The Ling-Madell-Hewitt (LMH) Test Battery*

Jane Madell, Ph.D. and **Joan Hewitt**, Au.D. discuss the new series of functional listening assessments

Introduction

One of Daniel Ling's many legacies is his introduction of the Ling Six Sound Test which was first published in 1976 (Ling, 1976). This test, which presents 6 phonemes ([m], [a], [oo], [ee], [sh], and [s]), was designed to present sounds which would broadly represent the speech spectrum. By asking children to initially indicate detection, then to indicate recognition, and finally to imitate the 6 sounds provided a "very low tech, very easy to learn" screening tool that "can provide quick and easy verification of auditory abilities, can establish continuity and preparedness for training and development of additional listening skills, can serve as a guide for setting auditory training goals, and can serve as a 'red flag' for problems related to hearing, hearing loss and hearing amplification systems" (Smiley, 2004).

Specific Perception Error	% of occurrence	% of correction
/z/ heard as /m/	69%	84%
/ch/ heard as /sh/ or /t/	67%	87%
/s/ omitted, distorted, or heard as /sh/	42%	+
/m/ /n/ confusion	41%	85%
Omission of /b/	36%	98%
/p/ heard as /h/ or omitted	29%	96%
/sh/ heard as /s/	21%	91%

TABLE 1: Percent of occurrence and percent of correction for the most common errors noted

Observations and Concerns

Over the years, the authors have observed that the Ling Six Sound Test has moved from a quick, easy screening tool to an almost daily regimen or curriculum. Children are tested at home, at school, at the clinician's office, etc. As soon as the tester's mouth is covered, some children will begin reciting "a, oo, ee, sh, s, m" even before the tester speaks. Other children have admitted that, since the test is repeated daily, they are so bored that they pay little attention as they are responding.

More importantly, as digital hearing aid and cochlear implant technology advanced, the authors began to note that there were children who "passed" the Ling Six Sound Test but still had poor speech perception. After observing this, the authors began to wonder if testing only 6 sounds and also only these specific 6 sounds provided sufficient information about speech perception.

Rationale for expanded testing

For children with hearing loss to acquire good speech production and morphemic functions in spoken English, they must be able to clearly perceive all ~ 44 phonemes of the language, not just 3 vowels and 3 consonants. To investigate whether the 6 sounds used in the Ling testing provided a sufficiently comprehensive screening, Lochner, Hewitt, Owen, and Madell (2015) completed a retrospective review of more than 230 cochlear implant MAPpings. This review found that the most common speech perception errors were not identified by the 6 sounds used in Ling test and that significant errors on Ling

Consonant Energy Bands						
Bands			1	2	3	4
Manner	Voiced	Voiceless	200-800	1000-1500	1500-3500	3500 +
Plosives	b		300-400		2000-2500	
	d		300-400		2500-3000	
	g		200-300		1500-2500	
		p			1500-2000	
		t			2500-3500	
		k			2000-2500	
Nasals	m		250-350	1000-1500	2500-3500	
	n		250-350	1000-1500	2000-3000	
	ŋ		250-400	1000-1500	2000-3000	
Fricatives	v		300-400			3500-4500
	z		200-300			4000-5000
	ʒ		200-300			4000-4500
	ð		250-350			4500-6000
		h			1500-2000	
		f				4000-5000
		s				5000-6000
		ʃ			1500-2000	4500-5500
		θ				~6000
Affricates		tʃ			1500-2000	4000-5000
	dʒ		200-300		2000-3000	
Liquids	r		600-800	1000-1500	1800-2400	
	l		250-400		2000-3000	

TABLE 2: Consonant Energy Bands

LMH 10 sounds	Band 1 200 – 1000Hz	Band 2 1000 – 1500Hz	Band 3 1500 – 3500Hz	Band 4 3500Hz +
/oo/	F1: 300HzF2: 870Hz		F3: 2240Hz	
/a/	F1: 730Hz	F2: 1090Hz	F3: 2440Hz	
/ee/	F1: 270Hz		F2: 2290Hz F3: 3010Hz	
/n/	250-350Hz	1000-1500Hz	2000-3000Hz	
/m/	250-350Hz	1000-1500Hz	2500-3500Hz	
/dʒ/	200-300Hz		2000-3000Hz	
/z/	200-300Hz			4000-5000Hz
/h/			1500-2000Hz	
/sh/			1500-2000Hz	4500-5500Hz
/s/				5000-6000Hz

TABLE 3: Vowel Formants and Consonant Energy Bands of Ling-Madell-Hewitt (LMH) 10 Sound Quick Test

testing indicated significant global programming issues. (See Table 1) Further analysis of error patterns indicated that the 6 phonemes used in the Ling test did not sufficiently assess access to mid-frequency information which is critical for consonant identification. With digital hearing aids and cochlear implants, it is critical to ensure that children, not only have access across the speech frequencies, but also sufficient distinction of subtle differences between sounds.

