Research Article

Stimuli and Normative Data for Detection of Ling-6 Sounds in Hearing Level

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Purpose: The purpose of this work was to develop and evaluate a calibrated version of the Ling-6 sounds for evaluation of aided detection thresholds. Stimuli were recorded, and data from calibration values in dB HL were developed. Aided performance was characterized in adults and children.

Method: Stimuli were recorded, prepared, and transferred to a CD for testing. Initial testing was completed on 29 normally hearing young adults to determine typical responses in dB SPL and reliability. Corrections to dB HL were determined for each stimulus. Twenty-seven adults and 5 children with hearing losses were tested.

Results: Average normal sound field thresholds were 1 dB HL. Aided thresholds for adults varied with unaided hearing level and were better for low-frequency sounds. Adults and children performed differently, possibly because of greater hearing aid gain for children.

Conclusions: Stimulus preparation and shaping resulted in a recorded, calibrated set of Ling-6 stimuli that provide flat normal thresholds in hearing level for normally hearing listeners. Typical performance ranges may vary with hearing level and prescription. More data are required to fully characterize this trend in the pediatric population.

Key Words: amplification or hearing aids, children, adults, efficacy, outcomes

Because the Ling sounds are commonly assessed by therapists who are clinical partners in providing intervention services, some audiologists also adopt the Ling-6 sound test in a variety of ways. Hearing aid fitting protocols for adults and children may include the use of Ling-6 sounds at the device validation stage as a rapid measure of speech sound reception (Cox, Mendel, & Bell, 2011; Smiley, Martin, & Lance, 2004). Anecdotal reports include either administration of the sounds as is done by therapists or measurement of aided detection thresholds by presenting each sound with the clinician’s voice via a clinical audiometer. Users of this test have noted the need to define whether the test is used to evaluate speech sound detection, discrimination, or identification and the relative advantages and disadvantages of each type of evaluation (Smiley et al., 2004). The work described in this article was focused on the use of Ling-6 sounds for the evaluation of speech sound detection. A detection task was chosen to facilitate future work with infants, who may be able to perform an aided audiogram as an outcome measure. The present work focuses mainly on adults in this early evaluation of this procedure.

Aided Detection Thresholds in Device Evaluation

Aided detection thresholds have been used for various purposes in hearing aid fitting. Within historical comparative methods for hearing aid fitting, both unaided and aided sound field thresholds were measured at many frequencies and used to calculate the functional gain of the hearing aid under consideration (Skinner, 1998). Functional gain was

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used when shaping the hearing aid frequency response in lieu of electroacoustic hearing aid analysis. In modern practice, this time-consuming process for verification and shaping of hearing aid gain has largely been replaced by faster and more accurate electroacoustic procedures. In previous studies, authors have proposed a variety of factors that may limit the validity of functional gain measures, including head and body movement during testing, hearing aid noise floor, hearing aid response differences between speech and nonspeech test signals, off-frequency listening for participants with steeply sloping hearing losses, and interactions of compression attack and release times with stimulus onsets and/or offsets (Hawkins, 2004; Kuk, Keenan, Lau, & Ludvigsen, 2004; Scollie & Seewald, 2002; Stelmachowicz, Hoover, Lewis, & Brennan, 2002). These factors have led some authors to suggest that electroacoustic hearing aid analysis is a more appropriate tool for estimating hearing aid gain and frequency response, compared with functional gain measures (Hawkins, 2004; Stelmachowicz et al., 2002).

However, aided sound field thresholds with hearing aids, cochlear implants, or bone-anchored hearing devices are sometimes obtained, even for a small number of stimuli, as an outcome measure to determine the lowest level of sound that may be detectable (Bass-Ringdahl, 2010; Davidson et al., 2009; Hodgetts, Hakansson, Hagler, & Soli, 2010; Tharpe, Fino-Szumski, & Bess, 2004). This procedure is done to evaluate the fitting, and although it does not include computation of functional gain for shaping purposes, it may include comparison of unaided versus aided conditions as a benefit measure. This validation procedure has been deemed as having higher clinical utility when the hearing device cannot be assessed electroacoustically (e.g., bone-conducted or bone-anchored devices) or when information about whether a listener can detect aided sound is of clinical interest (Stelmachowicz et al., 2002). With either of these goals, interpretation of aided thresholds is difficult without knowledge of a “target” or “appropriate” aided threshold, which may vary with hearing threshold levels and/or hearing technology. Very little recent data exist, particularly regarding aided thresholds for speech stimuli with contemporary hearing devices. Typical performance with modern devices may be of interest for several reasons. First, contemporary devices may have increased wearable gain for low-level stimuli as a result of more effective feedback controls, increased processing bandwidth, and more frequency use of multichannel wide dynamic range compression, compared with early-era digital and linear analog devices. These changes may result in lower levels of sound being detected by the user. Second, modern prescriptive and fitting methods better account for the use of wide dynamic range compression and the different listening needs and preferences of adults and children (Keidser, Dillon, Flax, Ching, & Brewer, 2011; Scollie et al., 2005). For these reasons, characterization of typical performance in users of modern hearing technologies, fitted using modern techniques, was of interest in this study.

