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From Soft to Loud:

Understanding Compression in Amplification

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CE Course	Presenter	Organization
Audiology Online	Natalie Hein, Au.D.	Starkey Hearing Technologies

Learning Objectives

Upon completion of this course, participants will be able to:

- Describe the purpose of compression in hearing aid amplification and explain how it addresses the reduced dynamic range associated with sensorineural hearing loss.
- Identify and explain key compression parameters — including threshold kneepoint (TK), compression ratio

(CR), attack/release times, and input vs. output compression — and their clinical implications.

- Differentiate between linear and non-linear signal processing approaches, explain wide dynamic range compression (WDRC) and expansion, and apply prescriptive fitting formula concepts to programming decisions for individual patients.

1. What is Compression?

Compression is fundamental to how hearing aids function. The settings of compression characteristics within a hearing aid form the foundation for patient success — influencing the ability to hear and understand incoming speech as well as the overall sound quality perceived by the patient.

The Dynamic Range of Hearing

Dynamic range is defined as the difference between an individual's loudness discomfort level (LDL) and their hearing threshold. A person with normal hearing may have a dynamic range as wide as 110 dB.

Normal Hearing DR	~110 dB — from threshold of audibility to loudness discomfort level

Sensorineural HL DR	Reduced — threshold rises while LDL often remains the same, narrowing the usable range to ~60 dB or less
Recruitment	Increased sensitivity to loud sounds due to outer hair cell damage — sounds get louder more quickly
Goal of Compression	Fit the full range of everyday sounds (soft, average, loud) into the listener's reduced dynamic range without discomfort

Bottom Line: The Goal of Compression

- Soft sounds must be made audible
- Loud sounds cannot become uncomfortably loud
- Speech should remain at a comfortable, intelligible level

2. Signal Processing Approaches

Linear Amplification

Linear amplification provides a fixed amount of gain regardless of input level, expressed as a 1:1 ratio (gain:output). While it can make soft sounds audible, it has key limitations for sensorineural hearing loss.

When Linear Approaches Apply	Limitations of Linear Amplification
• Long-time users of analog/linear hearing aids who have acclimated to that sound quality • Severe to profound hearing losses where maximum audibility is the primary goal • Conductive and mixed hearing losses where the cochlea is healthy	• Average conversational speech can sound too loud • Intense sounds amplified beyond the patient's dynamic range • Peak clipping causes audible signal distortion

Non-Linear Amplification (Compression)

Non-linear amplification, or compression, varies gain based on the input level. Key parameters include: Threshold Kneepoint (TK), Compression Ratio (CR), Attack and Release Times, and Output Compression Limiting.

3. Compression Parameters

Threshold Kneepoint (TK)

The TK is the input level at which compression begins. Below the TK, gain is linear (1:1). Above the TK, compression is active.

Terminology Note: These terms are used interchangeably

- Threshold Kneepoint (TK) = Compression Threshold (CT) = Compression Kneepoint
- All three terms refer to the same concept: the input level at which compression activates. You will see all three used in the literature, manufacturer documentation, and clinical settings.

Higher TK	Linear gain for longer. May benefit severe losses and previous hearing aid wearers.
Lower TK	Compression applied earlier. May benefit users experiencing recruitment or reduced dynamic range.

Compression Ratio (CR)

The CR describes how much the signal is compressed above the TK. A 2:1 ratio means every 2 dB change in input produces a 1 dB change in output.

1:1	Linear — no compression

>1.1:1	Compression is active
Low CR (1.0–3.0)	Improves audibility of soft speech components; best for mild losses and new wearers
High CR (>8:1)	Protects from loudness discomfort; may adversely affect clarity if overused; used in compression limiting

Attack and Release Times

These define how quickly compression activates and deactivates in response to input level changes.

Attack Time	Duration to enter compression and reduce gain. Typically fast to quickly protect against loud sounds.
Release Time	Duration to exit compression and restore gain. Typically longer to avoid signal fluctuation; too long can reduce speech intelligibility after brief loud sounds.

Input vs. Output Compression

Input Compression (AGC-I)	Compression acts BEFORE the volume control. TK is unaffected by user volume adjustments. Most common in WDRC.

Output Compression (AGC-O)	Compression acts AFTER the volume control. TK IS affected by volume changes. Volume control does not affect max output.
Compression Limiting	Uses high TK (70+ dB) and high CR (8:1+) to control loud sounds without peak clipping distortion. Used to manage maximum pressure output (MPO).

