Phonak Insight

February 2018

Slow compression for people with severe to profound hearing loss

For people with severe to profound hearing loss, poor auditory resolution abilities can make the spectral and temporal cues in speech difficult to identify and use. This can be an important factor when considering compression in digital hearing aids (Gatehouse, S. Naylor, G. Elberling, 2006). Linear gain settings or hearing aids with slow compression may benefit some clients. For example, the 20% of clients who do not acclimatize to fast compression (Turton & Smith, 2013). For some clients no amount of acclimatization can restore their auditory resolution abilities. With Naída, hearing care professionals have been able to choose linear gain and fast compression. With the introduction of Phonak Naída™ B a new choice has been added, slow compression, with Adaptive Phonak Digital Contrast. This way the HCP can better meet the individual needs of clients with severe to profound hearing loss.

Introduction

There has been extensive scientific literature published about the relative advantages and disadvantages of fast and slow compression systems in hearing aids (Moore, 2008 p.108). A linear gain system, such as that found in analog hearing aids, provides a fixed amount of gain for all input levels. In digital hearing aids, the equivalent may be considered linear gain settings which will result in amplitude compression ratios of 1:1. In a linear system the large amount of gain which is required to make low input levels audible, must also be applied to high input levels. A disadvantage of this system is the amount of output limiting which must be applied to prevent loud inputs exceeding the loudness discomfort level or the prescribed MPO. Compression systems apply less gain to high input levels and more gain to low input levels. The gain is said to be non-linear and compression has proved to be ideal for addressing the limited dynamic range of hearing resulting from sensorineural hearing loss (Moore, 2007). In general, fast acting compression utilizes fast compression release and attack times resulting in very rapid adjustments to the gain as the input varies. Dillon describes typical hearing aid attack time as < 5 msec and release times as >20 msec (2012). "Fast acting wide dynamic range compression systems…maximize the effective moment-to-moment audibility of a speech signal. As such, they must act rapidly over periods of time comparable to the rapid fluctuations in the speech signal" (Gatehouse et al 2006a, p133). By slowing the attack and release times, the gain may be expected to remain constant for more of the time, resulting in a system which behaves more like a linear system. In contrast to fast acting compression, "slow acting [systems] are designed to provide the listener with access to the external auditory world with minimal processing and distortion artefacts, …adapting to the longer-term changes as the listener's auditory environment alters or the listeners move from environment to environment" (Gatehouse et al 2006a, p133). In slow compression typical attack and release times fall between 0.5sec and 20sec (Moore (2016).

Evidence has shown that for many listeners "slow compression provides increased comfort when listening to speech and fast compression delivers improved clarity for low input levels" (Moore et al 2011, p.563). However there is no established method to select the candidates who will benefit from slow compression. Multiple studies have resulted in sometimes conflicting findings (Gatehouse et al 2006b; Moore 2008). Typical research populations reported in the literature have normal hearing, mild to moderate or sloping hearing loss. Examples are Gatehouse et al (2006), Moore (2011& 2012), Souza et al (2008, 2012, 2013, 2015), Strelcyk et al (2013) and Kowalewski et al (2017). In considering severe to profound hearing loss, there is almost no evidence which includes this population. An exception is the study by Bor, Souza, & Wright, (2008) which is discussed below. Despite the variability in subject populations across studies, a common finding in all studies was that in every case individual subjects were identified who prefer and perform better with fast or with slow compression (Dillon 2012, p196).

Fast compression to overcome loudness recruitment

It is known that "any effective non-linear amplification [compression] by definition introduces distortions into the spectral and temporal structure of the signals it operates on" (Gatehouse et al 2006a, p131). Those with very poor auditory resolution abilities might be more vulnerable to changes in the spectral and temporal structures introduced by non-linear amplification in general and fast compression in particular.

Sensorineural hearing loss results in "poorer hearing thresholds and abnormal growth in loudness, poorer frequency resolution, poorer temporal resolution and abnormal masking patterns" (Moore 1998). Although not fully explained by the audiogram, we expect that problems with spectral and temporal resolution will increase with increasing hearing loss. Souza hypothesized that "temporal cues will be more resistant to degradation from hearing loss than spectral cues , provided the listener can access a sufficiently wide signal bandwidth" (Souza (2015) p521). "Fast-acting compression can degrade [temporal] envelope cues. A listener who depends heavily on temporal envelope versus spectral cues may be affected by even minimal envelope distortion" (Souza (2015) p532). One of the major differences between slow and fast compression is the resulting change in the level of the different syllables of speech. Dillon describes this as " best understood in terms of the signal's envelope which is an imaginary line drawn through the extremities of a waveform." (2012 p 196) This envelope illustrates the changes in spectral and temporal structures resulting from compression. Souza notes that fast compression will "smooth spectral contrasts and degrade recognition when the essential information is carried by spectral contrasts and presented to a listener who is sensitive to these contrasts" (Souza (2015) p532). Figure 1. below, illustrates how the resulting waveform envelope is smoothed when fast compression is applied.