Rationale for Current Study

In this article, we describe a set of stimuli and procedures for performing aided threshold evaluations, in dB HL, using prerecorded Ling-6 stimuli. The rationale for this study is fourfold. First, the Ling-6 stimuli span the speech frequencies by using only six test stimuli. Therefore, the use of Ling-6, rather than warbled tones or other narrowband stimuli, could probe a broad frequency range while requiring fewer measurements. Second, the Ling-6 stimuli are well understood by clinicians and have high face validity. Third, the Ling-6 stimuli are natural speech tokens and therefore support aided threshold evaluation with modern signal processing. Recent hearing aid efficacy studies have used aided Ling-6 thresholds as an outcome measure, with results indicating that this measurement is sensitive to frequency-specific differences between aided conditions (Glista et al., 2009; Wolfe et al., 2010, 2011). Finally, we speculated that clinical interpretation of detection thresholds for Ling-6 sounds would be supported if calibrated in the hearing level (HL) scale. Considering these arguments, the purpose of this study was to develop Ling-6 stimuli with calibration in dB HL and to characterize typical aided outcomes for these stimuli by using testing procedures that are feasible for use with commonly available clinical equipment.

Method

Pilot Stimuli and Procedure

The Ling-6 stimuli were spoken by a woman who was a native speaker of English. She was seated within a double-walled IAC sound booth. Recordings were made with a pedestal microphone (AKG Acoustics) located approximately 30 cm from the talker’s mouth and routed to a pre-amplifier (USBPre). Digitization was performed via sound card, and recordings were made with commercially available software (Spectraplus). The talker was instructed to produce each sound in isolation, with neutral vocal effort. The following orthographic representation of the Ling sounds was provided for her reference: “AH as in operate, EE as in beep, OO as in shoe, SH as in stop, MM as in man.” Ten repetitions of each sound were recorded, and the token with the most neutral pitch contour and best sound quality was chosen and uploaded into editing software (Goldwave). Stimuli were excised from the original recordings and edited to preserve the naturally produced token as much as possible and to be approximately 1 s in duration (range: 0.89–1.25 s) and peak intensity (0.5 full-scale deflection). These edits required the shortening of only /l/ and /s/, which had naturally produced durations of about 1.5 s each. When shortening was required, the stimulus was clipped at a zero crossing, and an offset ramp in volume was imposed to prevent offset transients. The spectral characteristics of these stimuli are presented in Figure 1. The edited stimuli were embedded in a computer-assisted threshold search procedure, which used a two-alternative forced-choice adaptive tracking paradigm to assess sound field detection thresholds. Response choices were “heard it” and “didn’t hear it.” Thresholds on the adaptive track were estimated from the last four reversals, using a 5 dB step size and a 50% criterion. Sound field levels from this task were quantified in dB SPL, by calculating the reference calibration levels minus the attenuation levels at threshold.
Figure 1. One-third octave spectra of the Ling-6 stimuli. The overall level of each stimulus has been normalized to 65 dB SPL.

Pilot Evaluation

Ten young adults (3 men, 7 women, ages 21–35 years) were recruited to participate in a pilot evaluation of these stimuli. Participants reported no hearing difficulties, had normal otoacoustic emissions, and had pure-tone audiometric thresholds in both ears at normal levels (at or below 15 dB HL) from 250 through 8000 Hz. Binaural sound field thresholds were measured twice for each participant. All measures were made in a double-walled sound booth. Noise levels within the booth met standards for maximum permissible ambient noise levels (MPANL) for the ears not covered condition, for testing at frequencies between 125 and 8000 Hz (Frank, 2000). Mean sound pressure levels at threshold ranged from 0 to 22 dB SPL across the Ling-6 sounds and formed a U-shaped curve across stimulus peak frequency similar to that of a minimum audible field curve. For example, the /u/ stimulus had a pilot RETSPL greater than that of the /a/ stimulus and so was increased by 3 dB. In contrast, the /m/ stimulus had a pilot RETSPL that was 17 dB greater than that of the /a/ stimulus and so was adjusted by 2 dB, assuming that a correction factor would be applied for the remaining 15 dB. The root-mean-square digital levels of the resulting stimuli were within 12 dB of one another, which more readily allowed the tester to hear the stimulus during testing, compared with the first version.

