SPAU332
Hearing Aids I

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Basics of compression

Aim of today's lecture: Understand the basics of compression and the impact on hearing aid provision and listening comfort.

Key learning outcomes

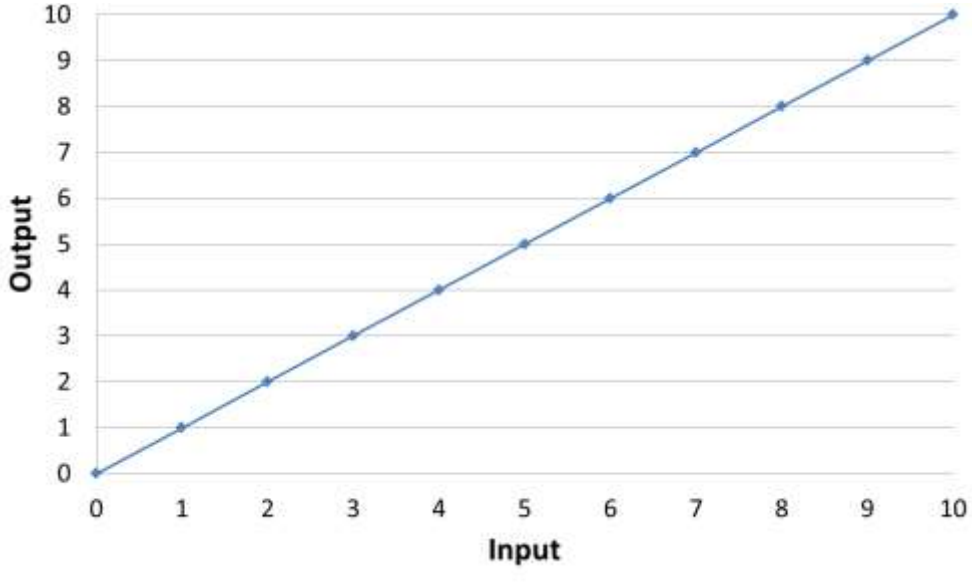
1. Understand limitations of linear amplification and peak clipping.
2. Differentiate between input and output compression circuits.
3. Define compression ratio and knee point.
4. Define attack time and release time.
5. Differentiate between output limiting compression and wide dynamic range compression.

Cochlear nonlinearity

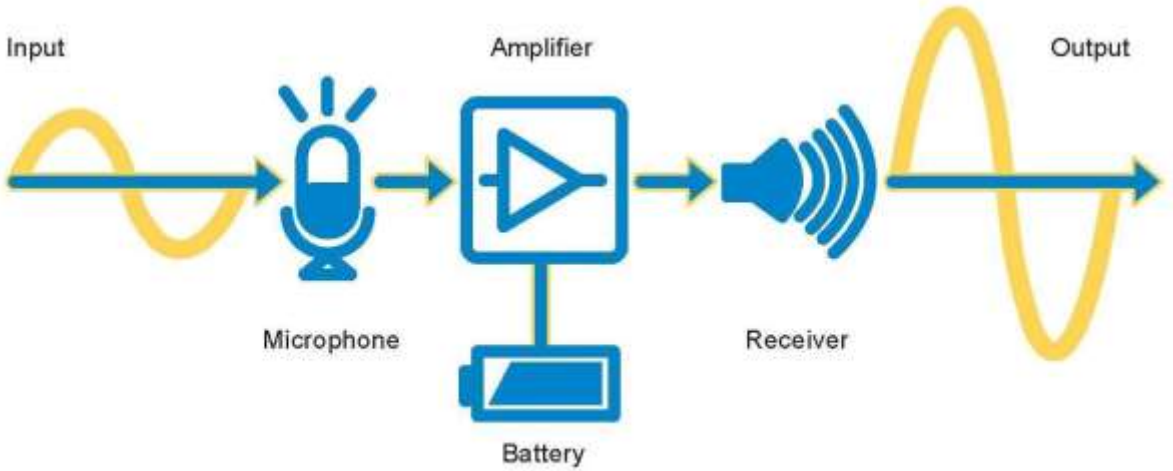
- Basilar membrane response is nonlinear
- We want to preserve this nonlinearity when fitting hearing aids

Cochlear nonlinearity

- Linear response
- Change in input results in the same change in output



Hearing aid components



Sensorineural hearing loss

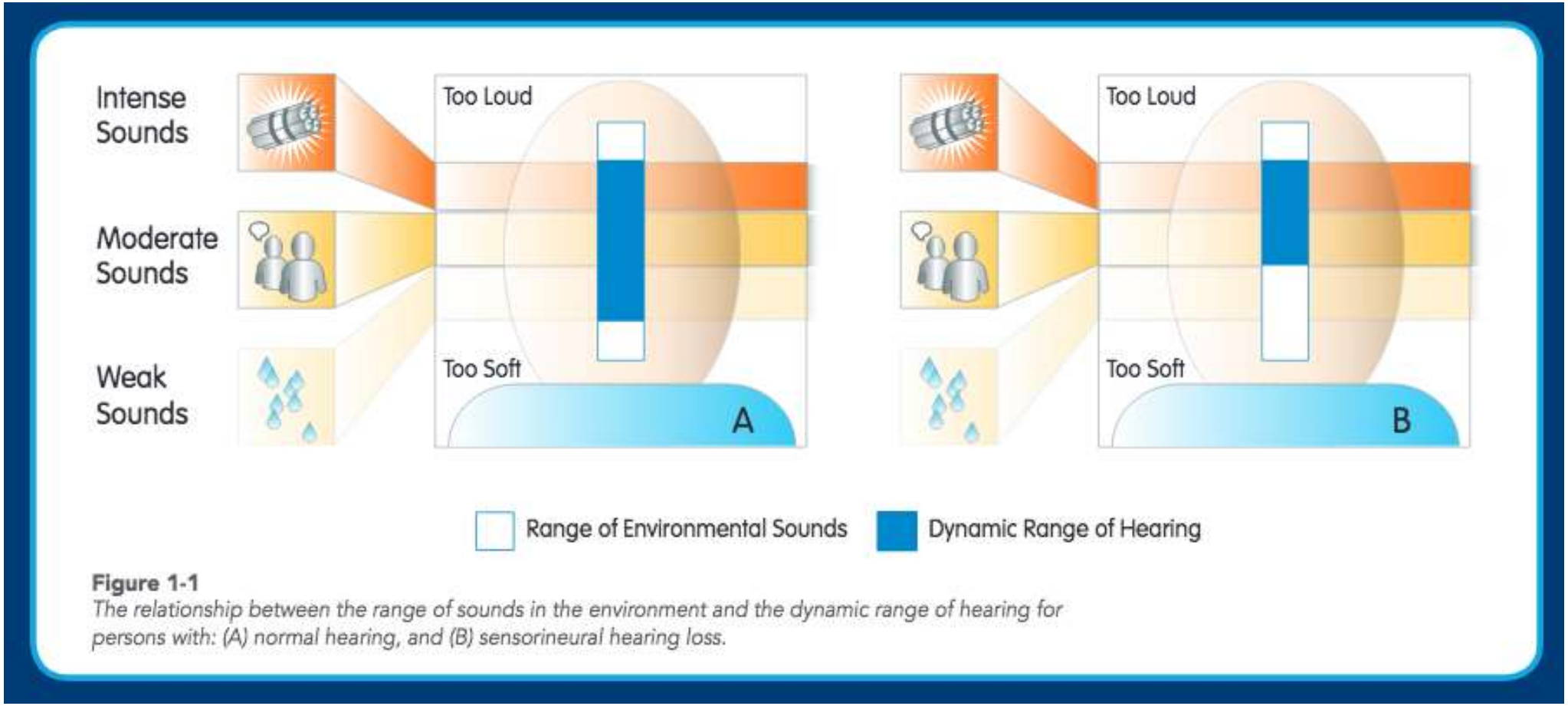


Figure 1-1
The relationship between the range of sounds in the environment and the dynamic range of hearing for persons with: (A) normal hearing, and (B) sensorineural hearing loss.

Input-output function

- Graphical representation of the output of a hearing aid at various input levels

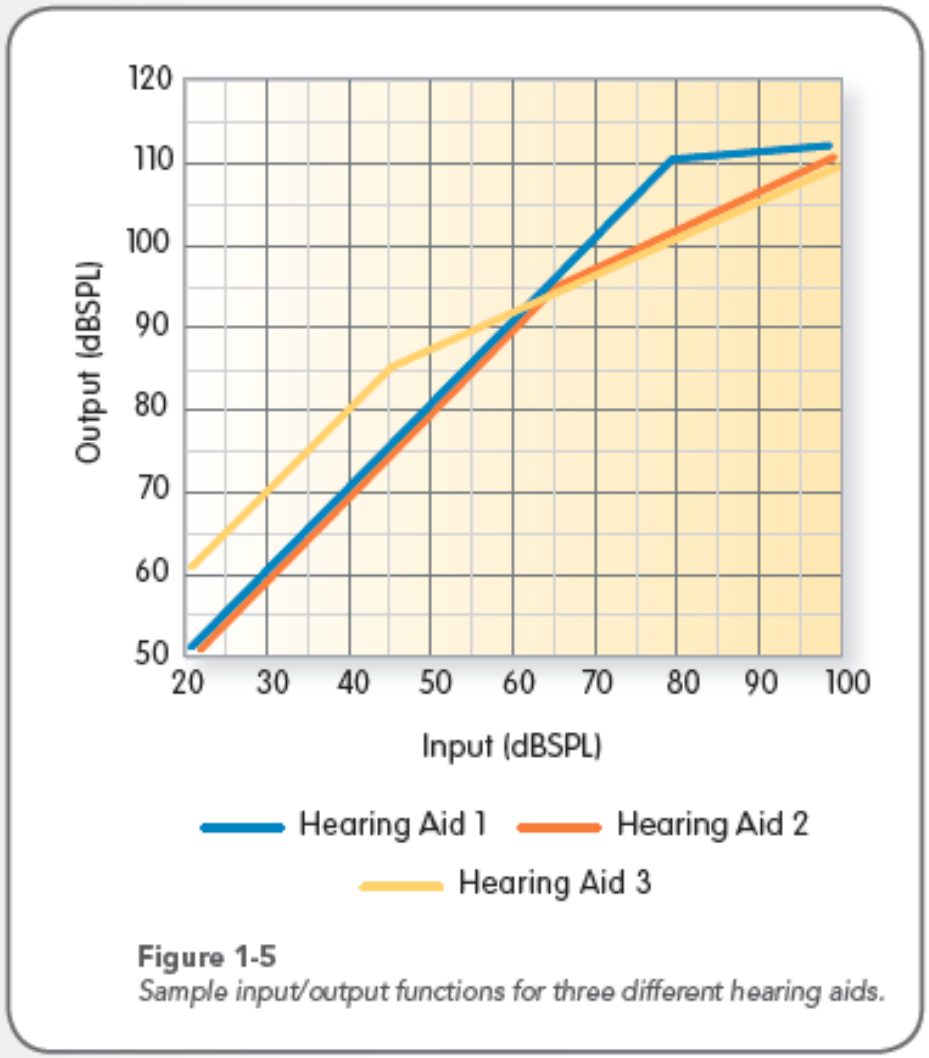
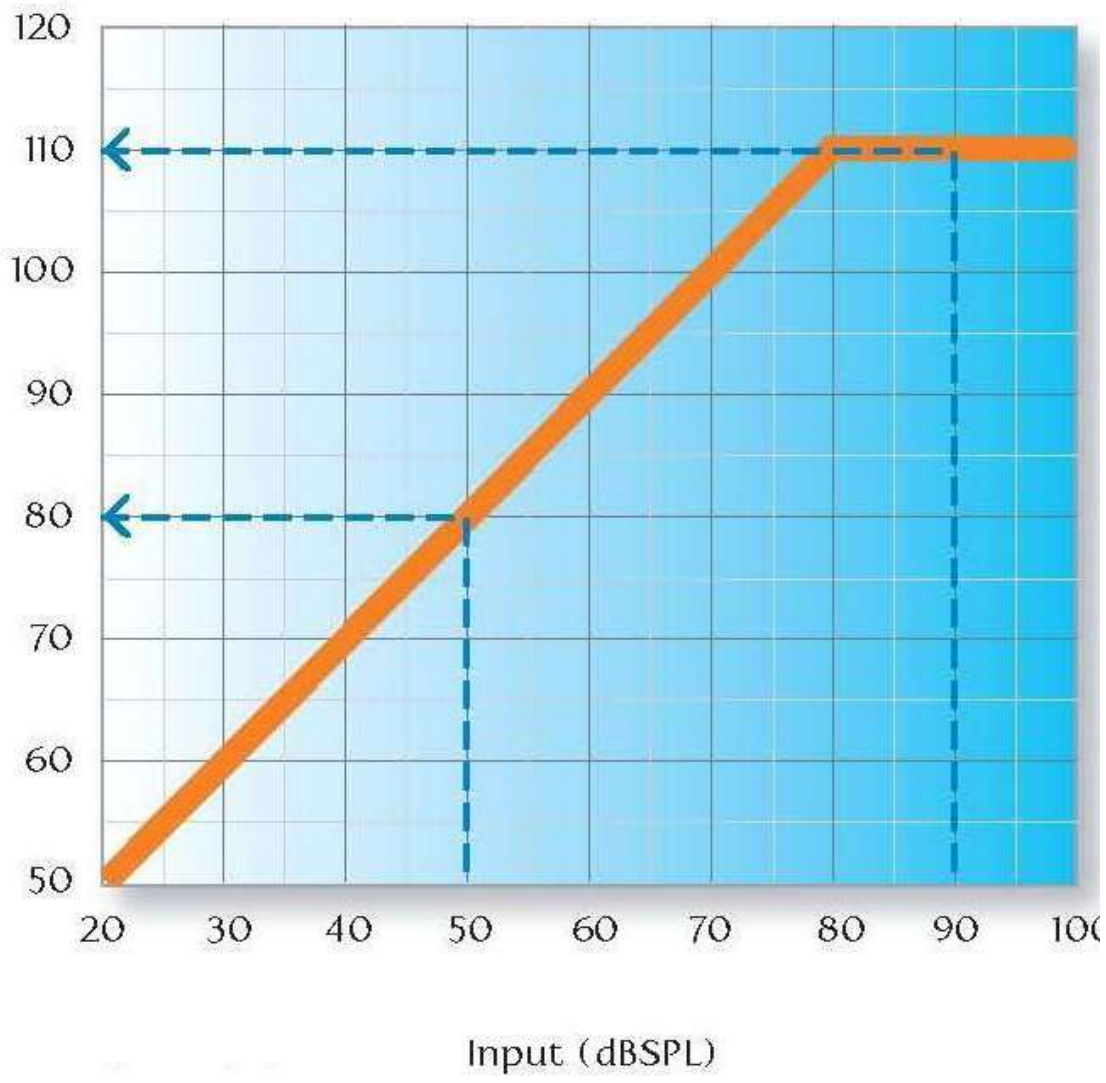


Figure 1-5
Sample input/output functions for three different hearing aids.

