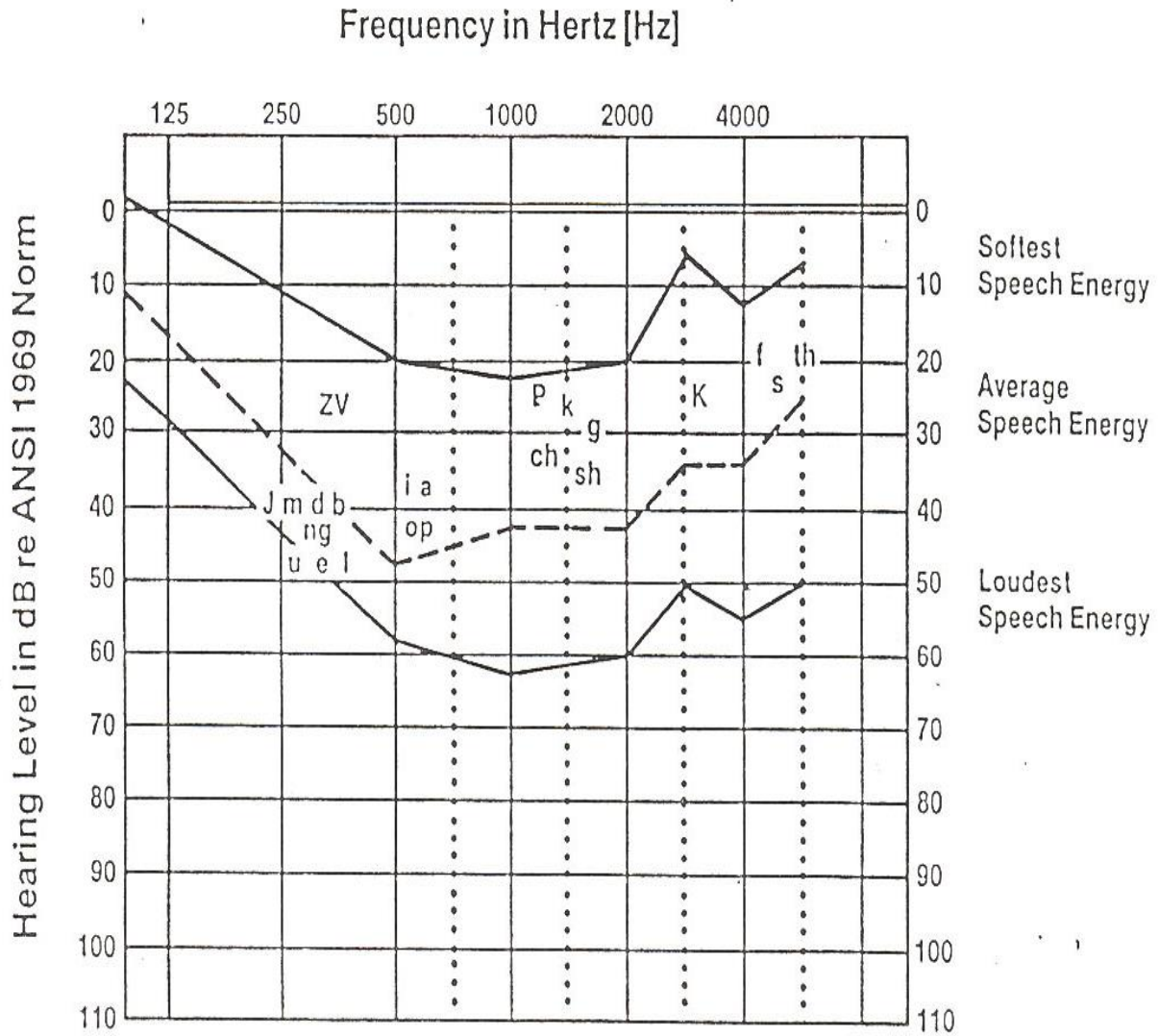


## SPEECH PERCEPTION IN A 3-D WORLD

A line on an audiogram is far from answering the question “How well can this child hear speech?” In this section a variety of ways will be presented to further the teacher/therapist’s understanding of a child’s ability to functionally perceive speech in various listening environments. “Hearing speech” is not the same as hearing all of the sounds of all of the words. Speech sounds occur in a 30 dB range of intensity (‘th’ in thaw vs ‘oo’ in through). The audiogram below represents various speech sounds on the audiogram by their primary frequency and intensity characteristics. The reality is that speech is dynamic and changes from soft speech to loud speech. One of the most relevant questions to try to answer about a student’s speech perception abilities is how accurately he or she can perceive speech when it is quiet (such as at a distance) or when it is loud (such as presented in close proximity). One of the vast limitations of using the ‘sound audiogram’ to interpret a child’s hearing ability for listening and learning is that it under represents the challenges typical of classroom learning where the student must listen to the teacher’s voice from any part of the room and the softer voices of peers in classroom discussions or small group learning.