Normative data for this version of the CD were gathered from a second group of normally hearing listeners, and clinical results were gathered on a group of adults with hearing impairment, as described below. Tracks on the CD included a calibration tone, a calibration noise, and six tracks of stimuli. Each stimulus track included 64 replications of the Ling-6 sound for use with conventional audiometric procedures. In the text below, this CD is referred to as the Ling-6(HL) test.

Clinical Stimuli and Procedure

On the basis of the pilot results, the levels of the stimuli were adjusted to approximate the pilot RETSPL per stimulus. As recommended by ANSI, a calibration tone was constructed that exceeded the peak levels of the highest level stimulus (ANSI, 2004). As well, a calibration noise was constructed that produced a target output level in the sound field, assuming that the field was calibrated for binaural listening at zero degrees azimuth. The intended purpose of the tone and noise was to permit replicable use of the CD, by providing the researchers with a tool to set the audiometer’s input sensitivity for the CD on repeated uses, and to verify the sound field levels produced over time. Calibrated levels were monitored daily during data collection for this study, with the requirement of meeting calibration targets within 2 dB each day that data were collected.

The resulting calibration and Ling-6(HL) stimuli were placed on a CD for use with manual audiometric procedures via a clinical audiometer (GSI-61). The VU meter was adjusted to place the calibration tone at zero prior to use of the CD, and pilot testing with normally hearing listeners was attempted. However, recall that a 22 dB range existed among the stimuli in the pilot evaluation. Those that had been most attenuated within the resulting stimulus set could not be heard by the tester during manual audiometry. Therefore, a revised version was constructed that used minimal digital attenuation of stimuli, anticipating that a manual correction would be applied to convert the results to HL (see Appendix A). Specifically, the stimuli were adjusted by up to 5 dB, with values chosen to support the use of 5 dB step sizes in both manual audiometry and in correction factors. The RETSPL for each stimulus was compared with the RETSPL of /a/, which had the lowest detection thresholds. Stimulus levels were adjusted relative to this to the nearest 5 dB step. Any changes greater than 5 dB were saved for manual correction. For example, the /a/ stimulus had a pilot RETSPL greater than that of the /a/ stimulus and so was increased by 3 dB. In contrast, the /m/ stimulus had a pilot RETSPL that was 17 dB greater than that of the /a/ stimulus and so was adjusted by 2 dB, assuming that a correction factor would be applied for the remaining 15 dB. The root-mean-square digital levels of the resulting stimuli were within 12 dB of one another, which more readily allowed the tester to hear the stimulus during testing, compared with the first version.

Participants

Twenty-nine normally hearing young adults (mean age: 24 years; age range: 20–28 years; 25 women and 4 men) participated in an evaluation of the Ling-6(HL) test. These participants reported no history of hearing problems and passed a hearing screening from 250 to 8000 Hz at 25 dB HL. Otoscopic examinations revealed no blockage of the external ear. Twenty-seven adults with hearing loss also participated (mean age: 68 years; age range: 21–87 years; 11 women, 16 men). Seventeen of these participants were regular users of hearing aids, all binaurally. Their hearing losses ranged from mild to moderate by pure-tone average (mean three-frequency pure-tone average [PTA]: 43 dB HL; PTA range: 31–60 dB HL). Audiometric slopes ranged from
zero to 90 dB between 4000 and 500 Hz (mean slope: 40 dB). Figure 2 shows the mean and individual audiometric thresholds for the better ear of each participant. In addition, to illustrate the application of this test, we evaluated five children from a typical clinical caseload. These children ranged in age from 6 to 9 years and had moderate hearing losses in the better ear. One child had conductive hearing loss, and the remainder had sensorineural losses.

**Hearing Aid Fitting Procedure**

Adult participants were fitted with a pair of laboratory hearing aids, which were commercially available devices with multichannel wide dynamic range compression, no frequency lowering processing, and omnidirectional microphones. Venting was incorporated into earmolds on a case-by-case basis and ranged from 1 mm to 3.5 mm. All other features of the devices, such as digital noise reduction, were disabled during testing. Feedback cancellation was required and enabled for five participants. Hearing aids were fitted using the fifth version of the Desired Sensation Level (DSL 5) method (Bagatto et al., 2005), which includes a prescription for use with adults (Scollie et al., 2005), and verified using probe microphone measures of the Real Ear Aided Response (REAR) for running speech at 55 and 65 dB SPL and for 85 dB warbled tones, using a commercially available system (Audioscan Verifit VF-1). For the group as a whole, 81% of participants were fitted to within 5 dB of target at 4000 Hz in both ears. Five participants with steeply sloping hearing loss could not be fitted to within 5 dB of target, although most were fitted closely to target through 2000 Hz. This fitting profile is similar to those in a recently published study of clinically typical and beneficial fittings using the DSL 5 adult prescription (Polonenko et al., 2010).