Gain

- Amount of amplification applied to the input signal
- Difference between output SPL and input SPL
- Gain = Output – Input



Input-gain function

- Graphical representation of the gain of a hearing aid at various input levels
- Output = Input + Gain

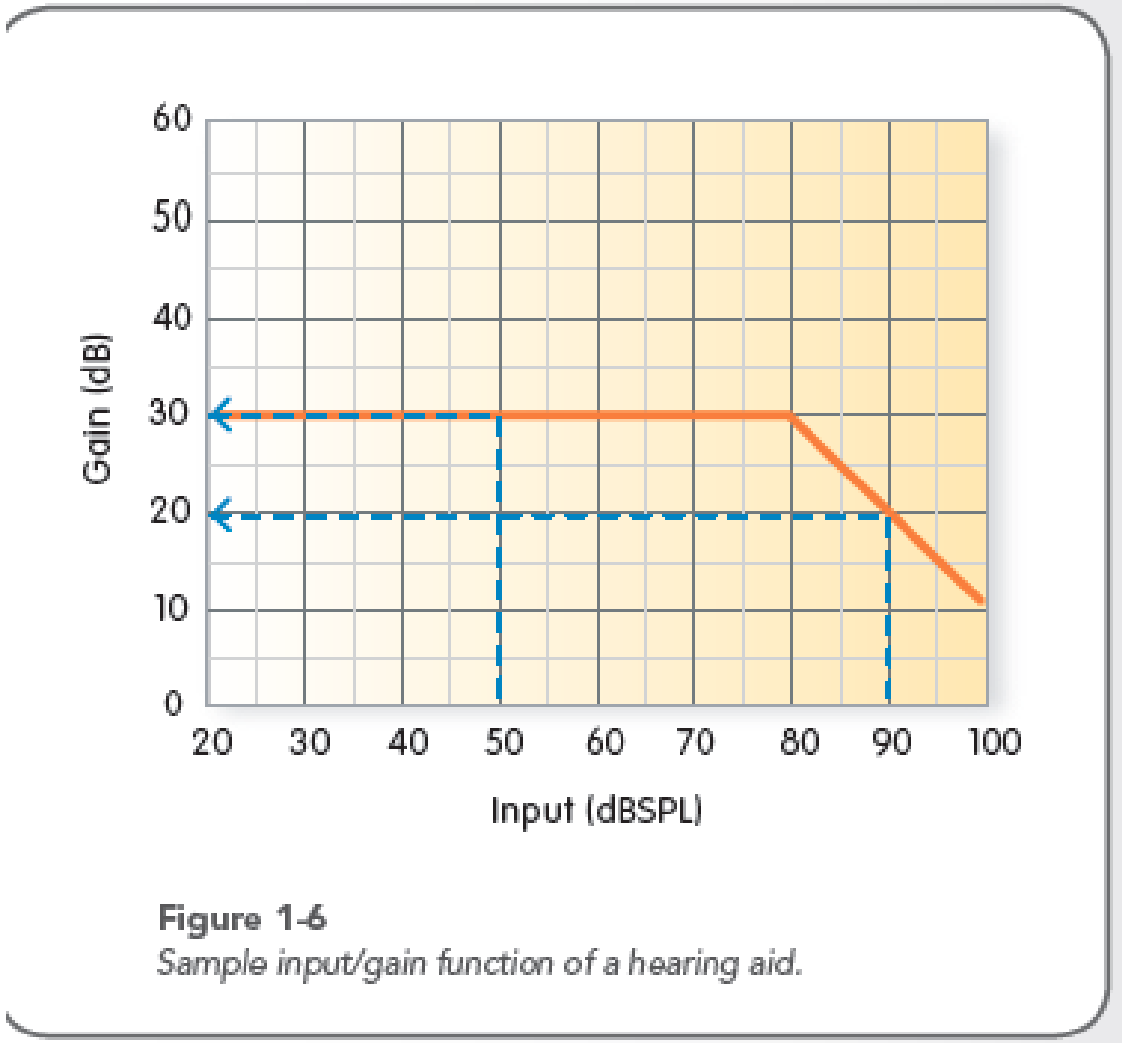


Figure 1-6
Sample input/gain function of a hearing aid.

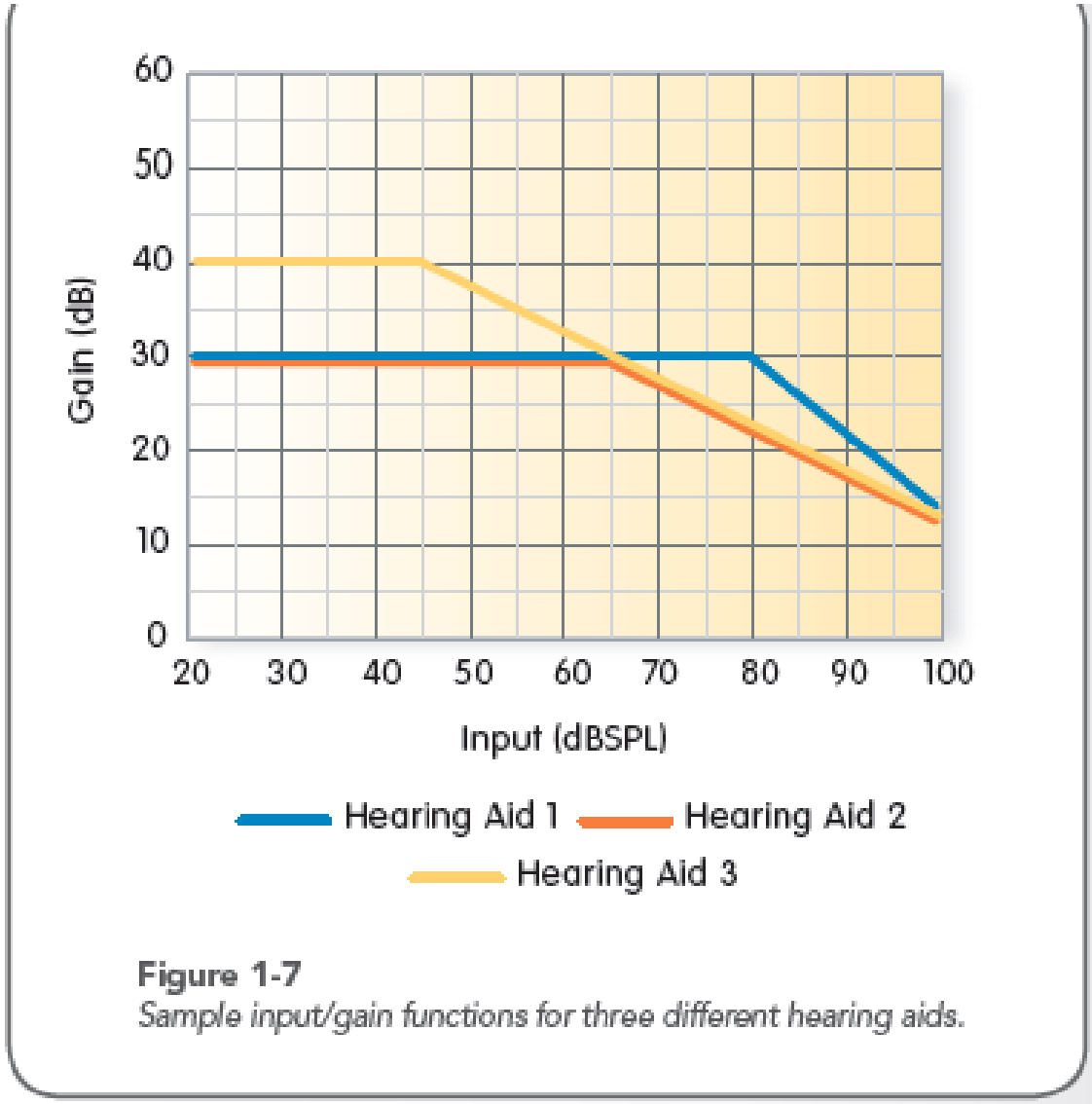


Figure 1-7
Sample input/gain functions for three different hearing aids.

Input-gain function

Frequency response curve

- Graphical representation of hearing aid output as function of frequency
- Input level and overall gain are fixed when measuring frequency response curve

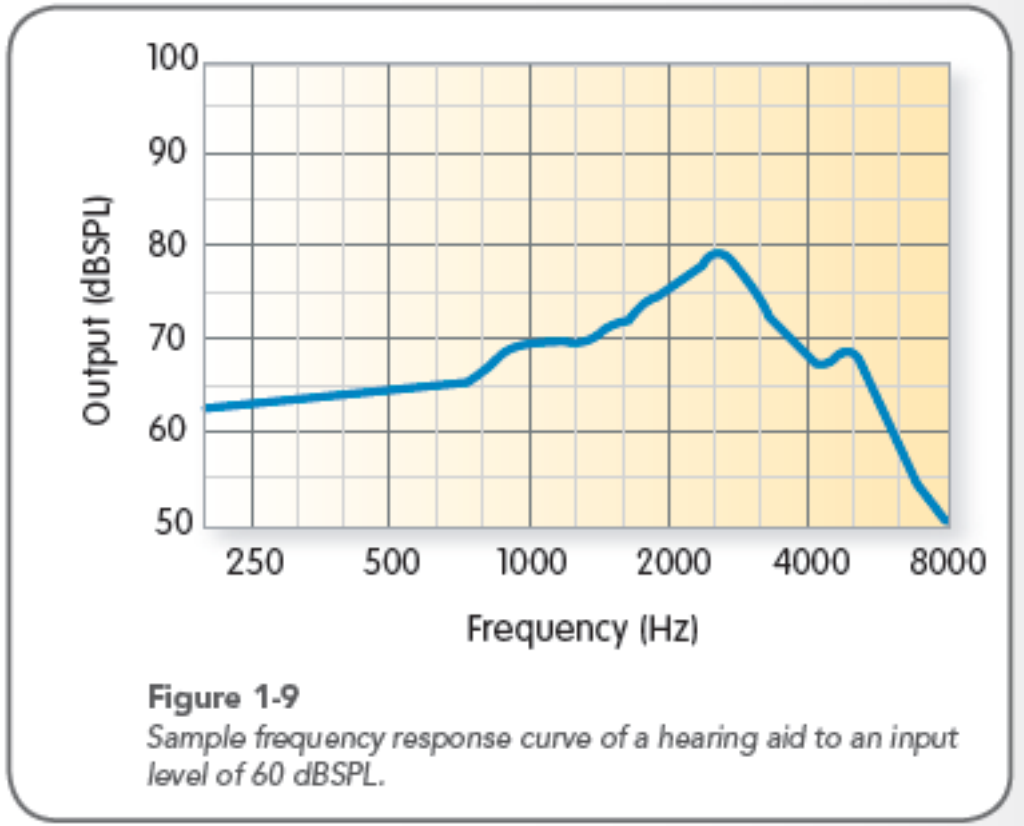


Figure 1-9
Sample frequency response curve of a hearing aid to an input level of 60 dBSPL.