In addition to common error patterns, Lockner et al (2015) found that, with programming changes, a significant number of perception errors could be corrected quickly and easily. (See Table 1) Analysis of phoneme errors and review of a frequency allocation chart for speech phonemes identified specific frequency bands to be adjusted. (See Table 2 for consonant energy bands.) By making needed changes in specific frequency bands, rather than globally increasing or decreasing all bands, speech perception was improved for those sounds that were not clear without jeopardizing information that was already clear. Moreover, the authors found that improved perception of the most common errors identified often had a positive ripple effect which improved perception of other, less common errors. Careful analysis of phoneme perception errors and specific programming changes targeted to improve perception were found to have an immediate impact on a child's speech perception and production.

The realization that certain perception errors were very common and also highly correctible led the authors to analyze the common errors and the Ling Six Sound Test. This analysis indicated that the 6 Ling phonemes did not include sufficient mid-frequency information (1500Hz to 3000Hz) to determine if the subtle differences in consonants could be perceived accurately. Data clearly showed that assessment of all phonemes provided the most complete picture of perception. However, the authors sought to identify specific phonemes which could be added to the Ling sounds to provide necessary information about the crucial mid-frequency perception if a quick screening was needed. (See Table 3.) The confusion of /m/ and /n/, which per the data and anecdotal parent / clinician report is very common, led to the addition of /n/ which provides additional information about perception from 2000 to 2500Hz. Correction of /m/ /n/ confusion was also found to have a positive ripple effect which improved perception of other mid-frequency consonants. Patient data also indicated the need to include a mid-frequency voiceless consonant in a quick test, so /h/ was added to assess if mid-frequency (1500 to 2000Hz) – not just high frequency (/s/, /sh/) – voiceless consonants were perceived without voicing. Finally, /z/ and /dʒ/ were added. Through testing and analysis, these two consonants were found to be "heavy weight" phonemes. Essentially, /z/ and /dʒ/ contain low frequency voicing (200 to 300Hz) combined with mid and high frequency sibilance, both of which must be perceived accurately. The common error of producing only a voiced sound like /m/ or /oo/ for /z/ and /dʒ/ often indicates an overabundance of low frequency information or insufficient mid or high frequency information. Thus, if all phonemes cannot be assessed because of the child's developmental level, the inclusion of /n/, /h/, /z/ and /dʒ provides significant additional information.

In summary, the compelling evidence that more comprehensive testing than the Ling Six Sound Test was needed to accurately assess and improve perception led to the development of the LMH (Ling-Madell-Hewitt or Low, Mid, High Frequency) Test Battery.

The LMH (Ling-Madell-Hewitt or Low, Mid, High Frequency) Test Battery

The LMH Test Battery is a series of functional listening assessments which increase in difficulty as the child's speech perception and ability to respond grow (Madell and Hewitt, 2021). As with all functional listening assessments, all tests in the battery are presented through audition only with no visual input. The goal is for consistent errors to be noted by parents and clinicians and shared with audiologists to ensure optimal programming and speech perception.