### Audiogram with Intensity and Frequency of Speech Sounds



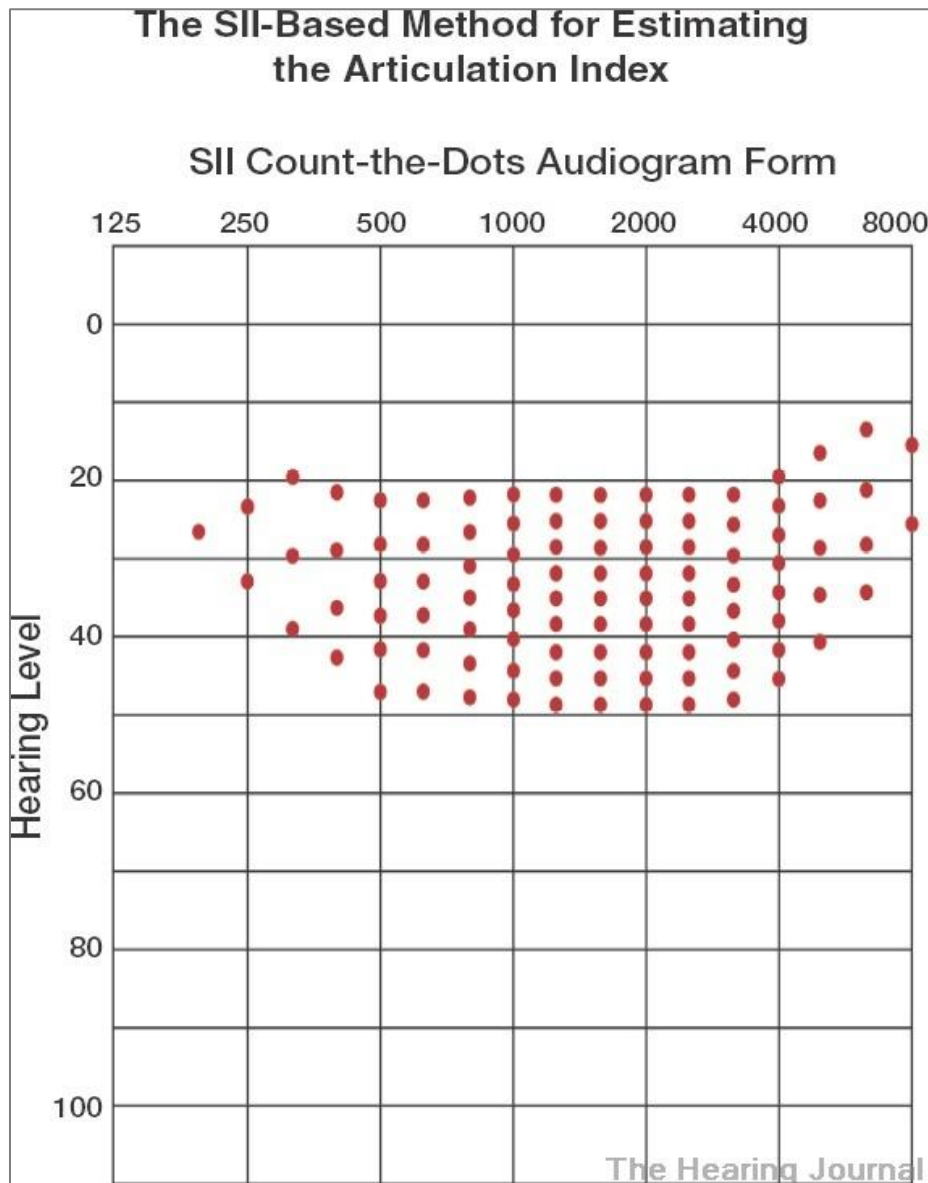
Another limitation of using the ‘sound audiogram’ to describe a child’s ability to listen to speech is that each speech sound is comprised of elements across various frequency bands. Another term for frequency bands is formants. A formant is the characteristic frequency that occurs when the shape of a tube (throat) and cavity (mouth/lips) change. As the speech sounds of English are formed, each one will have a characteristic ‘footprint’ of frequency bands. As you consider the frequency ranges of each sound, think about how a high frequency hearing loss that prevents speech perception above 2000 Hz will confuse a child’s ability to differentiate between certain vowel and consonant sounds. This ability to perceive speech sounds across all four formants is what allows a child to perceive speech completely. Thus, if an amplification device is not fit well or not functioning appropriately and preventing a child from perceiving the whole frequency range it will become apparent by his or her inability to discriminate between similar vowel and/or consonant sounds. As a child achieves on the hierarchy of auditory skills, his or her ability to discriminate between vowels and especially consonant sounds will relate directly to optimal speech perception via consistent use of hearing aid(s) and/or cochlear implant(s).