Frequency response curve

- Output varies across frequencies
- Shape of curve may change as input level increases

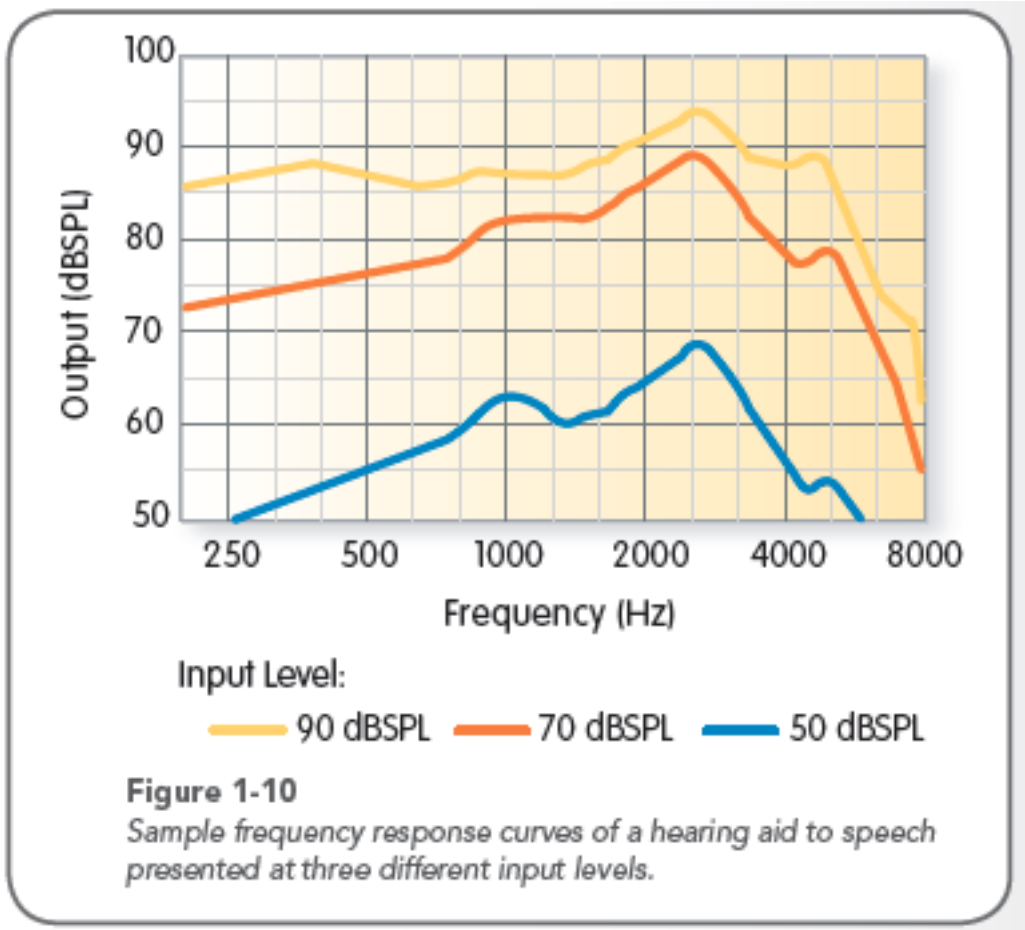


Figure 1-10
Sample frequency response curves of a hearing aid to speech presented at three different input levels.

Frequency gain curve

- Gain of hearing aid as function of frequency

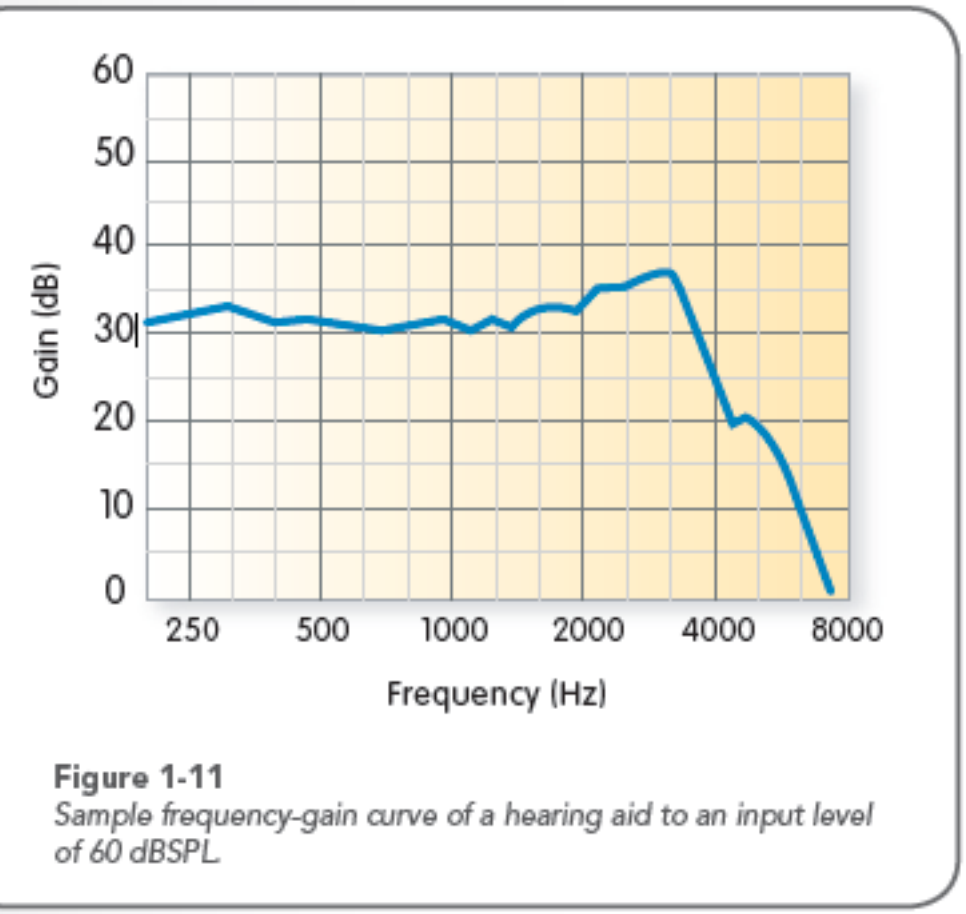
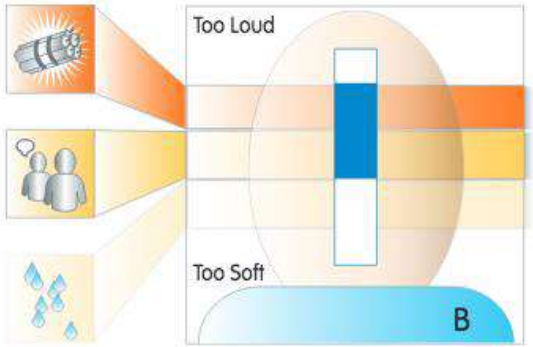
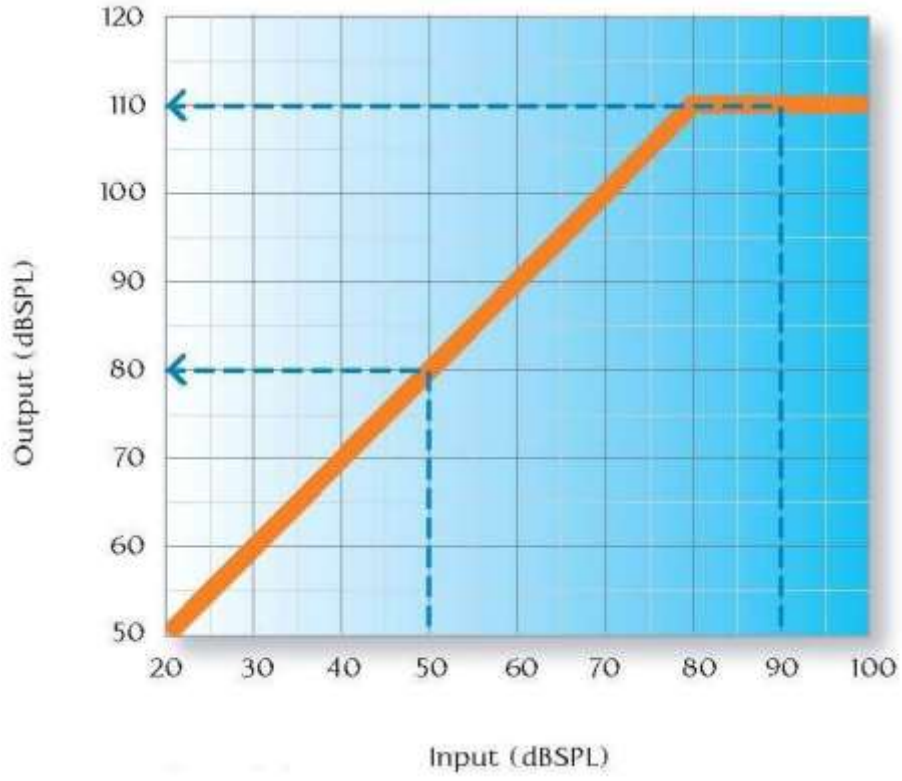


Figure 1-11
Sample frequency-gain curve of a hearing aid to an input level of 60 dBSPL.

Linear hearing aids

- Amplify all levels of a frequency by the same amount
- Problem – louder sounds become uncomfortably loud
- Solution – use some type of limiting to prevent thi





Terminology

Maximum output

- Highest possible signal that a hearing aid is capable of delivering
- Determined by the characteristics of the microphone, amplifier and receiver

Saturation

- When input level and gain exceed maximum output

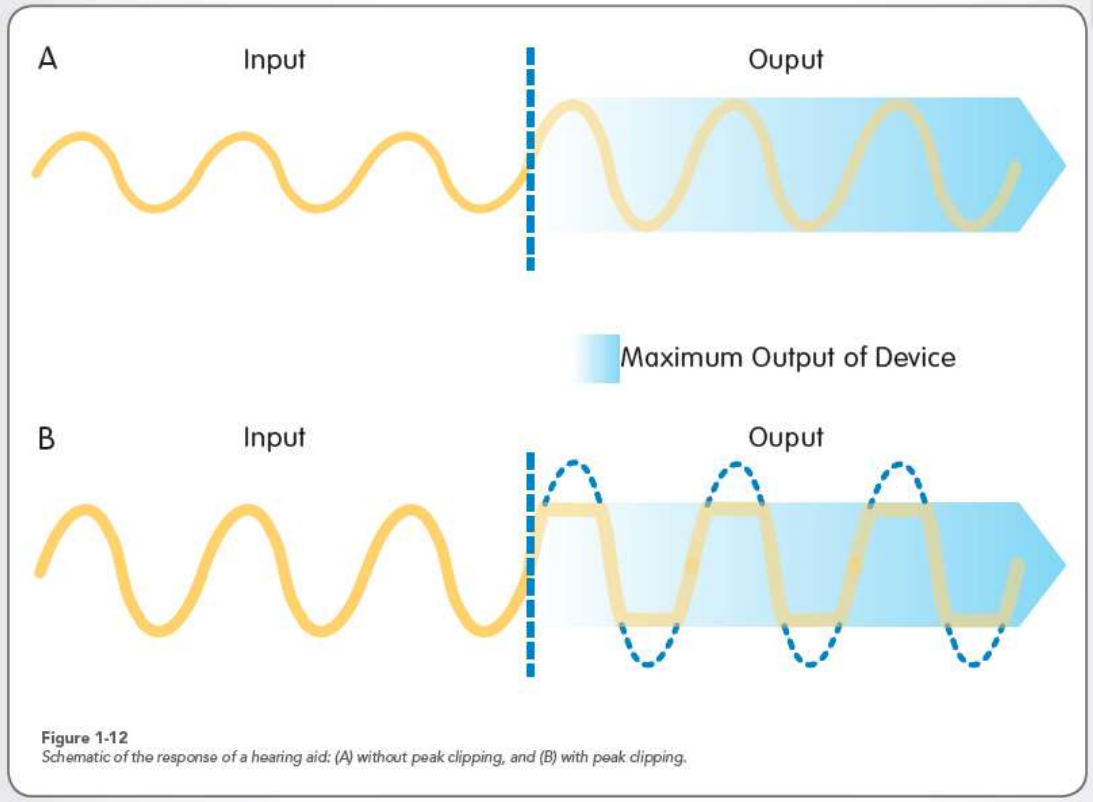


Figure 1-12
Schematic of the response of a hearing aid: (A) without peak clipping, and (B) with peak clipping.

