability in LDLs consisted of the standard deviation of the last five (of the eight) blocks of trials completed, at one test frequency, during a given test session. The results available for each of the 10 test sessions, at each test frequency, are shown in Figure 1. The within session intra-subject variability of individual subjects did not exceed 3.1 dB for any of the test conditions for which measurable LDLs were obtained.

Figure 1. Within session variability of individual subjects displayed as a function of test session. Each subject is identified by a unique symbol (refer to legend in the top-right corner of the figure). Data are shown only for experimental conditions for which measurable LDLs were obtained. Each panel displays the results obtained at one test frequency. Dashed lines show results obtained from subjects who provided measurable estimates of LDLs during all 10 test sessions, at a given test frequency.



For each test frequency investigated, at least two subjects had measurable LDLs for all 10 test sessions (i.e., PS, JB, and KS at 250 Hz; PS and SM at 500 Hz; PS, JB, TM, and JS at 1500 Hz; PS and TM at 2000 Hz). Results obtained from those subjects were used to examine the effects of repeated testing on intra-subject variability. A visual inspection of the results obtained from those subjects (see the connected symbols in Figure 1) failed to reveal any systematic decreases in within session intra-subject variability as a function of test session. Based on the limited data available from the present investigation there is no evidence that practice (or familiarity) with the modified Pascoe procedure reduced the within session intra-subject variability in LDLs. However, this finding needs to be verified experimentally with a larger number of subjects for whom measurable LDLs can be obtained repeatedly during consecutive test sessions.

Five subjects provided measurable LDLs at 500 or 2000 Hz during the initial three test sessions of the investigation (i.e., PS, RL, and SM at 500 Hz; and, PS, RL, SD, and JS at 2000 Hz). The same subjects also participated in a companion experiment that investigated intra-subject variability in DTs at the same two test frequencies (Gagné et al., 1991). The data obtained from those subjects were used to compare the within session intra-subject variability associated with DTs and LDLs. For the DTs, the mean within session intra-subject variability consisted of the average of the standard deviations obtained during the three test sessions during which a modified Pascoe procedure was used to measure DTs (Gagné et al., 1991). For the LDLs, the mean within

Figure 2. Within session variability associated with DTs and LDLs shown for individual subjects. Results obtained at 500 and 2000 Hz are shown in separate panels. Solid bars depict the intra-subject variability associated with the measurement of DTs. Cross-hatched bars depict the intra-subject variability associated with the measurement of LDLs.

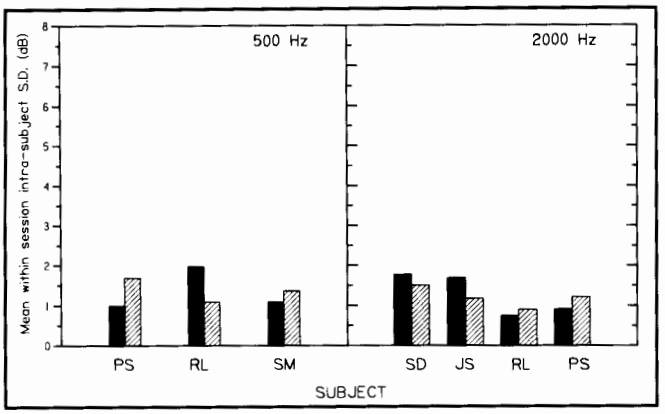
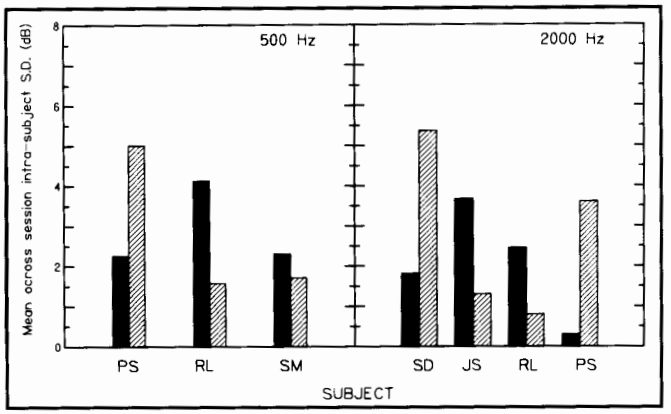


Figure 3. Across session variability associated with DTs and LDLs shown for individual subjects. Results obtained at 500 and 2000 Hz are shown in separate panels. Solid bars depict the intra-subject variability associated with the measurement of DTs. Cross-hatched bars depict the intra-subject variability associated with the measurement of LDLs.



session intra-subject variability consisted of the average of the standard deviations obtained during the initial three (of the 10) test sessions during which LDLs were measured. The mean within session intra-subject variability of DTs and LDLs obtained from individual subjects did not exceed 2.0 dB at either test frequencies (see Figure 2). Moreover, a visual inspection of the data failed to reveal any systematic differences in within session variability for both of these measures.