### Formant (frequency band) characteristics of vowel sounds (Hz).

Vowels	Formant 1	Formant 2			
bo <u>o</u> ed	200-500	650-1100			
g <u>oo</u> d	250-550	850-1250			
pu <u>t</u>	450-700	750-1200			
pa <u>w</u> ed	425-675	725-1200			
br <u>a</u>	525-775	825-1275			
bo <u>o</u> x	650-1000	1200-1600			
bu <u>d</u>	600-950	1175-1600			
sch <u>wa</u>	400-650	1250-1750			
bi <u>r</u> d	350-600	1325-1900			
ba <u>d</u>	600-950	1750-2300			
be <u>d</u>	450-700	2000-2500			
bi <u>d</u>	250-525	2250-2850			
be <u>a</u> d	150-450	2300-2900			
Consonant	Formant 1	Formant 2	Formant 3	Formant 4	dB HL
r (err)	600-800	1000-1500	1800-2400		46
l (let)	250-450		2000-3000		43
sh (shot)			1500-2000	4500-5500	41
ng (wing)	250-450	1000-1500	2000-3000		41
ch (chat)			1500-2000	4000-5000	38
n (no)	250-350	1000-1500	2000-3000		37
m (me)	250-350	1000-1500	2500-3500		35
th (that)	250-350			4500-6000	34
t (tap)			2500-3500		34
h (hat)			1500-2000		32
k (kit)			2000-2500		34
j (jot)	200-300		2000-3000		36
f (for)				4000-5000	34
g (get)	200-300		1500-2500		33
s (sit)				5000-6000	32
z (zip)	200-300			4000-5000	31
v (vat)	200-300			3500-4500	31
p (pat)			1500-2000		30
d (dot)	300-400		2500-3000		29
b (bat)	300-400		2000-2500		29

th (thin)				about 6000	28
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Another way to represent a child's ability to perceive speech is to consider his or her ability to perceive speech energy, or the acoustic energy of speech sounds. This method takes the relative acoustic energy at each of the frequency bands and breaks it down into dots. The more dots the more speech energy that the child will perceive. You will notice that there is a much heavier distribution of dots between 1000 and 4000 Hz as this is the range that is most critical for discrimination of speech. That said, 11% of relative speech energy occurs above 4000 Hz, a frequency range most hearing instruments were not able to amplify until recent years. The Count the Dots Audiogram represents speech produced at an average loudness of 45 dB HL (conversational speech). In a classroom setting the teacher's voice is often at 50 – 60 dB HL. Students speaking quietly or from across a classroom would have quiet speech energy at about 35 dB HL. Again, just considering speech energy at a single loudness will under represent the listening challenges faced by children in a classroom setting. The exception to this would be when a student uses a personal FM system to hear the teacher at a consistent loudness regardless of her vocal loudness or direction. An FM system will not boost the loudness of classroom peers unless the teacher passes the FM microphone transmitter every time another student contributes to the class.



Killion, Mead C.; Mueller, H. Gustav. *The Hearing Journal*. 63(1):10,12-14,16-17, January 2010. Included with permission.

The percent of speech energy (audibility) received does NOT equal the percent of word understanding. How a person uses audible speech energy depends upon their knowledge of what is being talked about, the complexity of the information, and their ability to use context and communication repair clues to mentally fill in inaudible portions of speech so that it can be interpreted meaningfully. An adult with 50% audibility may be able to identify 70% of single words and 95% of sentences. Although the count-the-dot method of interpreting a child's speech perception is very convenient and based on research evidence, its utility is limited. Obtaining a speech audibility percentage is valuable only in the context of how well the student is able to use audibility in combination with linguistic knowledge for actual perception of speech. Even a speech perception measure is limited as it is well known that some children who are hard of hearing or deaf can repeat words but are not able to use them in context.