Peak clipping

Distortion

- Presence of frequency components in the output of a hearing aid that were not present in the input signal
  - Harmonic distortion: output contains frequency components that are integer multiples of the input signal frequency
  - Intermodulation: generated by the interaction of at least two signals of different frequencies

Compression

- Non-linear amplification
  - A compressor is an amplifier which turns down its gain as the input to the amplifier increases
  - Squeezes range of environmental sounds to fit within reduced dynamic range of person with SNHL
  - Weak sounds: audible
  - Moderate sounds: comfortable
  - Intense sounds: loud without being uncomfortable

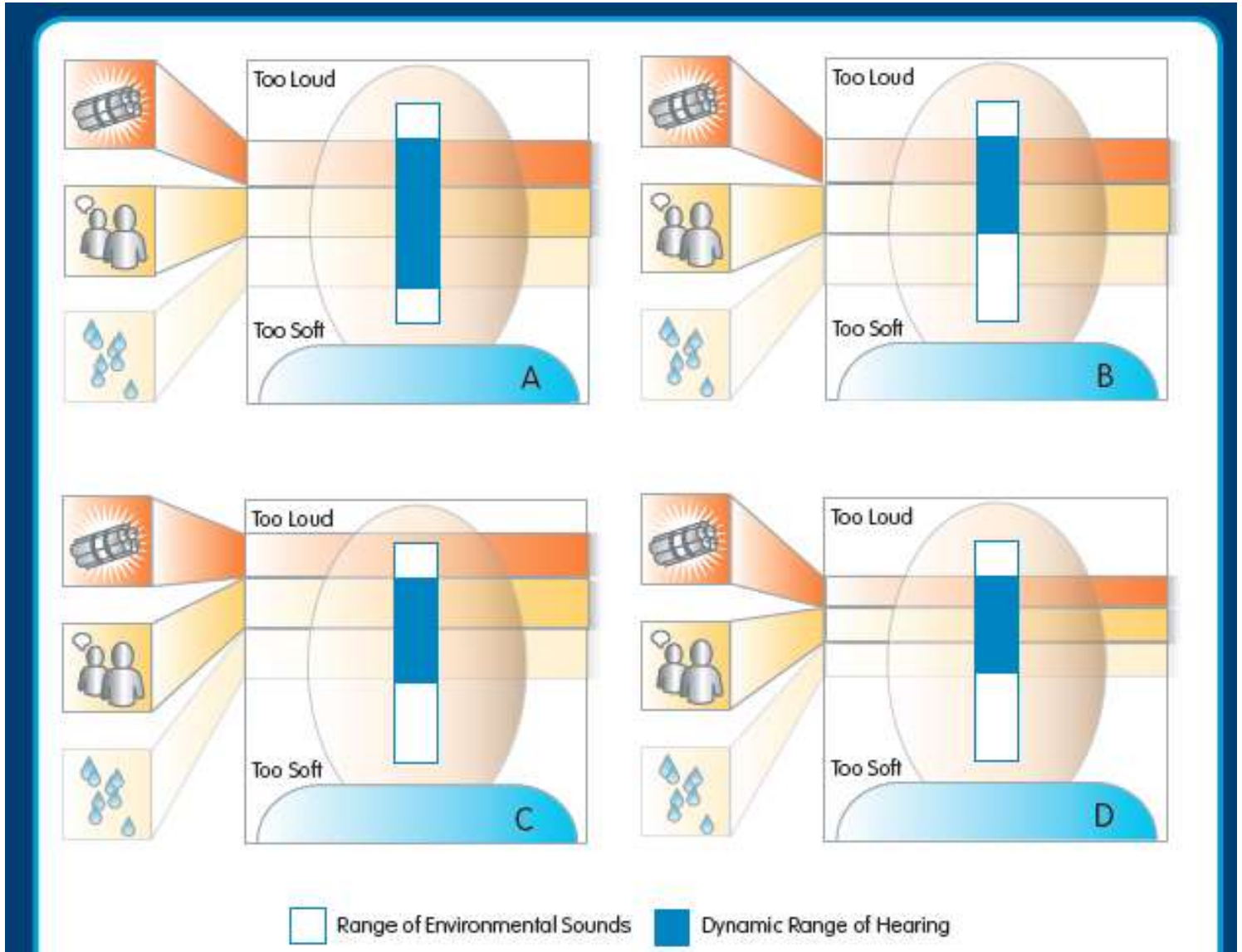


Figure 2-1
The relationship between the range of sounds in the environment and the dynamic range of hearing for persons with: (A) normal hearing, (B) sensorineural hearing loss, (C) sensorineural hearing loss with linear amplification, and (D) sensorineural hearing loss with compression amplification.

Compressor characteristics

- Static features
  - Compression threshold/threshold kneepoint
  - Compression ratio
- Dynamic features
  - Attack time
  - Release time

Compression threshold/ threshold kneepoint

- Predetermined intensity level where gain is reduced
- Input SPL

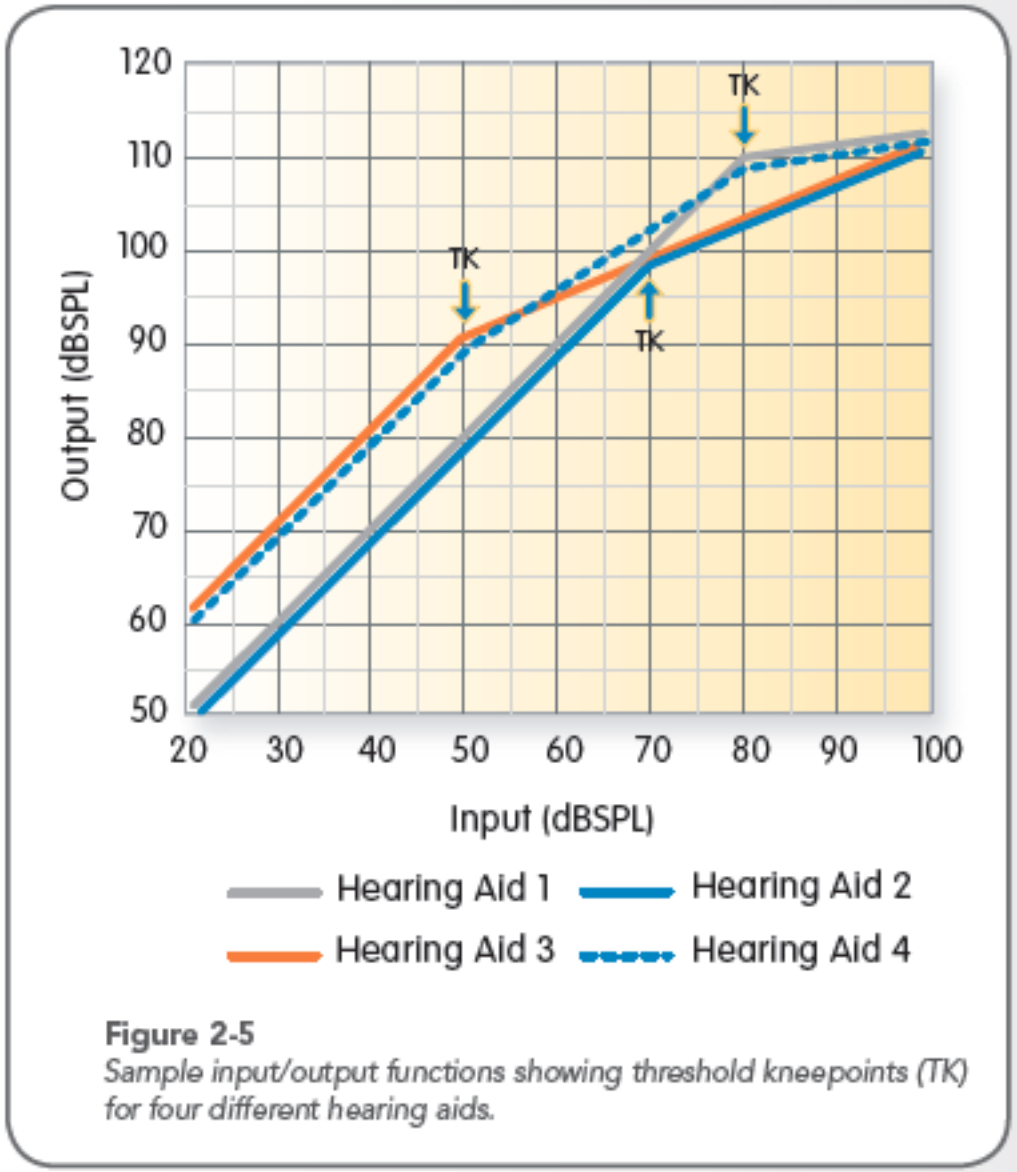


Figure 2-5
Sample input/output functions showing threshold kneepoints (TK) for four different hearing aids.

Compression ratio

- Determines how much signal will be compressed
- Relates a change in the input level (ΔInput) to a change in the output (ΔOutput)
- CR = ΔInput / ΔOutput

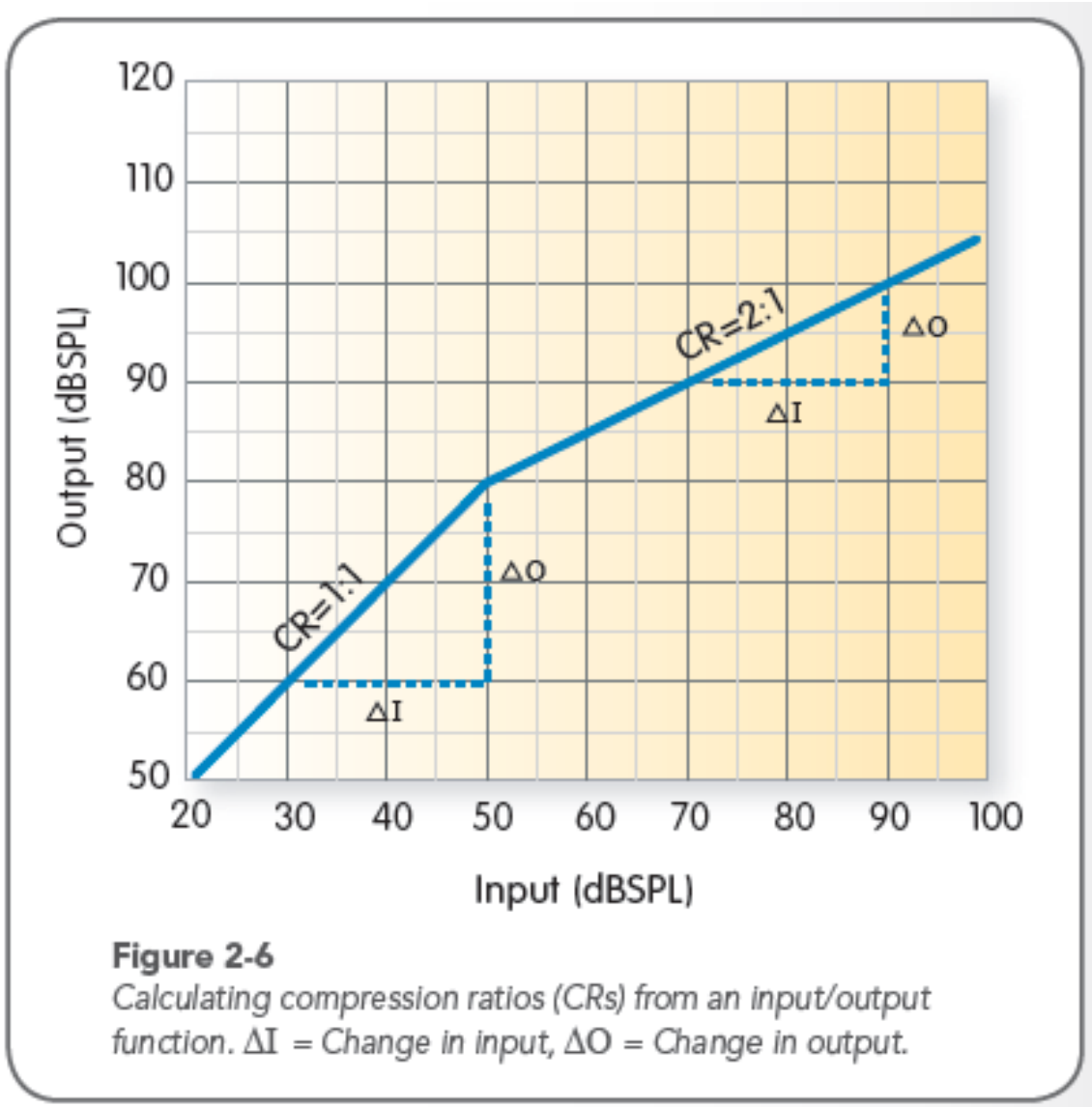
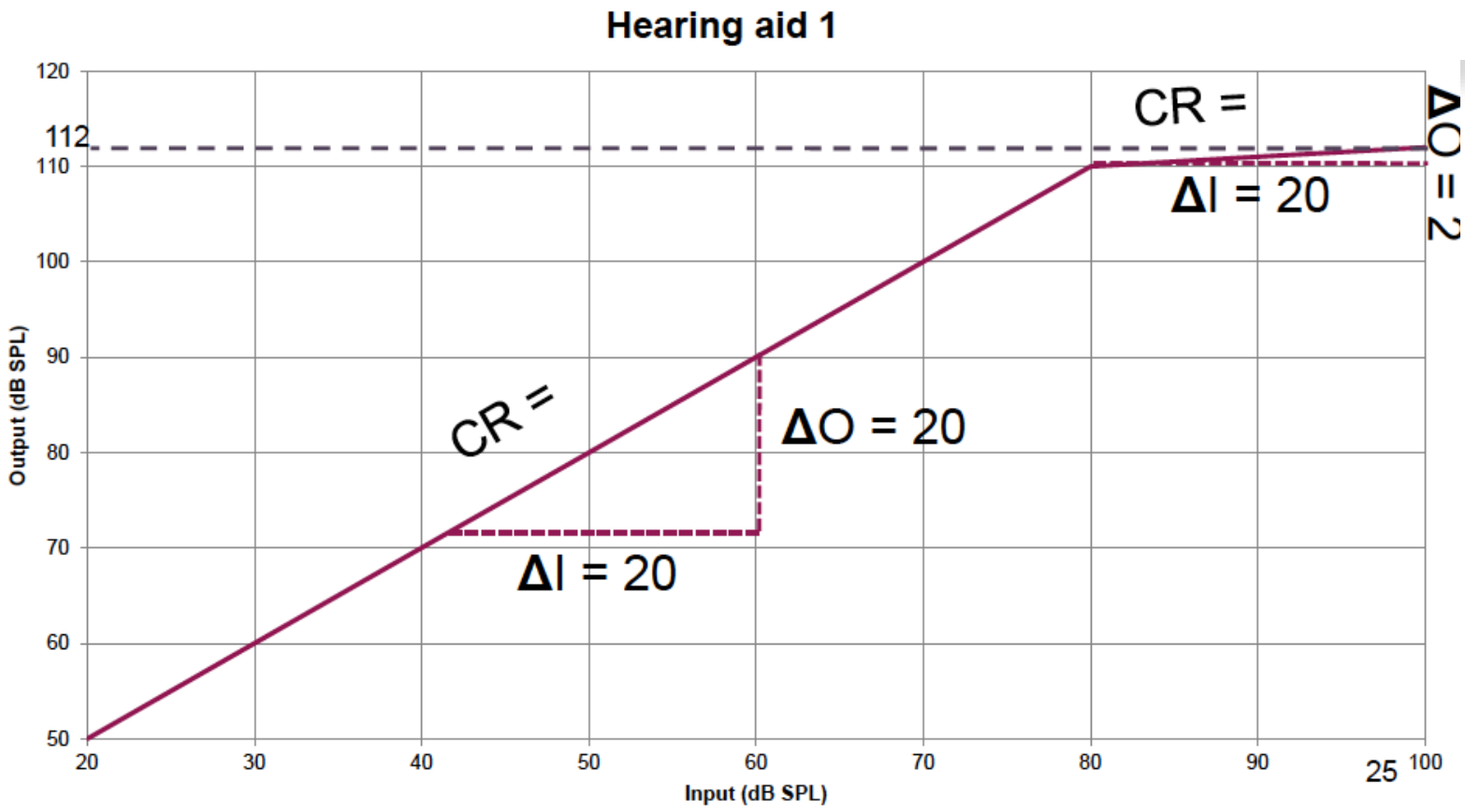