The children in this study were tested while wearing their own hearing aids of varying makes and models. The hearing aids had been fitted using the DSL 5 method (Bagatto et al., 2005). These hearing aids were prescribed and verified by an experienced pediatric audiologist using simulated REAR measures, individually corrected using measured Real Ear to Coupler Differences. The fit to targets of each hearing aid was within 5 dB of targets for running speech at 65 dB SPL and for warble tones at 90 dB SPL.

**Data Collection in dB HL**

Each participant’s detection thresholds were measured for each Ling-6(HL) stimulus with manual administration using 5 dB step sizes and a two-down, one-up bracketing procedure. Testing was completed within a double-walled audiometric booth (IAC) with a loudspeaker, placed at zero degrees azimuth, connected to an audiometer (GSI-61). Participants were seated in a height-adjustable chair with their heads located in a marked point within the booth. Each test was completed twice within one session. Participants with normal hearing were tested with ears uncovered, and they listened binaurally. Participants with hearing loss were tested in the binaurally aided condition. Testing was completed within the same booth used for pilot data, which exceeded the standards for MPANL for ears uncovered.

**Results**

**Normative Values and Test–Retest Reliability**

All twenty-nine normally hearing listeners completed the protocol, including the evaluation of test–retest reliability. Threshold values for each Ling-6(HL) stimulus were averaged across the two tests, and a final correction factor was determined that resulted in average thresholds near 0 dB HL across frequencies. Across stimuli and participants, corrected threshold values ranged from −12.5 to 15 dB HL. Table 1 displays the average corrected threshold per sound, as well as the 95% confidence interval for normal detection of each sound. In general, the upper limit of normal performance for this test was approximately 15 dB HL. Mean test–retest for this participant group was 2 dB across participants and stimuli and was one audiometric step size (5 dB) or less for all but two of 174 thresholds (99%) measured in the normally hearing group. The upper limit of the 95% confidence interval for test–retest difference was between 5 and 8 dB across stimuli (Table 1). Correlations between test and retest ranged from 0.71 to 0.90 in this group.

**Characterization of Aided Results in Adults**

As with the normally hearing listeners, adults with hearing loss completed two administrations of the Ling-6(HL) detection test but performed the test while wearing hearing aids. Test and retest aided thresholds were within 5 dB for all listeners and all stimuli. Test–retest correlations ranged from 0.89 to 0.97 across stimuli. Therefore, aided thresholds

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Figure 2. Better ear audiograms of 22 adult participants. Mean thresholds for this group are also shown (●). Thresholds beyond the test limits of the audiometer are coded as 120 dB HL.
were averaged across test and retest for all participants in this group. The aided thresholds ranged from 0 to 47.5 dB HL. This range includes scores that fall outside the normal range of test performance, indicating that not all listeners had normal speech sound-detection abilities even though they were binaurally aided. It is possible that the outcome of normalized versus nonnormalized aided detection thresholds might interact with the degree of unaided hearing loss, as normalization for all degrees of hearing loss is not a goal of the adult-based prescriptive method used in these fittings (Scollie et al., 2005). To determine the relation between unaided hearing levels and aided detection thresholds, we computed correlation coefficients between the magnitude of the unaided hearing loss and the aided Ling-6(HL) results. These correlations were computed both for each audiometric frequency in the better ear and also for the overall hearing loss, computed as the better ear four-frequency pure-tone average (BE4FPTA) of thresholds at 500, 1000, 2000, and 4000 Hz. The results, shown in Table 2, indicate several considerations that are important for interpreting test results. First, consider the predictive ability of the unaided pure-tone thresholds. In general, unaided thresholds are good predictors of performance when they are similar in frequency to the peak energy regions of the stimulus. For example, unaided thresholds at 250 and 500 Hz were the best two predictors of aided thresholds for /m/, /u/, and /i/. As shown in Figure 1, these stimuli had their highest spectral peaks in the low-frequency region. This trend occurred also for most stimuli, with /a/ correlated with low- and mid-frequency thresholds, and /s/ correlated with unaided hearing across frequencies, to 4000 Hz. However, both /l/ and /s/ were also correlated with unaided hearing thresholds in the lower frequencies. This correlation might indicate that audibility of low-frequency energy in these fricatives contributed to detection, although the design of this study precludes direct evaluation of this. It may be the case that further sampling, a greater range of audiograms, or experiments with filtered stimuli would be necessary to determine the frequency-importance function of these stimuli for detection.