To better understand the meaning of speech audibility, consider the analogy of trying to recognize the picture in a picture puzzle with only a limited number of pieces. How easy it is to recognize the subject of the puzzle depends on what pieces are missing and the complexity of the picture. So it is valuable to consider the picture puzzle as an analogy to speech audibility. An analogy for perceiving speech would be more similar to a puzzle that was made up of text that had pieces missing. The challenge for the student includes understanding the word puzzle for well known stories and also for information with vocabulary that has never before been encountered. Unlike a picture puzzle, audibility and speech perception will be further compromised by the presence of varying background noise and classroom reverberation levels of 1.0 seconds or greater, although understanding may be enhanced by visual cues.



Representation of 25% of puzzle pieces missing.

Representation of 40% of puzzle pieces missing.

To estimate a child's speech intelligibility for sentences and/or words under different listening conditions a Functional Listening Evaluation<sup>5</sup> or a listening in noise assessment should be performed in a clinical setting at 0 S/N, +5 S/N, +10 S/N at 35 dB HL and 50 dB HL.

The following audiogram has decreased speech energy for soft and loud speech overlaid. In addition to speech energy in quiet, audibility of speech in noise for soft and loud speech for adults has been included.

Find analogies for improving understanding of audibility (puzzle pieces above), listening in reverberation and in background noise at [Visual Analogies for speech perception challenges when listening in a classroom.](#)

## SPEECH AUDIBILITY AUDIOGRAM FOR CLASSROOM LISTENING

Loudness in dB HL	250	500	1000	2000	4000	8000 Hz
	<b>Soft speech (35 dB HL)</b>			<b>Teacher voice (50 dB HL)</b>		
0	Typical hearing children: 93-98% word recognition in quiet 86-94% at 35 dB HL in 0 S/N noise <sup>1</sup> .			Typical hearing children: 92-100% word recognition at 50 dB HL in quiet, 90-97% in +5 S/N, and 89-96% in 0 S/N noise <sup>1</sup> .		
10	95% audibility of speech energy perceived with hearing levels between 0 – 10 dB HL <b>64% at +10 S/N, 34% at 0 S/N<sup>6</sup></b>			0-20 dB HL should perceive 98% of speech sounds at a comfortable level <b>in a quiet classroom and acceptable reverberation levels</b> (35 dBA or less background noise in an unoccupied classroom & reverberation no greater than 0.9 sec <sup>4</sup> ) <b>84% at +10 S/N, 48% at 0 S/N</b>		
15	75% audibility of speech energy perceived with hearing levels between 10 – 15 dB HL <b>44% at +10 S/N, 24% at 0 S/N</b>					
20	60% audibility of speech energy perceived with hearing levels between 15 – 20 dB HL <b>29% at +10 S/N, 9% at 0 S/N</b>					
25	40% audibility of speech energy perceived with hearing levels between 20 – 25 dB HL <b>9% at +10 S/N, 0% at 0 S/N</b>			95% audibility of speech energy perceived with hearing levels between 20 – 25 dB HL <b>81% at +10 S/N, 55% at 0 S/N</b>		
30	25% audibility of speech energy perceived with hearing levels between 25 – 30 dB HL <b>0% in any setting that is not quiet</b>			81% audibility of speech energy perceived with hearing levels between 25-30 dB HL <b>67% at +10 S/N, 41% at 0 S/N</b>		
35	15% audibility of speech energy perceived with hearing levels between 30 – 35 dB HL <b>0% in any setting that is not quiet</b>			60% audibility of speech energy perceived with hearing levels between 30-35 dB HL <b>46% at +10 S/N, 20% at 0 S/N</b>		
40	10% audibility of speech energy perceived with hearing levels between 35 – 40 dB HL <b>0% in any setting that is not quiet</b>			45% audibility of speech energy perceived with hearing levels between 35 – 40 dB HL <b>31% at +10 S/N, 5% at 0 S/N</b>		
45					30% audibility of speech energy perceived with hearing levels between 40 - 45dB HL <b>16% at +10 S/N, 0% at 0 S/N</b>	