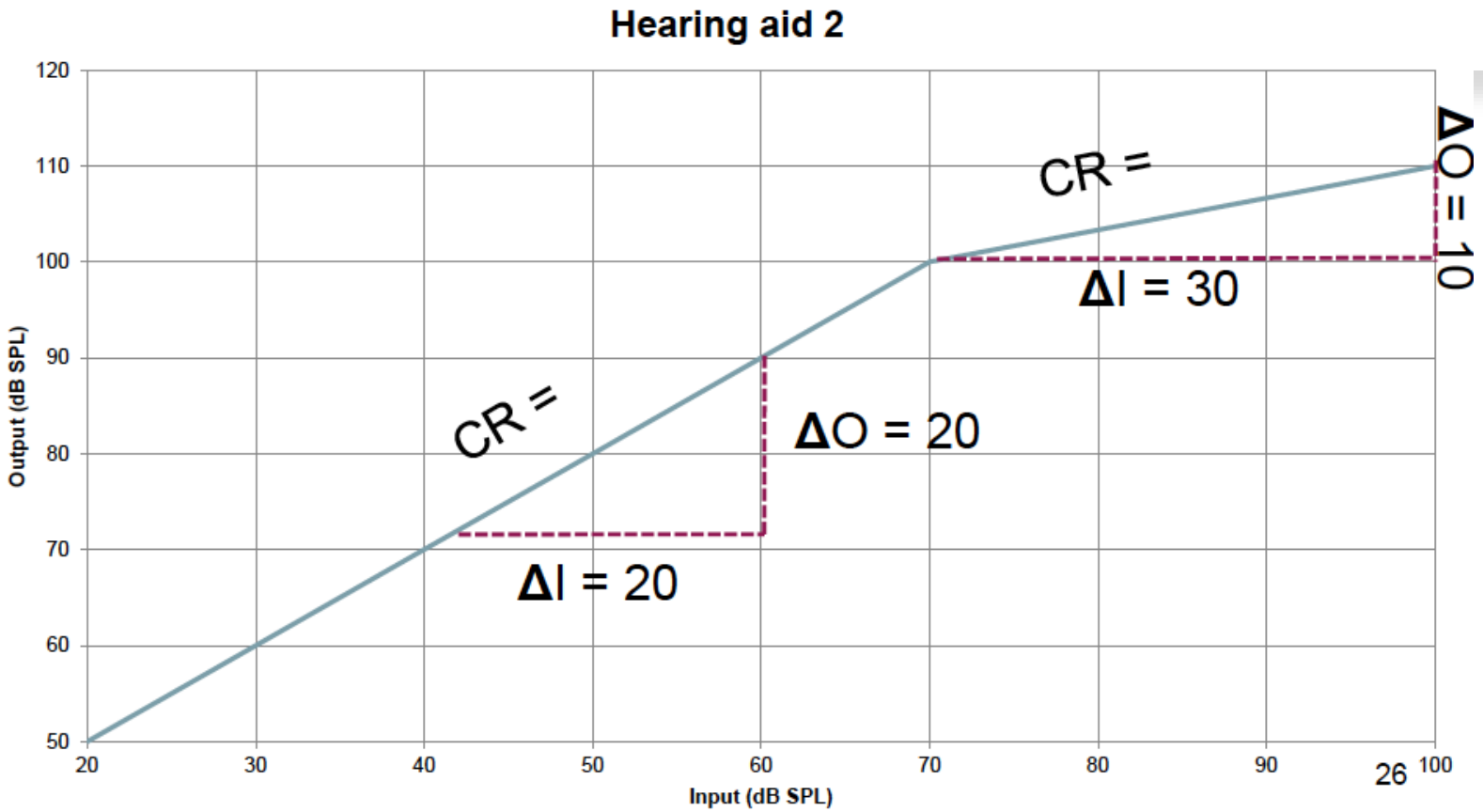
Figure 2-6
Calculating compression ratios (CRs) from an input/output function. ΔI = Change in input, ΔO = Change in output.

Compression ratio

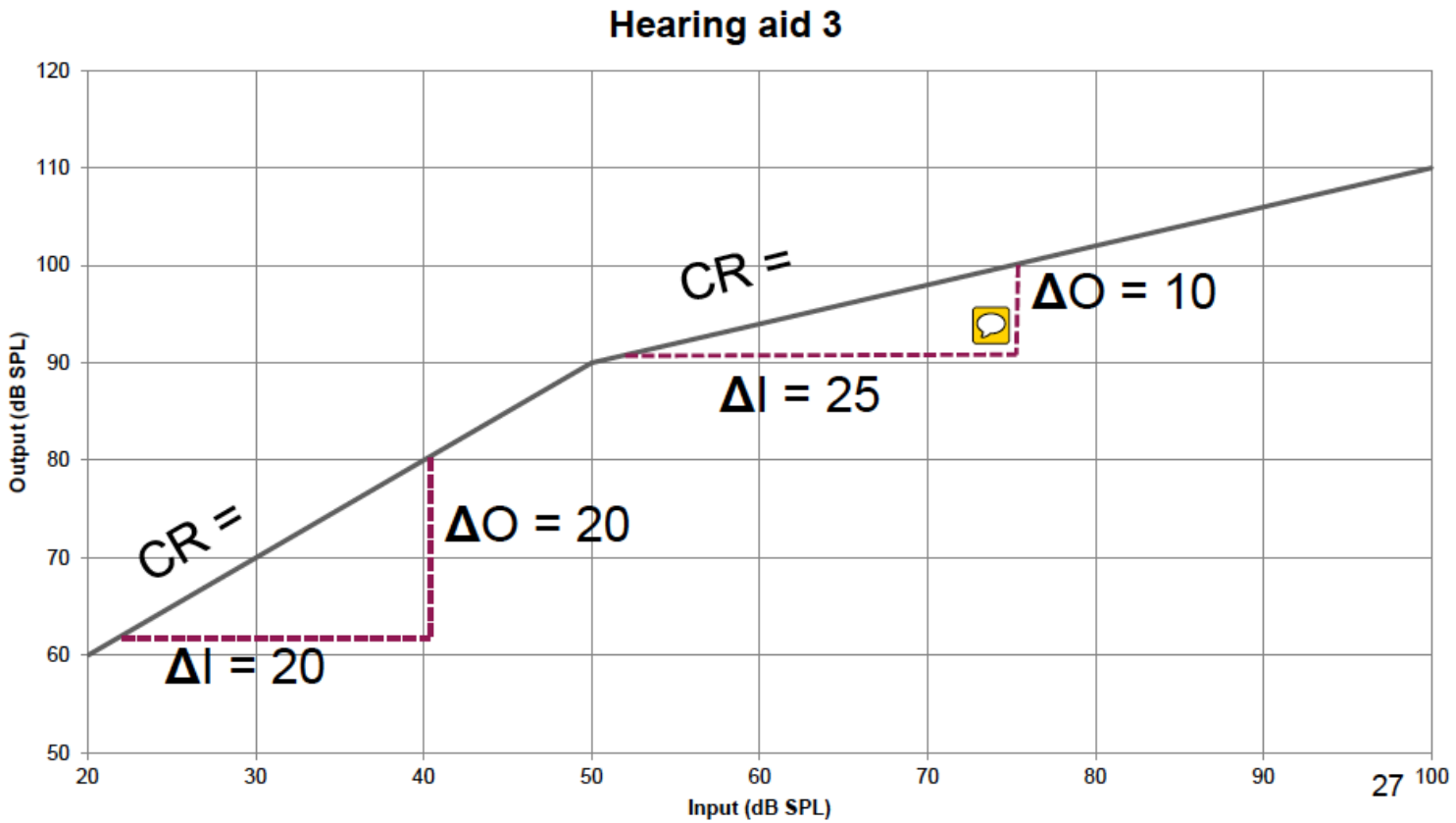
Compression ratio



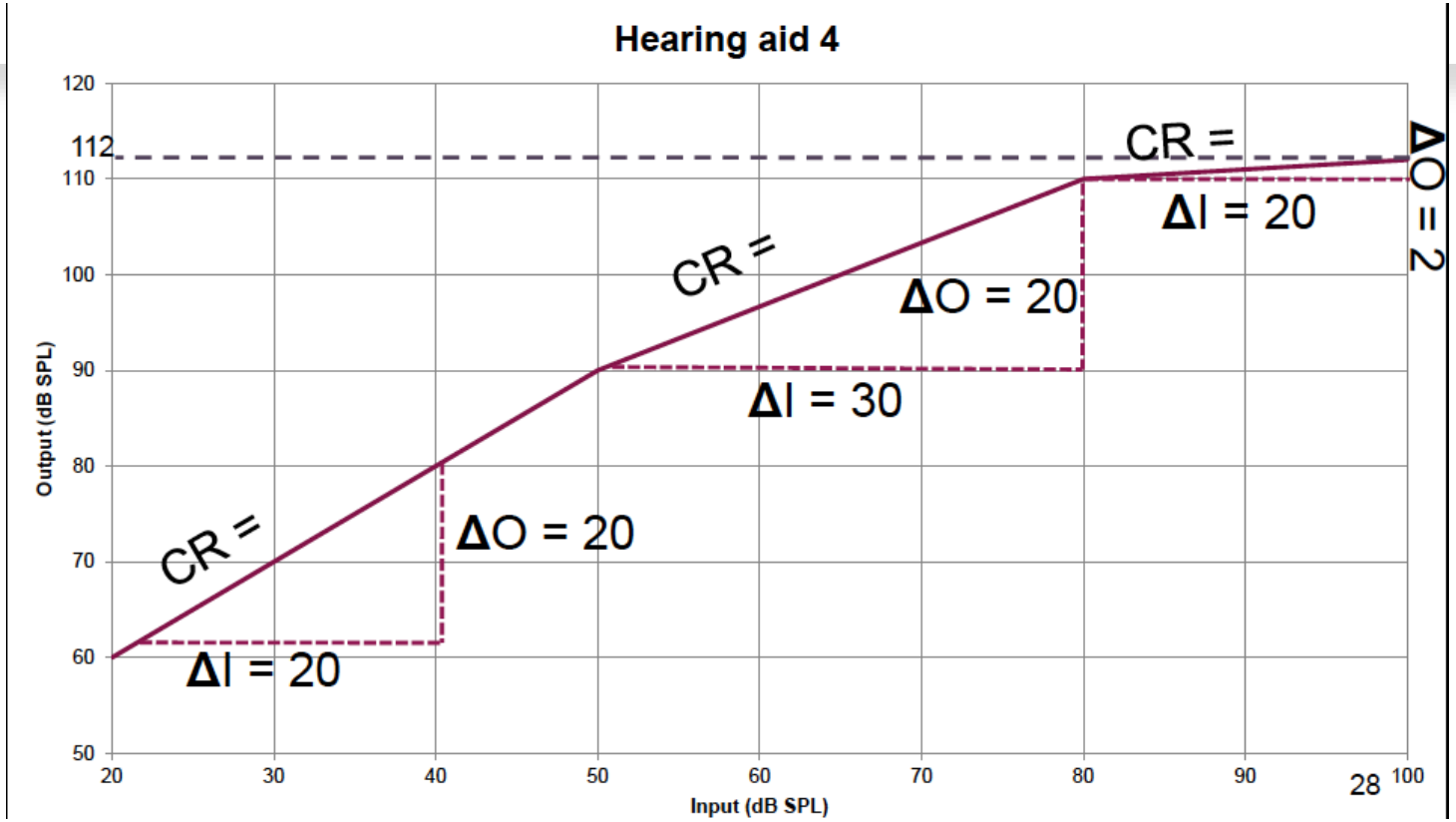
Compression ratio



Compression ratio



Compression ratio



Attack and release time

- When incoming signal changes abruptly in level from below TK to above, the compressor is unable to change the gain instantaneously
  - Gain decreases take time to occur
  - Output of amp has overshoot “spike” followed by decline to steady value