4. Wide Dynamic Range Compression (WDRC) & Expansion

WDRC provides different degrees of amplification depending on input level — more gain for soft sounds and less for loud sounds — to reproduce the full range of environmental sounds within the listener's reduced dynamic range.

WDRC Key Principle

- Soft sounds receive more amplification
- Loud sounds receive less amplification
- Goal: reproduce the full world of sound within a reduced dynamic range

Expansion

Expansion addresses a limitation of compression: because compression amplifies weak sounds, it can also make unwanted environmental sounds (circuit noise, HVAC hum) audible. Expansion applies less gain to the very weakest inputs — below the Expansion Threshold (XT) — without affecting speech.

Expansion Threshold (XT)	Input level BELOW which expansion operates. Often shared with the compression TK.
Low XT (<40 dB SPL)	PRO: protects soft speech audibility. CON: hearing aid may still be noisy.
High XT (>50 dB SPL)	PRO: quieter hearing device. CON: may reduce soft speech audibility.
Expansion Ratio (XR)	Always between 0 and 1. Closer to 0 = more aggressive expansion (quieter); closer to 1 = less expansion (softer speech preserved).

Dynamic Compression & Time Constants

Time constants relate to how quickly compression responds over time.

Faster Time Constants

- More compressive processing
- May enhance audibility for smaller residual dynamic range
- Risk of distorting speech intelligibility

Slower Time Constants

- Less compressive processing
- Better for patients with cognitive considerations
- More natural-sounding output

5. Channels, Bands & Prescriptive Fitting Formulas

Bands vs. Channels

Bands	Frequency-specific gain adjustment regions. More bands = more precise tailoring of the frequency response. Example: 16, 20, or 24 bands.
Channels	Frequency ranges where advanced signal processing (noise reduction, directionality, binaural interaction) operates. More channels = more accurate noise classification. Example: 8, 12, or 16 channels.

Think of it this way: Bands control gain. Channels drive the advanced features.

Prescriptive Fitting Formulas

Prescriptive fitting formulas define the compression architecture of a hearing aid — controlling how gain is applied across input levels and frequency regions.

NAL-R	Linear formula. Loudness equalization rationale — all frequency bands amplified equally. Foundation for later non-linear formulas.
NAL-NL1 (1999)	First validated non-linear (WDRC) formula. Loudness normalization rationale. Based on the Speech Intelligibility Index (SII).
NAL-NL2 (2011)	Refined NL1 based on a decade of clinical data. Added user-specific variables: gender, language, hearing aid experience.
NAL-NL3 (2025)	Machine learning-based. Built on millions of real-world fittings and 10,000+ ecological momentary assessment data points.
DSL v5.0	Developed for pediatric fittings. Loudness equalization rationale. Accounts for ear canal characteristics and incidental learning needs.
e-STAT 2.0 (Starkey)	Proprietary WDRC formula. Low CRs, low CTs, fast-acting. Works with the Additive Compressor architecture for balanced comfort and clarity.

Important: Fitting Formulas Are Not Equivalent Across Manufacturers

- Manufacturer-specific signal processing means universal formulas (NAL-NL2, DSL) produce different hearing aid responses across brands.

- Real ear measurement remains essential for verifying actual gain targets, regardless of formula selected.

Starkey Additive Compressor (Neuro Sound Technology 2.0)

The Omega AI hearing aid platform uses two independent compressors running in parallel, with results additively combined:

Slow Compressor

- Accounts for the audiogram
- Ensures environmental sounds fit within the patient's dynamic range
- Soft sounds are soft but audible; loud sounds are not too loud

Fast Compressor

- Operates on dynamic, fast-moving broadband signal components
- Provides better audibility for soft speech elements like consonants
- Reduces contrast between loud and quiet portions of speech

6. Clinical Applications & Programming Scenarios

Understanding compression characteristics enables targeted programming adjustments. General principle: environment sounds too soft = more compression for soft sounds; environment sounds too loud = less compression for soft sounds, more for loud.

Programming for Restaurant Environments

Restaurants are loud acoustic environments. Lowering the loud input curve may provide comfort but can reduce speech clarity. A frequency-specific approach is recommended.

150–750 Hz	Linear — limited usable speech information; linear processing reduces loudness without impacting clarity.
1000–3900 Hz	Compression present — primary speech intelligibility range; compression preserves clarity in noise.
4000 Hz and above	Linear — limited speech information; linear processing manages high-frequency noise.