*S/N means the loudness of the speaker's voice (i.e. teacher) over the background noise. 0 S/N means the noise and voice are the same loudness. +10 means that there is noise but the teacher's voice is 10 dB louder. Use of FM is necessary to negate the affects of background noise and to provide optimal access to verbal instruction when used in large and small group listening.*

Plot an individual's audiogram above (aided or unaided hearing) for a description of listening challenges in perceiving soft and loud speech. Audibility information<sup>2</sup> does not take into account sloping hearing losses that are more than 10 dB greater in the high frequencies than the low frequencies. Audibility should not be interpreted as speech intelligibility. How a person uses audible speech energy depends upon their knowledge of what is being talked about, the complexity of the information, and their ability to use context and communication repair clues to mentally fill in inaudible portions of speech so that it can be interpreted meaningfully. A person with 50% audibility may be able to identify 70% of single words and 95% of sentences<sup>3</sup>. Audibility will be further compromised by the presence of varying background noise and classroom reverberation levels of 1.0 seconds or greater<sup>4</sup> which can be negated by the use of FM during large group instruction. Understanding may be enhanced by visual cues. To estimate a child's speech intelligibility for sentences and/or words under different listening conditions a Functional Listening Evaluation<sup>5</sup> or a listening in noise assessment should be performed in a clinical setting at 0 S/N, +5 S/N, +10 S/N at 35 dB HL and 50 dB HL.

1. Bodkin, K, Madell, J., & Rosenfeld, R. (1999). Word recognition in quiet and noise for normally developing children, AAA Convention, Miami, Poster Session.
2. Killion, M. & Mueller, G. (2010). [Twenty years later a new count the dots method](#). *The Hearing Journal*, 63(1), 10, 12-14, 16-17.
3. Miller GA, Heise GA, Lichten W (1951). The intelligibility of speech as a function of the context of the test materials. *J Exp Psychol* 41(5):329-335.
4. Yang, W., & Bradley, J. S. (2009). Effects of room acoustics on the intelligibility of speech in classrooms for young children. *J. Acous. Soc. Am.*, 125(2), 922-933.
5. Revised 2004 by Johnson. Based on [Functional Listening Evaluation](#) by C.D. Johnson & P. Von Almen, 1993.
6. Nelson, P. Anderson, E., Nie, Y., Katare, B. (2010). Effect of reduced audibility on masking release for normal- and hard-of-hearing listeners, *JASA* 127, 1903.

Again, audibility is not the same as speech understanding. It does however represent the listening challenge of the child. The student's speech understanding for soft and loud speech should be identified via a Functional Listening Evaluation. The quietest sounds are typically those that are most important to speech discrimination and noise tends to mask the most critical elements of speech. The difference between audibility and understanding can be attributed to the student's level of language complexity, ability to attend (listen with focused effort) in challenging conditions, and skill at using context to build understanding. The greater the gap between audibility and speech understanding the greater the support the student will require to prevent or minimize an increasing gap in academic performance over time.

### How do children with typical hearing perform in background noise?

Bodkin, Madell, and Rosenfeld (1999) studied word recognition in quiet and noise for 126 typically hearing and developing children ages 3-17 years to obtain age-appropriate normative data in a variety of listening situations. They conducted their testing at two different loudness levels, normal/loud conversational speech (50 dB HL) and soft or quiet voice loudness (35 dB HL). Age appropriate open set single word lists were used and the competing noise was 4-talker speech babble. Based on results of this study, word recognition scores did not decrease significantly as the listening task became more difficult, regardless of age. The results of this study for the different ages, loudness levels and S/N are as follow. **Thus, the typically developing child can perform at about 90% or better even in high levels of background noise when listening to soft speech.**