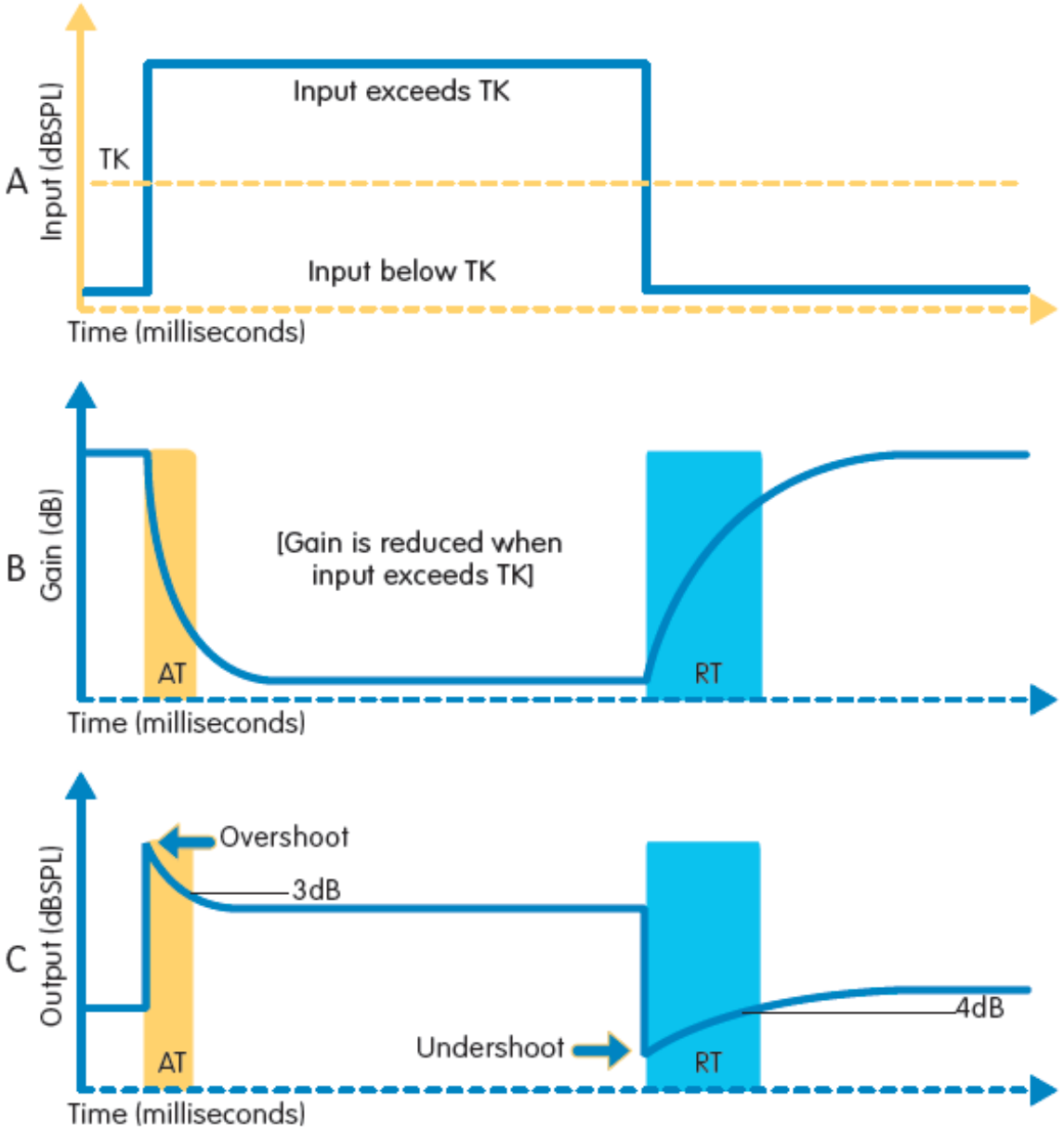
Attack time

- Time delay that occurs between onset of input signal loud enough to activate compression and resulting reduction of gain to its target value

- Defined as the time interval between the moment when the input signal level is increased abruptly by a stated number of decibels and the moment when the output SPL from the hearing aid stabilizes at the elevated steady-state level within ±2dB

Release time

- Time delay that occurs between the offset of an input signal sufficiently loud to activate compression and the resulting increase of gain to its target value
- Defined as the time interval between the moment when the input signal level is decreased abruptly by a stated number of decibels and the moment when the output SPL from the hearing aid stabilizes at the lower steady-state level within ±2dB


A
Input (dBSPL)
TK
Input exceeds TK
Input below TK
Time (milliseconds)
B
Gain (dB)
[Gain is reduced when input exceeds TK]
AT
RT
Time (milliseconds)
C
Output (dBSPL)
Overshoot
3dB
Undershoot
4dB
AT
RT
Time (milliseconds)

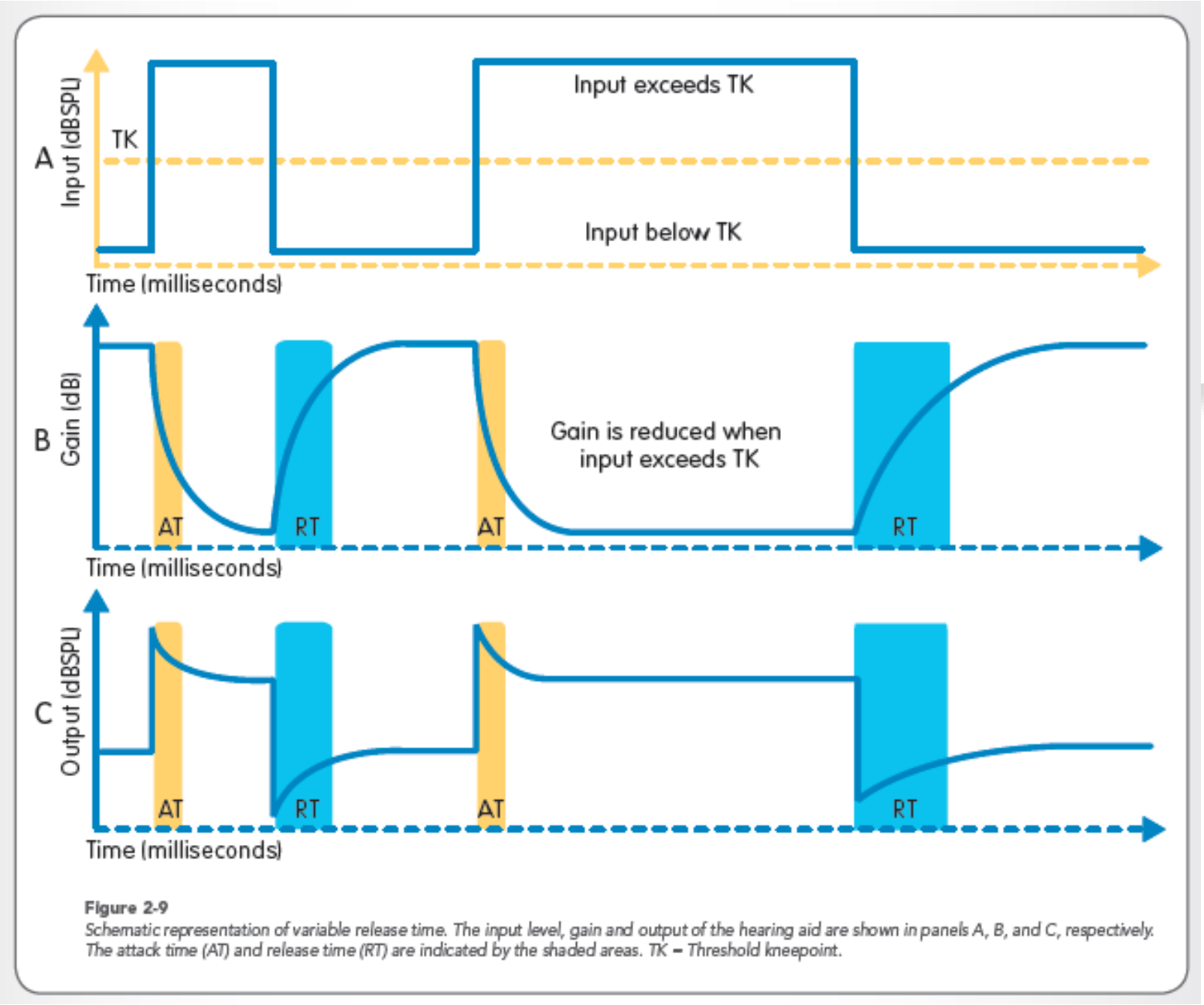


Figure 2-9
Schematic representation of variable release time. The input level, gain and output of the hearing aid are shown in panels A, B, and C, respectively. The attack time (AT) and release time (RT) are indicated by the shaded areas. TK = Threshold kneepoint.

Attack time and release time

- Speed
  - Depends on purpose

- Fast attack time
  - Short duration of overshoot
  - Shorter period of time hearing aid is over amplifying
  - Desirable when compression used to limit maximum output of hearing aid

Attack time and release time

- Release time
  - Generally longer than attack time
  - Fast release time (< 20 ms) combined with fast attack time may result in pumping sensation where level of background noise increases and decreases
  - Slow release time (> than 2 s) combined with fast attack time will adversely affect audibility of speech that follows immediately after gain reduction to loud sound

Attack time and release time

- Short time constants offer best audibility, because they maximize the gain for soft consonants within a word. Better consonant audibility translates into better intelligibility (Souza, 2007)
- Short release time can distort usable speech cues
- Listeners prefer longer release times when speech quality and comfort are listening goals.
- Some data suggest that adults with lower cognitive abilities have higher speech intelligibility with longer release times (Gatehouse, 2006)

Automatic gain control (AGC)

- Amount of gain applied is automatically determined by the signal level
- Level detector is therefore essential component of any compression circuit
- Two types depending on position of level detector relative to volume control

Input-controlled compression (AGC-I)

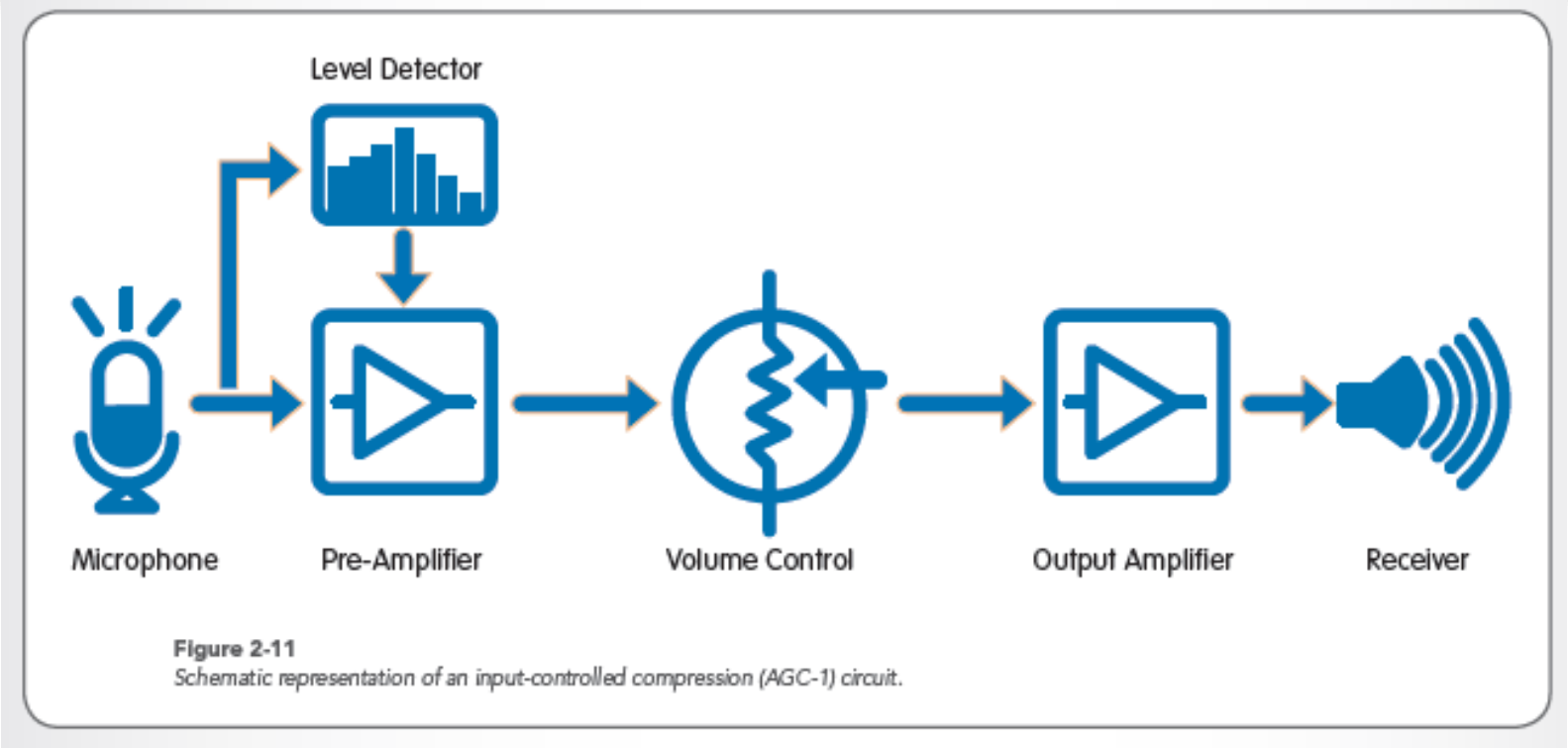


Figure 2-11
Schematic representation of an input-controlled compression (AGC-1) circuit.