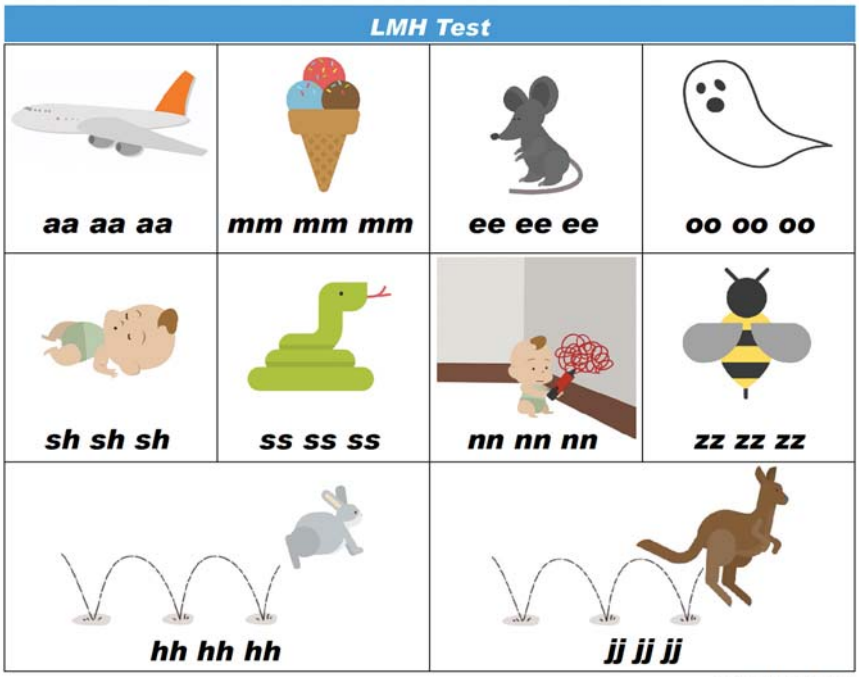

FIGURE 1: The Ling-Madell-Hewitt (LMH) 10 Sound Quick Test

Detection, Identification, and Imitation of the LMH 10 Sound Quick Test

The first test, the LMH 10 sound quick test, is a quick and easy way to check a child's perception across the speech spectrum. (See Figure 1) Madell and Hewitt (2021) added four additional consonants (/z/, /h/, /n /, and / dʒ) to the 6 Ling sounds to provide additional information about mid-frequency perception. Figure 1 shows the Ling-Madell-Hewitt (LMH) 10 sound quick test.

The test is administered by the parent or professional who presents the sounds in random order and with varying intervals of silence between sounds. Each sound is presented three times in quick succession (eg [a a a] or [z z z]), and children indicate that they heard (or detected) the sound. It is important when presenting the sounds to produce each sound with the same duration so that no clues are given (eg Do not make [sh] longer than [h]). It is also important to present the sounds at the level of normal conversation and not louder. For example, in normal conversation [s] is much softer than the vowel [oo]. Care should be taken not to exaggerate the loudness of [s], but rather present each sound at the same loudness in which it would normally be presented in general conversation.

Testing begins with detection. Babies may demonstrate detection by alerting, by starting or stopping sucking, or by localizing. Toddlers may respond by dropping a block into a bucket or building a tower. As children develop their auditory skills, they should quickly move from detection to identification of the 10 sounds by either pointing to the appropriate picture or repeating the sound.

Imitation of All Individual Phonemes

The LMH Test Battery does not end with the LMH 10 quick sound test. English has ~44 phonemes. To truly understand how well a child hears all the phonemes, it is essential to begin testing every phoneme, not only the LMH 10. Evaluating perception of all consonants will enable clinicians to know what children hear and what they do not hear.

Children progressing from the LMH 10 sound quick test to all phonemes can be asked to imitate all phonemes using the same three quick presentations (eg [ba ba ba] or [t t t] or [f f f]). (Note that voiceless consonants are not presented with a vowel.) Practitioners and parents may be concerned about moving to this next step because a child cannot articulate all the phonemes yet. Articulation concerns should not deter professionals from introducing this next step. Errors that children make can provide significant information about their speech perception, even when the articulation is imprecise or inaccurate. For instance, if a child does not yet know how to articulate