Restaurant Programming Tip

- Rather than globally reducing loud inputs (which may affect speech), adjust soft input curves with frequency-specific linear regions to improve comfort without sacrificing speech clarity.

Programming for HVAC Systems

HVAC noise (mechanical fans, aerodynamic hiss, duct pathway noise) typically sits above the expansion threshold but below the compression kneepoint — meaning the quiet algorithm may not fully address it.

150–750 Hz	Linear — mechanical noise often concentrated here; linear prevents over-amplification.
1000–3900 Hz	Compression — preserves speech clarity when a speaker is present.
4000 Hz and above	Linear — aerodynamic/high-frequency HVAC noise; linear reduces gain fluctuation.

HVAC Programming Advantage

- Frequency-specific compression targeting reduces overall environmental gain fluctuations compared to relying solely on the machine algorithm.

- Avoids the gain cycling that occurs when the machine algorithm engages and disengages as speech appears and disappears.

Data & Statistics Highlights

430M people worldwide currently require rehabilitation to address disabling hearing loss — over 5% of the global population. Source: World Health Organization.

700M people — 1 in 10 — projected to have disabling hearing loss by 2050. Source: World Health Organization.

110 dB the dynamic range of a person with normal hearing — from threshold of audibility to loudness discomfort level.

50×/sec the rate at which noise reduction algorithm parameters are re-evaluated (every 6 ms) in each channel in a modern hearing aid.

10,000+

real-world ecological momentary assessment data points incorporated into the NAL-NL3 fitting formula (released 2025).

Clinical Q&A

Key questions and answers from the course:

Q: Why is compression necessary for sensorineural hearing loss?

A: Sensorineural hearing loss damages outer hair cells, which normally compress the incoming signal non-linearly. Without healthy outer hair cells, the cochlea functions more linearly, narrowing the dynamic range. Compression in hearing aids mimics this lost non-linear processing, fitting the full world of sound into the reduced dynamic range of the individual.

Q: What is the difference between a band and a channel in a hearing aid?

A: A band is a frequency region where gain can be adjusted to shape the frequency response for the hearing loss. A channel is a frequency region where advanced features — noise reduction, directionality, binaural processing — make decisions about the acoustic environment. More bands = better gain precision; more channels = better noise classification accuracy.

Q: When should a clinician consider a linear fitting approach?

A: Linear approaches are most appropriate for: (1) long-time users of analog/linear hearing aids who have acclimated to that sound quality, (2) severe to profound hearing losses where maximum audibility is the primary goal, and (3) conductive hearing losses where the cochlea is healthy and simply needs additional volume to overcome the conductive block.

Q: What happens if the compression ratio is set too high?

A: A high compression ratio (>8:1) can adversely affect the clarity and pleasantness of amplified sound. While necessary for compression limiting, an excessively high CR for milder losses can distort the perceptual qualities of speech and make acclimatization more difficult for new wearers.

Q: Why might a patient report that their old hearing aids sounded better than new ones?

A: Long-time wearers of linear or analog technology have learned to process the specific characteristics — including distortions — associated with that sound. When moved to a compressive system, the absence of those familiar cues may feel like the new aids are not working. Gradual acclimatization settings or a fitting formula tailored to experienced wearers can help.

Q: How does the patient's volume control interact with compression?

A: With AGC-I (input compression, most common in WDRC), the volume control has no effect on the compression threshold (TK), protecting the consistency of compression behavior. With AGC-O (output compression), volume control adjustments can shift the TK, which may affect sound quality.

References & Resources

Venema (2006)	Compression for Clinicians. Thomson Delmar Learning, Clifton Park, NY.

Venema (2010)	Compression Handbook (2nd ed.). Delmar Cengage Learning, Clifton Park, NY.
Dillon (2012)	Hearing Aids (2nd ed.). Boomerang Press, Sydney, Australia.
Starkey (2017)	The Compression Handbook (4th ed.). Starkey Hearing Technologies.
EHMA 2019	Ricketts et al. — Dynamic compression time constants and cognitive considerations.
NAL-NL3 (2025)	National Acoustic Laboratories. Built on machine learning and large-scale real-world data.

Online Resources

- StarKeyPro.com — Fitting guides, quick reference materials, compression handbook, white papers
- Starkey.com — Patient quick tips and educational videos
- AudiologyOnline.com — Course materials, CEU claims, and pending courses

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Notes

Starkey Hearing Technologies

starkeypro.com

starkey.com