Condition	CA	List	Male				Female			
			N	WR%	SD	95% CI	N	WR%	SD	95% CI
Quiet 50 dB	3-5	NU-C	14	98	3.7	96-100	12	98	3.2	96-100
Quiet 50 dB	6-8	PBK	13	98	3.1	97-100	12	98	3.2	96-100
Quiet 50 dB	9+	W-22	13	99	1.9	98-100	6	96	5.1	92-100
Quiet 35 dB	3-5	NU-C	19	95	5.2	92-97	13	96	4.8	93-98
Quiet 35 dB	6-8	PBK	23	97	3.7	95-98	24	98	3.1	97-99
Quiet 35 dB	9+	W-22	17	98	2.8	97-100	9	96	4.2	93-98
50 @ +5 SNR	3-5	NU-C	28	93	4.6	91-95	16	94	4.1	92-96
50 @ +5 SNR	6-8	PBK	13	94	4.5	92-96	25	95	5.1	93-97
50 @ +5 SNR	9+	W-22	17	97	4.1	95-99	7	93	3.8	90-96
50 @ 0 SNR	3-5	NU-C	23	91	6.9	88-94	17	92	6.5	89-95
50 @ 0 SNR	6-8	PBK	18	91	5.4	89-93	28	93	6.0	90-95
50 @ 0 SNR	9+	W-22	19	95	4.7	93-97	11	93	4.8	91-96
35 @ 0 SNR	3-5	NU-C	23	90	6.1	87-93	16	92	6.0	89-94
35 @ 0 SNR	6-8	PBK	28	91	6.2	88-93	28	90	6.1	87-92
35 @ 0 SNR	9+	W-22	18	91	6.2	88-94	11	90	7.0	86-94

CI = confidence interval Presented at the 1999 American Academy of Audiology conference, Miami FL. Poster session.  
WR = Word recognition as expressed in percent correct

Download more information on resources to assist in understanding speech perception at <https://successforkidswithhearingloss.com/impact-on-listening-and-learning/speech-perception>

## Interpretation of the Functional Listening Evaluation

Based on the student's amplified listening ability, the audibility information from the Speech Audibility Audiogram for Classroom Listening can be combined with the Functional Listening Evaluation results to form a powerful statement about his or her ability to perceive speech and understand in the classroom. It is suggested that these findings be stated such as the following:

*This student has an average hearing level of 25 dB when wearing hearing aids. This report will review her audibility of speech and her speech understanding under different conditions typical of classroom listening. Audibility can be compared to a 100-piece puzzle made of a picture that is missing pieces. Speech understanding can be compared to a 100-piece puzzle made of a page of text. This student perceives approximately 40% of speech energy for soft speech and 90% for loud speech (teacher voice) when the listening situation is quiet. Due to a variety of factors, noise is often present in the classroom. When noise is introduced, it is predicted that this student's ability to perceive audible speech energy decreases to less than 10% for soft speech and as low as 55% for loud speech in noise. A Functional Listening Evaluation determines a student's ability to understand speech at close/far, quiet/noisy, and watching/not watching conditions. Typically developing students with normal hearing can understand about 90% or more of speech even if the classroom listening situation is very noisy. Functional Listening Evaluation results for this student indicate that her word recognition ability in quiet at 3 feet from the speaker (loud speech) is 95% and decreases to 80% when she is 12 feet from the speaker (soft speech) when watching the speaker and dropped to 85% at 3 feet and 70% at 12 feet when not watching the speaker. When listening to speech in background noise at a level typical of the classroom (+5 dB S/N) her scores at 3 feet and 12 feet when watching were 75% and 60% respectively and only 65% and 45% when not watching. See tables below.*

AUDIBILITY	Quiet listening	Noisy listening	<i>Audibility can be compared to a 100-piece puzzle made of a picture that is missing pieces. Speech understanding can be compared to a 100-piece puzzle made of a page of text.</i>
Quiet speech (i.e., far)	40%	10%	
Loud/teacher speech (i.e., near)	90%	55%	

SPEECH UNDERSTANDING	close/quiet	close/noise	distant/quiet	distant/noise
Auditory and visual	95%	75%	80%	60%
Auditory only	85%	65%	70%	45%

*In order for this student to access verbal instruction similar to her peers (90%) it is necessary for her to utilize hearing aids daily and a personal FM system for all large and small group listening. She misses fragments of all speech perceived in the classroom and uses her knowledge of language context to 'fill in the blanks'. Students who must put forth more effort to listen and to fill in the blanks will have fewer cognitive resources and less energy to understand instructional content and integrate it into their knowledge. It is important for this student to learn to utilize communication repair strategies in classroom and social situations and to advocate for her listening needs in distant and noisy conditions. It is also critical for instructional staff and parents to recognize that she needs to be given extra processing time and/or more repetition of information for her to be able to learn at the same pace as classroom peers with similar cognitive potential. Students with hearing loss frequently develop increasing gaps in language learning and academic performance due to this resulting slower pace of learning. Thus, due to this student's greater listening and probable learning pace challenges it is critical for her classroom function and academic achievement to be monitored closely, at least quarterly, throughout the school year.*