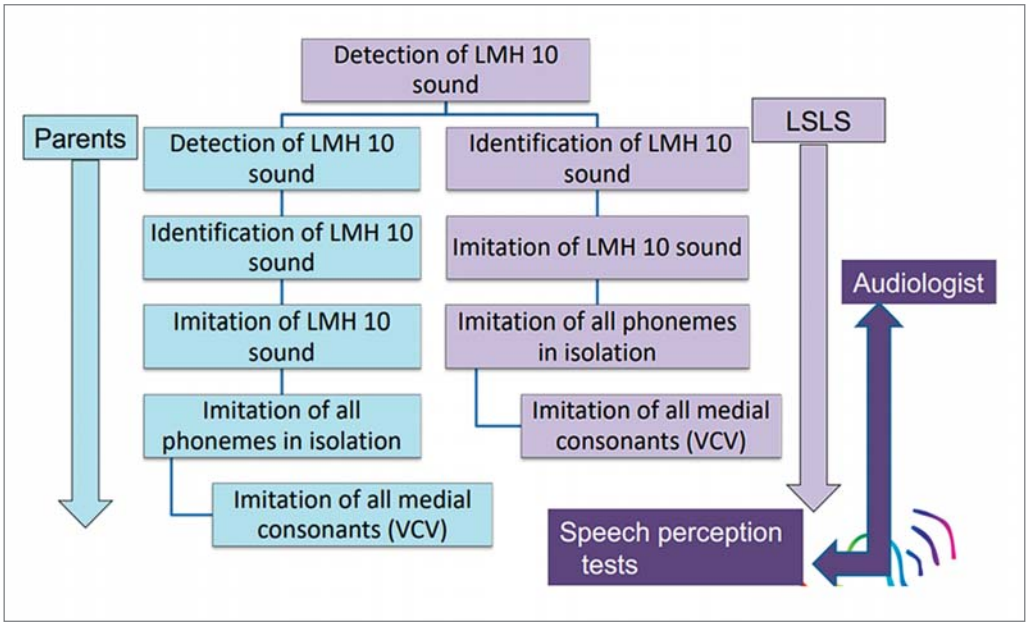

FIGURE 2: Progression of LMH Test Battery from detection of 10 sounds to imitation of all medial consonants and progression from clinician directed to parent directed

[g] or [k] but produces [b b b] for [g g g] and a glotally [uh uh uh] for [k k k], there is confidence that the child is hearing the voicing and frequency band of the [g] and the voiceless stopping of the [k]. The errors are appropriate and point to good perception even though articulation is difficult.

On the other hand, if the same child produces [m m m] for [g g g] and [hm hm hm] for [k k k], the responses suggest that the presence of too much low frequency information may be negatively impacting perception. The authors have found that toddlers and preschoolers using a conditioned play type toy to encourage engagement take approximately 1 to 2 minutes per ear to imitate all phonemes.

Imitation of Medial Consonants

Once children's imitation skills have advanced to the point that they can imitate vowel-consonant-vowel (VCV) combinations, the LMH Test Battery moves to perception of all consonants in this manner (eg [aba], [ata], [afa]) In the authors' experience, children with hearing loss as young as 2 years of age can begin to participate in this level of assessment which provides the most realistic perception information for running speech. The authors have found that, for school age children, this type of testing takes less than 30 seconds per ear.

Progression of testing

Finally, while a child's perception needs to be checked every day, the LMH Test Battery advocates for moving assessment from professionals to parents as the child demonstrates the ability to complete each step. (See Figure 2.) Thus, once a child begins showing detection of the LMH 10 quick sounds, the practitioner should be encouraging the parent to take responsibility for monitoring detection at home each day. The practitioner can then gather that daily detection information from the parents and, at the same time, be working to develop identification of the sounds through the use of the pictures. As the child learns to identify the sounds, the parents should be encouraged to check identification each day while the practitioner now begins encouraging imitation of the 10 sounds and then all sounds. The goal is for all children to able to complete the medial consonant (VCV) level of imitation within their home and clinical settings. Working through the LMH Test Battery as the child's skills grow provides valuable information for the audiologist to optimize technology settings, for the practitioner to plan intervention, and for the parents to understand what their child hears.

Summary

While completing the Ling Six Sound Test provides some information about hearing across the speech frequencies, it does not provide sufficient information to ensure speech perception of all phonemes. Digital hearing aid and cochlear implant technology has progressed to the point that, if appropriately fitted, children with hearing loss should be able to make fine distinctions between phonemes. Utilizing the LMH Test Battery allows clinicians and parents to tailor testing to the child's developmental level, to assess finer distinctions in perception, and to more realistically evaluate perception in running speech. Then by knowing which sounds are consistently inaudible or which are consistently perceived incorrectly, clinicians can work to modify technology settings to improve auditory access and to provide optimal speech perception.

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Apologies

We would like to apologise to **James Fitzgerald** that in the heading of his January article, we made a mistake with his name and called him James Fitzpatrick.

James Fitzgerald is the Professional Lead of the F/HE 16+ (Post-16) Team in Surrey County Council's Physical and Sensory Support Service

To access the article:
https://www.batod.org.uk/wp-content/uploads/2022/03/Access-and-support-for-deaf-students-in-Post-16-v2-2.pdf

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