Across session intra-subject variability

Data obtained from the five subjects who provided measurable LDLs during the initial three test sessions of the investigation (same as above) were used to examine across session variability in LDLs. For each subject, the across session intra-subject variability was operationally defined as the standard deviation of the mean absolute LDL obtained during each of the initial three test sessions. The across session variability in LDLs observed for individual subjects are displayed in Figure 3. The across session intra-subject variability computed from the three test sessions during which DTs were measured with the modified Pascoe procedure (Gagné et al., 1991) are also shown for the same subjects. For the five subjects for whom data were available, the intra-subject variability in DTs ranged from 0.31 to 4.12 dB. The across session variability in LDLs observed for the same subjects ranged from 0.90 to 5.01 dB. A visual inspection of the data failed to reveal any systematic differences in across session intra-subject variability between DTs and LDLs. Based on the limited set of data available from the present investigation it would appear that the variability associated with both types of measures (DTs and LDLs) would be acceptable for clinical purposes. However, further investigations are required to substantiate these preliminary observations. Finally, a comparison of the data displayed in Figures 2 and 3 suggests that, for these five subjects, the within session intra-subject variability in LDLs was less than the across session intra-subject variability in LDLs. This result needs to be verified with a larger number of subjects. However, this preliminary finding is consistent with the results of previous investigations that have reported the within session (Stuart et al., 1991) and across session (Kawell et al., 1988) intra-subject variability in LDLs observed among hearing impaired children.

Summary and Conclusions

All of the subjects who participated in the present investigation were able to learn and perform the response task required to measure LDLs with the modified Pascoe procedure. Moreover, subjectively, the subjects did not report that the modified Pascoe procedure was more difficult to complete for the measurement of LDLs than for the measurement of DTs. It is noteworthy that only one subject provided measurable LDLs for all test sessions, at all test frequencies. More than half of the attempts to measure LDLs were unsuccessful because the subjects' absolute LDL exceeded the maximum output of the signal delivery system, at that test frequency. A lower proportion of LDLs were measured at 250 and 500 Hz than at 1500 and 2000 Hz. The maximum output of the sound delivery system was greater at the two higher test frequencies. The maximum output levels of the signal delivery system used in the present investigation were similar to (or exceeded) the maximum output level of most commercially available audiometers. The limited results available from the present investigation clearly indicate that

limitations in the maximum output of the sound delivery system constitutes an important impediment to measuring LDLs among subjects with a severe/profound hearing loss. Previous investigators also have reported that, in some cases, limitations in the sound delivery system made it impossible to measure LDLs among hearing impaired subjects (Stuart et al., 1991).

Results obtained from six different subjects for whom measurable LDLs were obtained on 10 consecutive test sessions, for at least one test frequency, suggested that the within session variability did not decrease systematically as a function of test sessions. No learning effects were apparent as a result of repeated testing. Based on the limited data available from the present investigation it would appear that long training periods may not be necessary to obtain reliable LDLs from hearing impaired adolescents. This finding needs further investigation.

A subset of the data obtained during the present investigation was used to examine the within and across session intra-subject variability in LDLs obtained from adolescents with a severe/profound hearing loss. Results obtained from a limited number of subjects suggest that the within session intra-subject variability was less than the across session variability. Also, a subset of the present results were compared to similar data obtained from the same subjects in a companion investigation of intra-subject variability in DTs (Gagné et al., 1991). The data examined failed to reveal any systematic differences in within or across session variability between DTs and LDLs.

In summary, the findings of the present study, as well as the results of a companion report (i.e., Gagné et al. 1991), indicate that the general procedures described in the present investigation (including the psychophysical procedure and the instrumentation system) could be implemented clinically to define the auditory area for the purpose of selection and fitting of an appropriate amplification system. Advantages of using a modified Pascoe procedure include: (1) easy administration (for the clinician), (2) simple to perform (for the subject), and (3) the same basic procedure can be used to measure all relevant aspects of the auditory area (i.e., detection thresholds, most comfortable listening levels, and LDLs) in a time-efficient fashion. Additional investigations will be required to assess the variability of LDLs obtained with a modified Pascoe procedure. These studies should be conducted with subjects who provide estimates of LDLs that do not exceed the maximum output level of the sound delivery system used to present the test stimuli. These studies would contribute to the evaluation of the reliability and validity of the modified Pascoe procedure as a means to define the auditory area for the purpose of hearing aid selection and fitting in a clinical setting.

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