Another possible predictor of aided performance is the magnitude of hearing loss, represented here as the BE4FPTA. This predictor was also significantly, although more modestly, correlated with aided detection thresholds. Taken together with the frequency-specific results, this indicates that the magnitude and configuration of hearing loss are associated with aided detection thresholds with Ling-6(HL) stimuli. This result means that participants with better unaided hearing detected the Ling-6(HL) stimuli at lower levels than did listeners with poorer hearing, even in the aided condition. This relationship is depicted in Figure 3, which displays aided Ling-6(HL) thresholds for each stimulus and listener, against the listeners’ unaided hearing levels by pure-tone.

Table 1. Average sound field detection thresholds and unsigned test–retest differences for a group of 29 young normally hearing listeners for the Ling-6 stimuli in dB HL.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stims</th>
<th>/m/</th>
<th>/u/</th>
<th>/a/</th>
<th>/i/</th>
<th>/l/</th>
<th>/s/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average threshold (dB HL)</td>
<td></td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>95% confidence interval of the normal range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper limit</td>
<td></td>
<td>12</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Lower limit</td>
<td></td>
<td>-8</td>
<td>-10</td>
<td>-9</td>
<td>-8</td>
<td>-6</td>
<td>-8</td>
</tr>
<tr>
<td>Average test–retest difference (dB)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Upper limit of 95% confidence interval</td>
<td></td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Note. Confidence intervals for the normal range and the range of unsigned test-retest difference are also shown.

Table 2. Correlations between unaided hearing loss and aided detection thresholds for the Ling-6(HL) sounds in a sample of adults.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>/m/</th>
<th>/u/</th>
<th>/a/</th>
<th>/i/</th>
<th>/l/</th>
<th>/s/</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 Hz</td>
<td>.85*</td>
<td>.000</td>
<td>.86*</td>
<td>.000</td>
<td>.70*</td>
<td>.000</td>
</tr>
<tr>
<td>500 Hz</td>
<td>.83*</td>
<td>.000</td>
<td>.88*</td>
<td>.000</td>
<td>.74*</td>
<td>.000</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>.77*</td>
<td>.000</td>
<td>.82*</td>
<td>.000</td>
<td>.81*</td>
<td>.000</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>.28</td>
<td>.157</td>
<td>.26</td>
<td>.197</td>
<td>.40*</td>
<td>.040</td>
</tr>
<tr>
<td>3000 Hz</td>
<td>.30</td>
<td>.133</td>
<td>.30</td>
<td>.130</td>
<td>.35</td>
<td>.076</td>
</tr>
<tr>
<td>4000 Hz</td>
<td>.22</td>
<td>.270</td>
<td>.21</td>
<td>.303</td>
<td>.28</td>
<td>.159</td>
</tr>
<tr>
<td>6000 Hz</td>
<td>.01</td>
<td>.943</td>
<td>.08</td>
<td>.703</td>
<td>.24</td>
<td>.237</td>
</tr>
<tr>
<td>BE4FPTA</td>
<td>.61*</td>
<td>.001</td>
<td>.62*</td>
<td>.001</td>
<td>.65*</td>
<td>.000</td>
</tr>
<tr>
<td>n</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
</tbody>
</table>

Note. Correlations are shown for unaided thresholds at audiometric frequencies as well as the better ear four-frequency pure-tone average (BE4FPTA).

*p < .05.
average. Each Ling-6(HL) stimulus is indicated by a specific symbol in Figure 3, grouped with vowels and nasal stimuli on the left panel and fricatives on the right. Data from both listeners with normal hearing and listeners with aided hearing loss are shown. All data are plotted against the BE4FPTA, to facilitate visual comparison between nasals, vowels, and fricatives on a common scale. Confidence intervals for typical aided detection results are indicated for each group of stimuli (vowels and nasals versus fricatives) by solid lines. The derivation of these intervals is discussed further below.

For vowel and nasal stimuli, listeners with normal hearing had detection thresholds of about 15 dB HL or better. Adults with aided hearing loss performed both within or poorer than the normal range, depending on their degree of hearing loss. Adults with unaided thresholds of 30 dB HL or better had aided thresholds within the normal range and not significantly correlated with the BE4FPTA. Mean aided Ling-6(HL) threshold for this group was 9.3 dB HL (SD = 5.12 dB). For listeners with hearing loss between 30 and 50 dB HL, average aided detection thresholds were poorer (M = 17.7 dB HL; SD = 7.2 dB) but not significantly correlated with varying unaided hearing levels. Above 50 dB HL, results indicated a significant trend for increasing aided nasal and vowel thresholds as hearing thresholds increased (n = 40, r = .495, p = .001). These participants detected nasal and vowel sounds at 25 dB HL on average (SD = 8.6 dB).