Input-controlled compression (AGC-I)

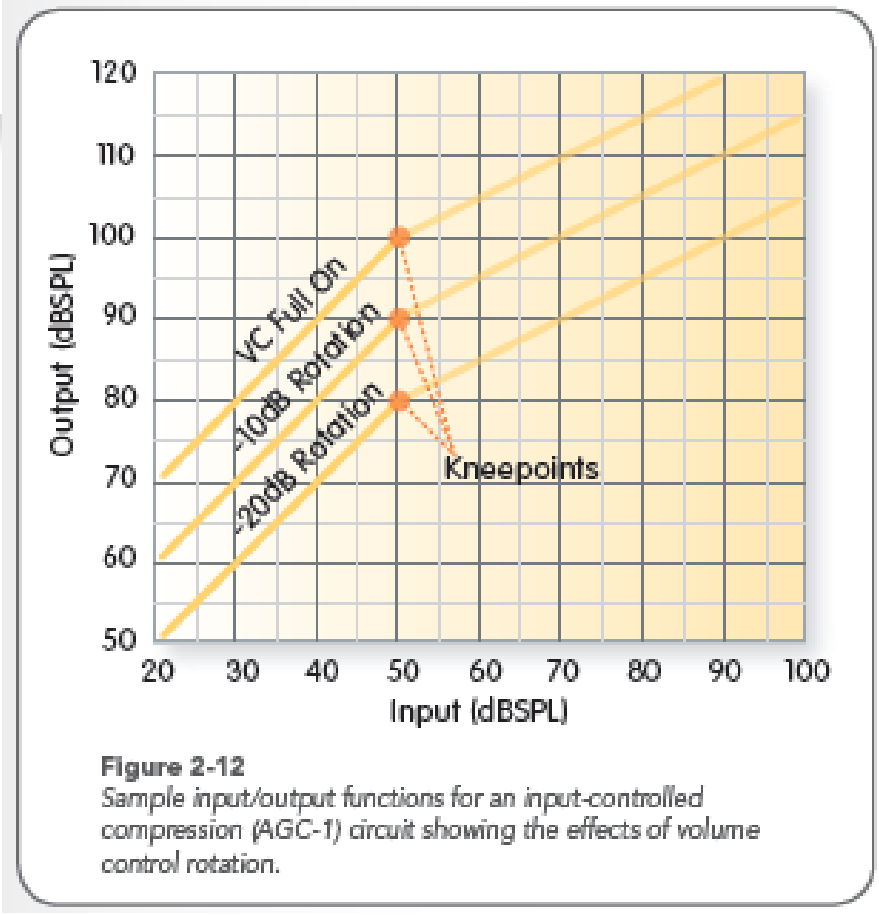


Figure 2-12
Sample input/output functions for an input-controlled compression (AGC-1) circuit showing the effects of volume control rotation.

Output-controlled compression (AGC-O)

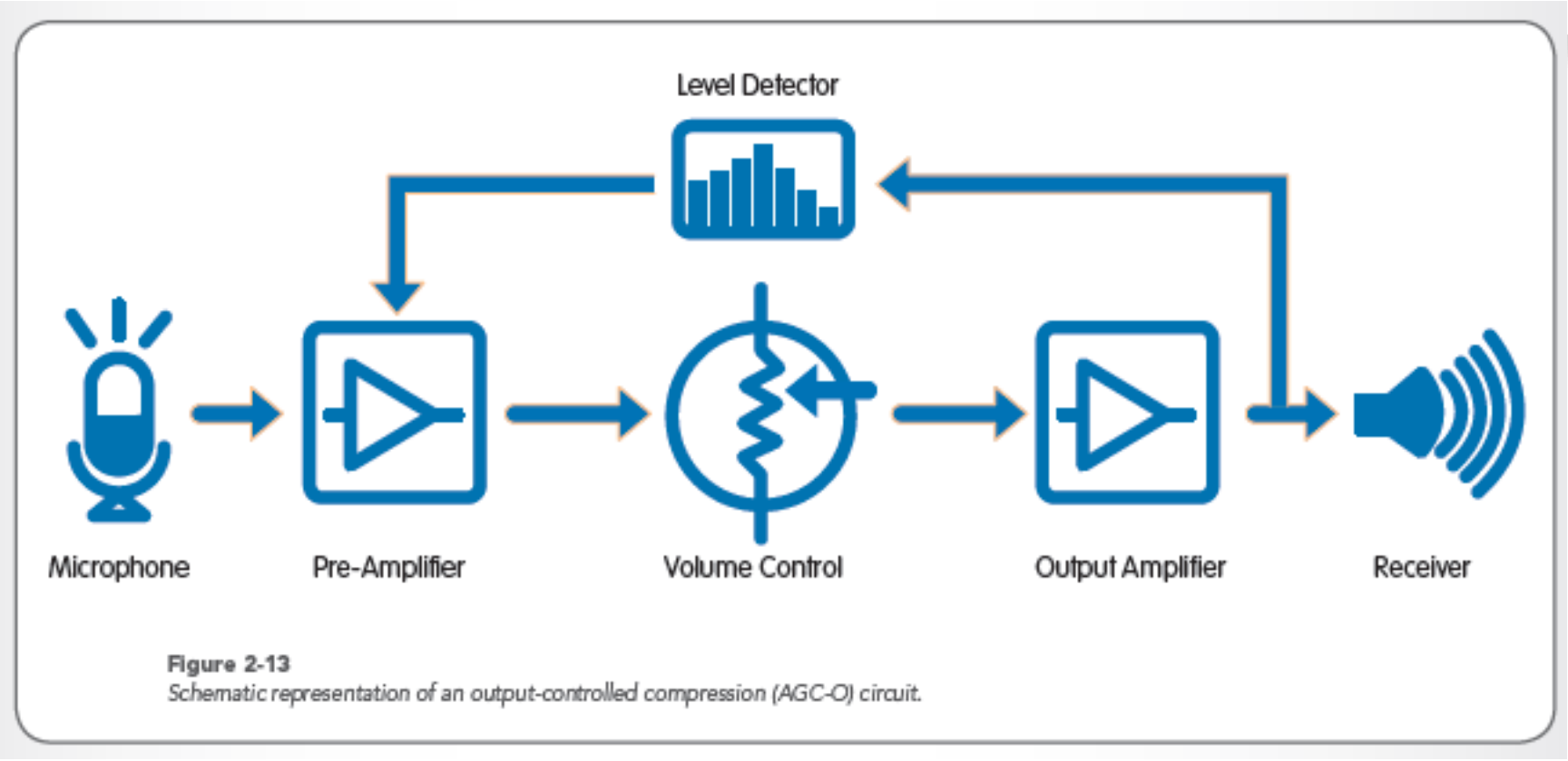


Figure 2-13
Schematic representation of an output-controlled compression (AGC-O) circuit.

Output-controlled compression (AGC-O)

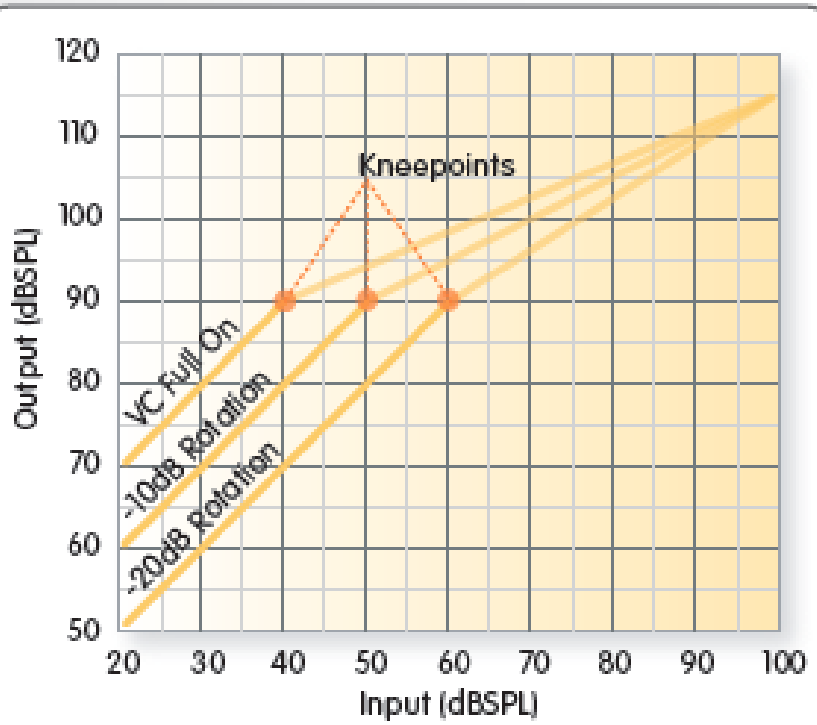


Figure 2-14
Sample input/output functions for an output-controlled compression (AGC-O) circuit showing the effect of volume control rotation.

Channels and bands

- Frequency bands
  - Independently controlled areas for gain adjustment
  - Increasing or decreasing the gain in a frequency band will equally affect the response to different intensity sounds within that band
  - Compression parameters are unaffected
- Compression channels
  - Allow separate adjustments for weak and intense input levels

Channels and bands

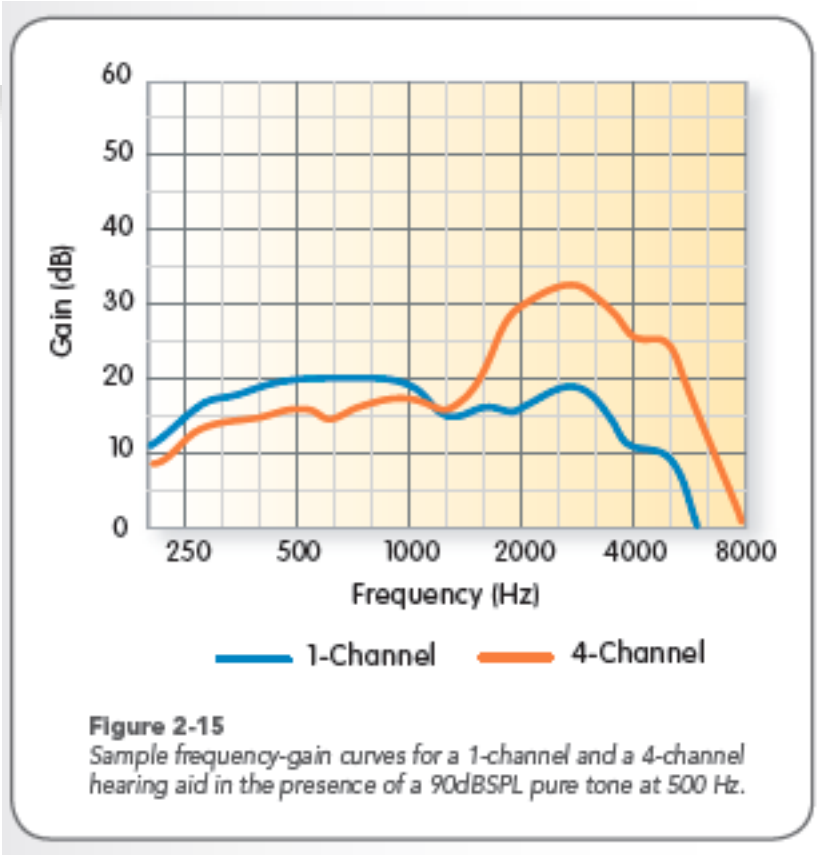
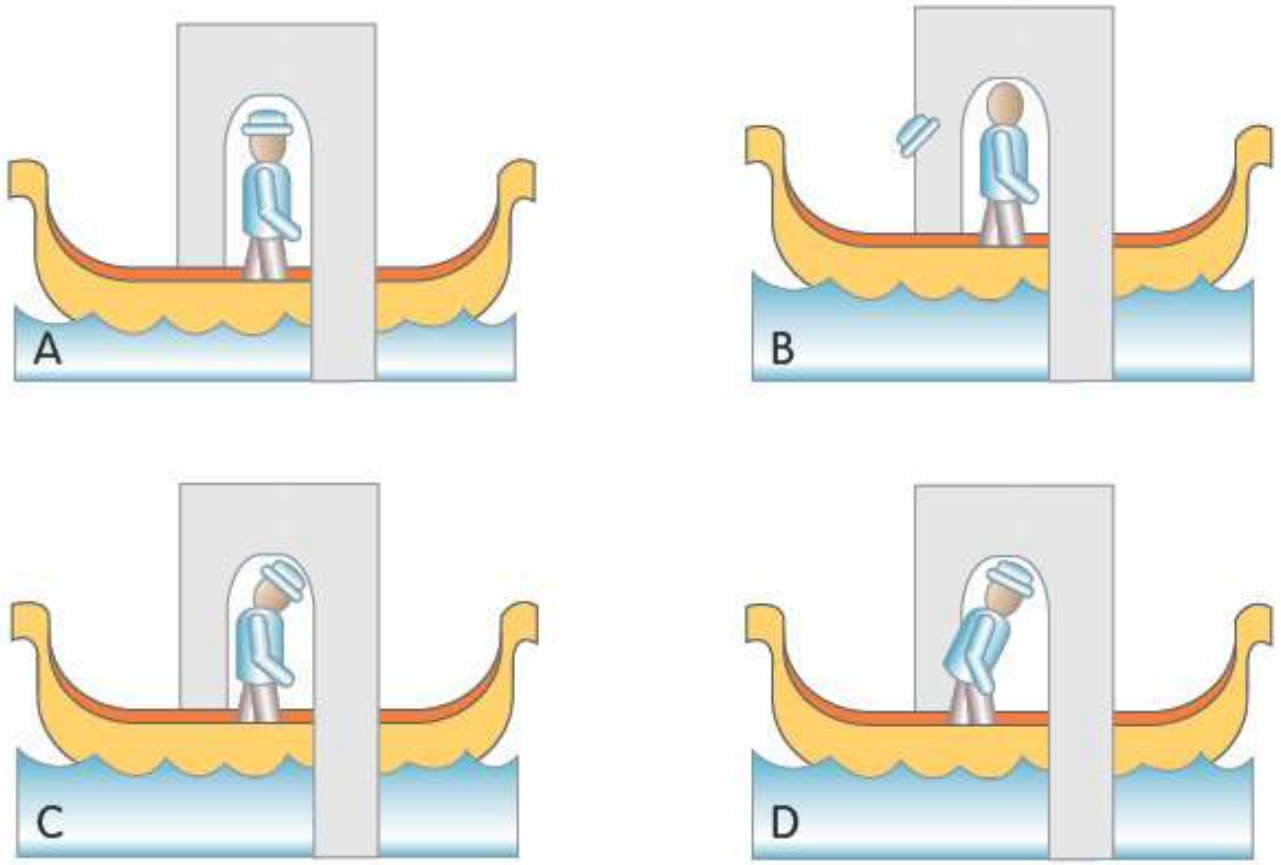