Detection thresholds for fricatives are shown as closed symbols in Figure 3. Results for the fricatives were somewhat poorer, with aided thresholds not within the normal hearing range but rather within a range of 15 to 50 dB HL. Aided detection thresholds were significantly associated with unaided better ear pure-tone averages for the fricatives (n = 54, r = .522, p < .001).

Correlations between better ear pure-tone average and each group of stimuli (nasals and vowels versus fricatives) were used to generate confidence intervals (solid lines in Figure 3). The BE4FPTA was selected as the predictor rather than frequency-specific thresholds, as it permits comparison of performance across stimuli using a single criterion. Accordingly, confidence intervals were computed as the mean aided Ling-6(HL) threshold in the range from 0 to 30 dB HL BE4FPTA, with a two standard deviation interval around the mean. Above 50 dB HL BE4FPTA, the range was computed as a linear regression of aided Ling-6(HL) thresholds versus unaided thresholds, with regressed values surrounded by two standard deviations. Between 30 and 50 dB HL BE4FPTA, the two previously described confidence intervals are joined by straight lines. This implies that aided threshold levels for the Ling-6(HL) stimuli may be related to the hearing loss of the listener, perhaps as a result of device-fitting differences for lesser versus greater hearing losses. This issue will be addressed in more detail below.

**Illustrative Cases With Children**

Aided detection of the Ling-6 sounds may assist pediatric audiologists in determining whether a child has auditory access to speech across a wide range of frequencies. In children, two other factors may also impact typical results. First, infants and younger children typically respond to a slightly suprathreshold minimum response level (MRL) rather than responding at true threshold for audiometric tasks (Sabo, Paradise, Kurs-Lasky, & Smith, 2003; Widen et al., 2000). Responses for young children on a Ling-6(HL) detection task may also be at MRL rather than at true threshold. Recall that average normal thresholds for the Ling-6(HL) stimuli were between 0 and 15 dB HL. The upper limit of the normative adult range may therefore differ from the upper limit of normal hearing commonly used to interpret visually reinforced audiometry (VRA) results for younger children (i.e., 25 dB HL; Sabo et al., 2003). Second, children who use hearing aids may be provided with more gain than would be given for an
adult with the same audiogram, using recent versions of some prescriptive formulæ (Keidser et al., 2011; Scollie et al., 2005). This may allow children who use hearing aids to detect the Ling-6(HL) sounds at a lower level than was typical of the adult data presented in this study. To illustrate this second issue, we examined five pediatric cases in the course of normal clinical practice. As described above, these children were between the ages of six and nine years of age and wore hearing aids fitted to within 5 dB of the DSL 5 child target. Aided Ling-6(HL) thresholds were measured with good within-test reliability by using standard audiometric procedures, as judged by the clinician. The results from these children are shown alongside adult data in Figure 3. It is evident that these children had lower (better) aided thresholds than were measured for adults with similar degrees of hearing loss. Two factors may have contributed. First, the DSL 5 child prescription requires more gain than does the DSL 5 adult prescription. Therefore, the children wore devices with approximately 7 dB more gain for a 50 dB HL audiogram (Scollie et al., 2005). Second, three of the children used frequency compression hearing aids. One of these children had aided detection thresholds for /s/ and /l/ at 15 dB HL or better despite having unaided high-frequency thresholds in the severe range. This result for DSL 5 child fittings using frequency compression is consistent with results in published studies using a non-HL version of this Ling-6 test (Glista et al., 2009). Finally, the best-performing child had a flat moderate conductive hearing loss and aided thresholds well below 0 dB HL for all six stimuli. Further data would be required to determine whether this type of result is consistently associated with aided conductive hearing loss.

Discussion

This article presents a set of prerecorded Ling-6 stimuli, implemented on a CD, with clinical calibration procedures and normative data for use as a speech sound detection test in the sound field. Data on a sample of adults with hearing loss and illustrative cases of children with hearing loss provide preliminary characterization of test performance as an aided outcome measure. These results indicate that typical performance on this test varies with the unaided hearing loss and the prescription type. These factors will be discussed in more detail below.

Test–retest reliability for both normally hearing listeners and for listeners with hearing aids was within one audiometric step size for the majority of test cases in this study. This is consistent with reports of aided sound field thresholds using warbled tone stimuli to assess listeners with nonlinear hearing aids (Kuk et al., 2004) and either similar to or slightly better than well-recognized reports in which aided thresholds were measured on adults and children with hearing loss (Hawkins, Montgomery, Prosek, & Walden, 1987; Humes & Kim, 1990; Stuart, Durieux-Smith, & Stenstrom, 1990). In general, the procedures used across these studies were similar, and they are similar to those used in the current study. Two differences warrant discussion. First, the data presented by Kuk and colleagues (2004) were gathered within a sound booth that had been modified to include absorptive fabric panels to further reduce standing waves, and the listener’s head was resting against a headrest to minimize head and body movement. To represent clinical conditions during testing, we did not incorporate these procedures into the current study. Second, the stimuli used in the present study are broader in bandwidth than the warbled tones used in the previous studies cited above. The broader bandwidth could reduce the effects of standing waves, which may be an advantage for test–retest reliability. The broader bandwidth also prevents this test from being highly frequency specific and prevents their use in characterizing aided hearing on a frequency-by-frequency basis, compared with testing with narrowband stimuli, such as pure tones. Test performance was characterized in a sample of adults with hearing loss, all of whom were fitted with a modern, commercially available hearing aid with multichannel wide dynamic range compression. The hearing aids were fitted using the DSL 5 method and verified in the ear canal of each participant using a probe tube microphone system. With these fittings, adults with better ear pure-tone averages of up to 30 dB HL achieved aided thresholds in the upper half of the normal range for the low-frequency stimuli in this test. For losses above this or for high-frequency stimuli, aided detection was not within the normal range and was related to the degree of hearing loss, characterized either by frequency-specific thresholds or by the overall magnitude of the hearing loss. This is consistent with the prescriptive goals and calculations of the DSL 5 method, which prescribes aided listening levels for adults that are significantly lower than those prescribed for children (Scollie et al., 2005). Clinically, this means that expected aided performance on this test ranges between about 0 and 50 dB HL, depending on the frequency content of the stimulus and the unaided hearing loss and gain of the hearing aid.

Adult performance was compared with illustrative cases of five older children who were tested while wearing their own hearing aids. These devices had also been fitted using the DSL 5 method, which prescribes more gain for children with early childhood hearing losses than is prescribed for adults with acquired losses. Specifically, DSL 5 uses a modified normalization algorithm for children, in which gain targets attempt to normalize audibility if the input is above the compression threshold (Scollie et al., 2005). Accordingly, the children had lower aided thresholds than did the adults, and their scores fell largely within the normal range. The current data set on children serves to illustrate that adults and children may have different test performance if they are fitted with a prescription that uses age-dependent gain. In addition, some of these children used frequency-lowering hearing aids, which may have been a factor in their aided thresholds for the higher-frequency stimuli. The current data set on children is not adequate to fully characterize typical children’s responses across hearing loss or technology type, and further work on this is recommended.

Considering the results presented here, it appears that the Ling-6(HL) stimuli support reliable estimation of sound field speech sound detection thresholds in several participant groups, using clinically available equipment such as a CD player and commercial audiometer. This test may support reliable test results across time and tester, compared with a live voice administration during aided threshold testing, although this was not studied directly in this research.
Limitations of either the test or our current knowledge of the test include the following: First, the performance of this test is not yet fully characterized on children who use hearing aids, particularly children in the developmental range for testing with VRA. The use of a VRA-based protocol for assessing aided Ling sound detection in infants and toddlers has been suggested in previous reports (Winter & Kuk, 1998). However, the test–retest, normative, and clinically typical test performance for VRA is unique (Hawkins, 2004; Sabo et al., 2003; Widen et al., 2000). We would therefore expect that a VRA procedure with the Ling-6(HL) stimuli would require specific evaluation to determine normative properties, clinical patterns of outcome, and appropriate application with test azimuths other than those used in this study. Second, the relative advantages or disadvantages of using Ling-6 sounds rather than warbled tones or narrow bands of noise for aided detection threshold evaluation is not addressed by the current study. Third, recalling that all data used here were measured using zero degrees azimuth, normative test properties with other azimuths have not yet been assessed. Fourth, the variation and importance of frequency content across the Ling-6 stimuli is not fully exploited by a detection task such as is presented here. Consider the spectral properties of the four low-frequency stimuli (/m/, /a/, /a/, /i/) in this set (Figure 1) against the typical test performance in hearing aid users (Figure 3). These stimuli have similar peak spectral levels yet different spectral properties. This detection test would likely have been driven by the primary spectral peaks between 200 and 500 Hz, where the stimuli have similar peak levels. This is consistent with the results, in which aided detection thresholds across these stimuli occupy essentially the same range in the aided adult listeners. Therefore, is testing all six stimuli necessary? This may be an important clinical consideration regarding test time. It also highlights the different test considerations when Ling-6 stimuli are used either for a detection task or for a more complex task such as speech sound discrimination or identification (Smiley et al., 2004). Whereas the former may be related to peak levels, the latter may be affected by other properties of the stimuli, including formant structure. Literature on vowel recognition indicates that audibility, frequency, frequency change, and frequency ratios of formats likely affect vowel identification (Hillenbrand, Getty, Clark, & Wheeler, 1995; Monahan & Idsardi, 2010). The present work addresses the use of the Ling-6 stimuli for detection purposes in decibel hearing level but does not address the suprathreshold tasks of discrimination or identification. Finally, the results presented here were gathered using the DSL 5 fitting method and nonlinear hearing aids. It is possible that typical performance with other fitting methods or technologies may vary from the results shown here.