Figure 2-15
Sample frequency-gain curves for a 1-channel and a 4-channel hearing aid in the presence of a 90dBSPL pure tone at 500 Hz.

Visualizing compression



Distortion, discomfort and damage

- Intense sounds
  - Force hearing aid into saturation causing distortion
  - May be amplified beyond LDLs causing discomfort
  - If left unchecked, may cause amplification-induced hearing loss

Wide dynamic range compression (WDRC)

- Weak sounds: audible
- Moderate sounds: comfortable
- Intense sounds: loud without being uncomfortable

WDRC

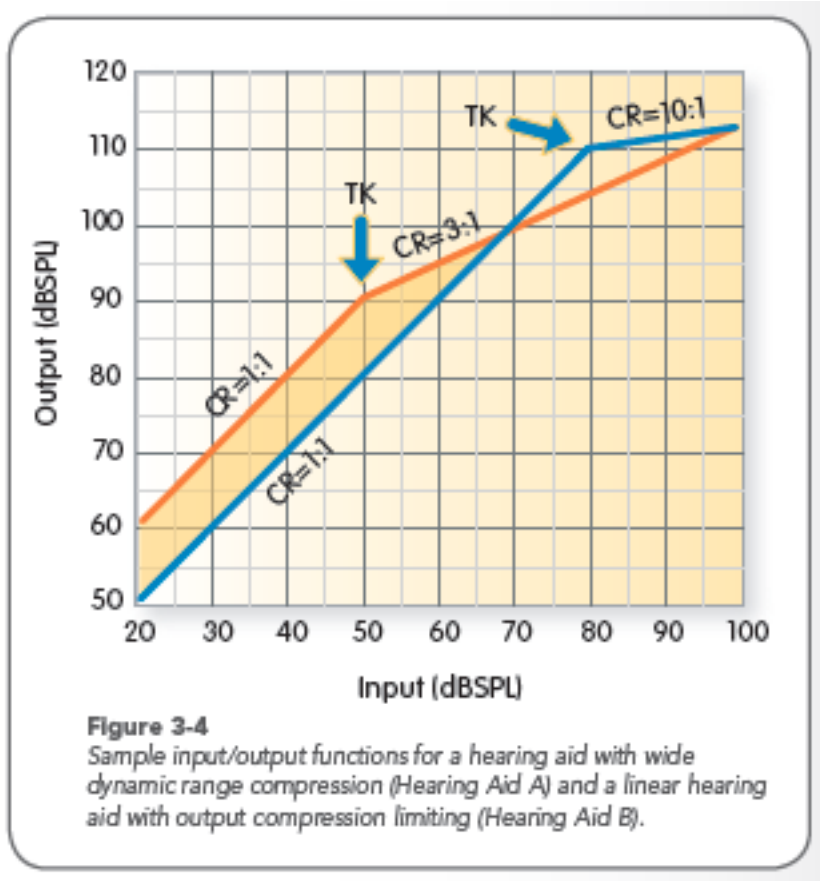


Figure 3-4
Sample input/output functions for a hearing aid with wide dynamic range compression (Hearing Aid A) and a linear hearing aid with output compression limiting (Hearing Aid B).

Desirable characteristics of WDRC

- AGC-I
  - Amount of gain applied depends on the level of the incoming sound
- TK
  - as low as possible in order to make weak sounds audible
- Low CR
  - Compression acts over wide range of inputs

Desirable characteristics of WDRC

- AT and RT
  - Faster than duration of typical syllable to provide more amplification for weaker components than for the more intense components of speech
- Multichannel compression
  - Used to accommodate different audiometric configurations
  - Amplify weak consonant sounds independently of more intense vowel sounds

Loudness growth

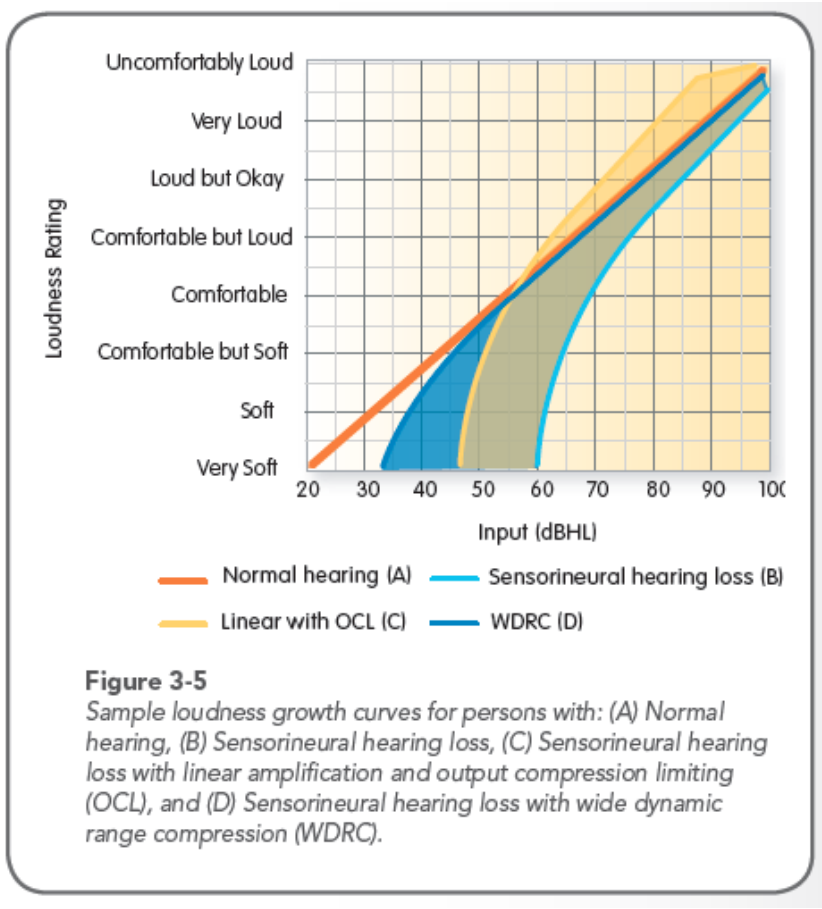


Figure 3-5
Sample loudness growth curves for persons with: (A) Normal hearing, (B) Sensorineural hearing loss, (C) Sensorineural hearing loss with linear amplification and output compression limiting (OCL), and (D) Sensorineural hearing loss with wide dynamic range compression (WDRC).

Advantage of WDRC over linear amplification with output compression limiting

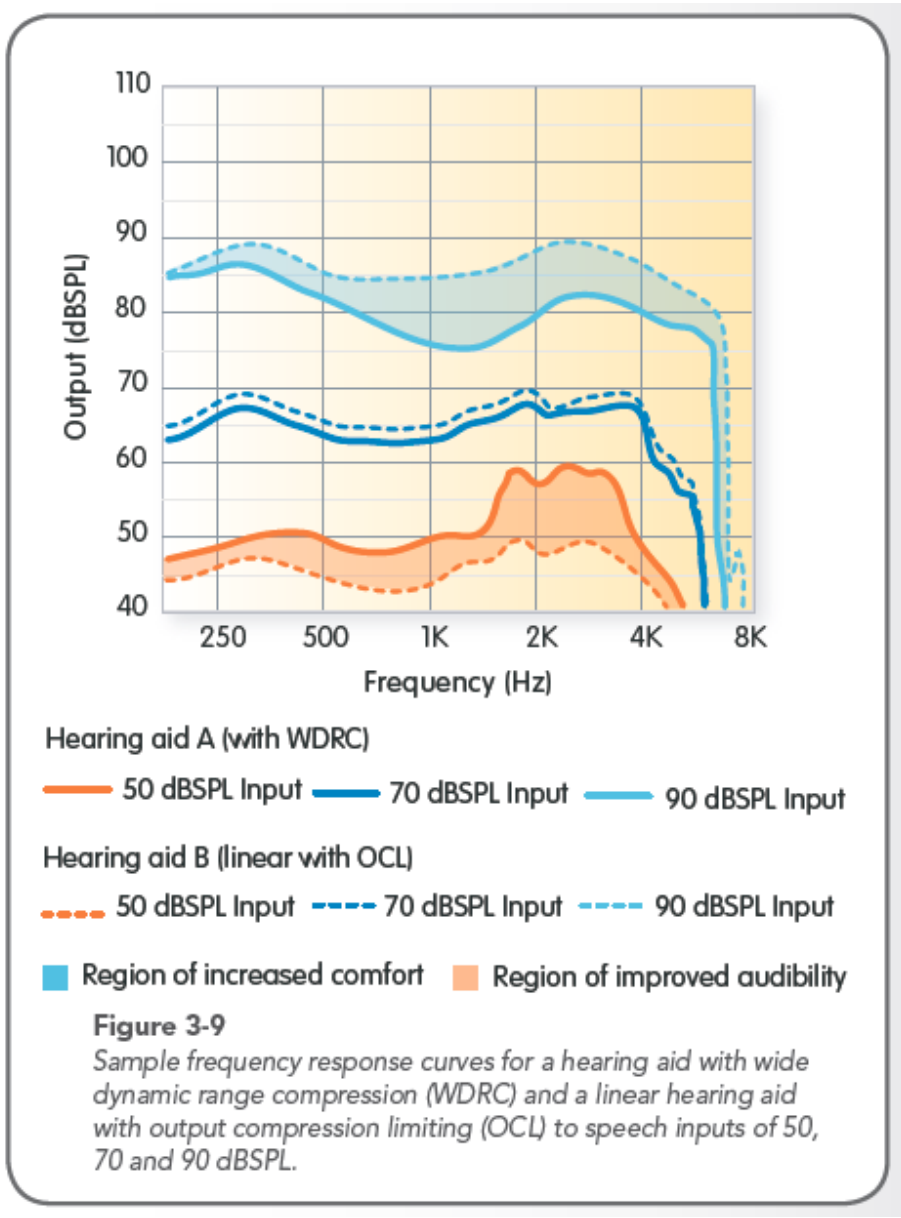


Figure 3-9
Sample frequency response curves for a hearing aid with wide dynamic range compression (WDRC) and a linear hearing aid with output compression limiting (OCL) to speech inputs of 50, 70 and 90 dBSPL.

Reducing adverse effects of noise

- Digital hearing aids have complex algorithms for noise reduction
- Effects of compression on reducing noise – two assumptions
  - Overall level of sound is relatively high in noisy environments
  - The hubbub of noisy environments such as restaurants and parties is dominated by energy in the low frequencies

Reducing adverse effects of noise

- Multi-channel compression
  - No assumptions made regarding frequency composition of noise
  - Gain is reduced only in frequency regions where a great deal of noise is present – gain and audibility in remaining channels are unaffected
  - When spectra of signal and noise are different, improvement in overall signal-to-noise ratio when outputs of channels with poor SNR are reduced relative to those where SNR is good

Reasons to use WDRC

- Optimize use of the residual dynamic range
- Normalize the perception of loudness
- Maintain listening comfort
- Maximize the intelligibility of speech
- Reduce the adverse effects of noise
- Minimize loudness discomfort
- Prevent damage to the auditory system
- Limit hearing aid output without distortion

Further reading

- The Compression Handbook. Shilpi Banerjee
- Compression Systems in Hearing Aids. Chapter 6 – Hearing Aids. Harvey Dillon