The clinical use of the Ling-6(HL) detection test requires use of the calibration tone to adjust the input sensitivity of the audiometer to the correct level and verification that the target calibration levels are achieved using a sound level meter. These requirements are typical of CD-based tasks that are routed to audiometers. If they are, use of the correction factors shown in Appendix A may be appropriate. As with other tests that are used across a variety of sound fields (e.g., Cox & Gray, 2001), site-specific verification of the corrections on a sample of otologically normal listeners is recommended either to ensure that the corrections are appropriate or to develop site-specific corrections. Although correction factors are perhaps inconvenient, the advent of computer-assisted audiometers may facilitate automation of such corrections in the future.

Appropriate clinical applications of this version of the Ling-6 stimuli may include measurement of aided speech sound detection thresholds as a measure of hearing device outcome. This application is not a replacement for electro-acoustic hearing aid analysis, specifically real ear measurement, as a method for ensuring that the gain and frequency shaping of a hearing aid is appropriate for a particular hearing aid user. Real ear measurement is more precise and provides more detailed and robust information about hearing aid response across frequency and level, compared with measures of either functional gain or aided thresholds. Therefore, aided Ling-6(HL) detection thresholds use may have greatest utility (a) for devices that cannot be evaluated with real ear measurements (e.g., cochlear implants, bone-anchored or conductive hearing devices, middle ear implants); or (b) when confirmation that the listener is receiving the aided signal is of clinical interest (e.g., for children, when measurement of aided thresholds is done to validate that aided speech sounds are detected by the child). This latter use is best considered an outcome measure as opposed to a verification measure. Either of these applications may assist in postfitting evaluations or provide information for further discussion with patients, caregivers, teachers, or speech-language pathologists. The score sheet presented in Appendix B displays the normal range measured in this study, based on the 95% confidence intervals measured for each group of listeners, and allows plotting of unaided and/or aided detection thresholds on a case-by-case basis.

Acknowledgments

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An audio CD is available with the stimuli used in this study, along with support documents that provide instructions and scoring sheets. Contact Phonak (www.phonak.com) for more information.

References


Scollie et al.: Ling-6(HL) Stimuli and Normative Data 239


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**Appendix A**

Sample scoring methods for Ling 6(HL) = results

The following example illustrates the corrections used to convert measured dial levels at threshold to values in dB HL:

<table>
<thead>
<tr>
<th>Variable</th>
<th>/m/</th>
<th>/a/</th>
<th>/a/</th>
<th>/i/</th>
<th>/i/</th>
<th>/a/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dial level at threshold</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correction</td>
<td>-10</td>
<td>-10</td>
<td>-10</td>
<td>-10</td>
<td>-15</td>
<td>-20</td>
</tr>
<tr>
<td>dB HL</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
Appendix B

Ling-6(HL) scoring sheet

Name: _______________________ DOB: _________________________
Date: ________________________ Respondent: ___________________
Notes on testing conditions: _____________________________________

Test method:  □ Standard □ CPA □ VRA
Reliability:   □ Good □ Fair □ Poor
Test type:    □ Aided □ Unaided □ CI □ Bone conducted □ BAHA
Masking (unaided ear)? □ n/a □ Yes □ No

Plot the corrected threshold values in dB HL below.

Note. The gray region shows the normal hearing range. Values assume binaural sound field testing at zero degrees azimuth. VRA = visually reinforced audiometry; CPA = conditioned play audiometry; VRA = visual reinforcement audiometry; CI = cochlear implant; BAHA = bone-anchored hearing aid.