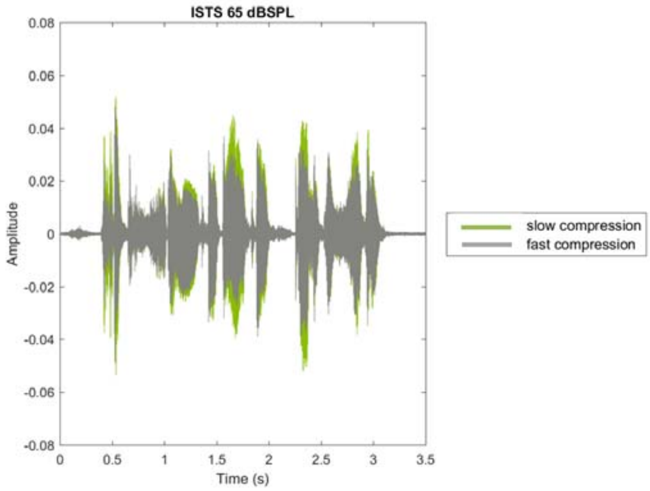


Figure 1. The time-intensity waveform for a speech input (ISTS at 65dBSPL) measured in a Naída B. Slow compression is shown in green and fast compression in grey. The speech envelopes are the imaginary outline shown in the same colors.

While fast acting compression has the advantage of providing more amplification for soft inputs while still maintaining comfort, a key advantage of slow compression is that "the temporal envelopes of the signal are hardly distorted. This may be important for maintaining speech intelligibility" (Moore 2016, p 115, Madsen, et al 2015), for some listeners.

Comparing fast and slow compression, Kowalewski et al (ISAAR, 2017) states that "a small but systematic benefit of fast-acting compression was found in both the quiet and the noisy conditions for the lower speech levels. Despite potentially detrimental speech envelope distortions, no negative effects of fast-acting compression were observed when the speech level exceeded the level of the noise." This finding was measured in participants with mild hearing loss.

Slow compression increases the options for severe to profound hearing loss

Evidence confirms that the "encoding of temporal envelope fluctuation in the auditory system seems to be affected by sensorineural hearing loss" and that hearing impaired listener's sensitivity in detecting slow and moderate envelope fluctuations is superior to normal hearing listeners (Winberg et al, 2015 p300).

The population most sensitive to the compression of speech, would be people with poorest spectral and temporal resolution abilities. In her work Souza found that hearing loss resulting in "broadened auditory filters can reduce the ability to process amplitude compressed vowel spectra. Vowel identification worsened with increasing auditory filter width, and when multichannel compression was used" (Bor, Souza, & Wright, 2008). She concludes that "in a very slow-acting [multi-channel compression] system where some or all of the vowel is linearly amplified," the improvement in vowel identification" might be more similar to the linear vowel scores presented here" (Souza et al., 2013, p11).

Naída B has more compression choices for individual clients

The exact implementation of the compression varies markedly across manufacturers, and there is no general agreement about the form of compression that is "best," if indeed there is an optimum; for reviews, see Moore (1990, 2007, 2008), Hickson (1994), Dillon (1996), and Souza (2002) in Moore B (2012) p160. To understand how slow compression in Naída B changes the spectral and temporal structures in speech, the measurements (described below) were made based on two assumptions:

1) For those with the poorest auditory resolution abilities, temporal envelope cues are the most robust and important cues for speech (after Souza 2015).

2) The dynamic of the signal calculated as the difference between the 99th and 30th percentiles at the output can quantify changes in the temporal envelope. We can infer that a larger dynamic represents better preservation of the temporal envelope of speech.

The option of linear gain remains. As always linear gain can be set by selecting this setting in Target 5.3 (and earlier Target versions) in the tab [Global Tuning], [Compression], select [Linear], see Figure 2.

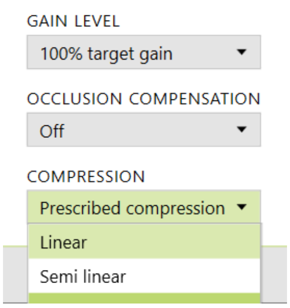


Figure 2: Linear gain can be selected in a drop-down menu for compression in Target 5.3.

The gain table will then display an equal value for all input levels and the compression ratio will be shown as in Table 1. In Naída, the default processing is fast compression. In Naída B it is now possible to select the slow compression setting in Target 5.3 by going to the tab [Global Tuning] , [Fitting Formula] and selecting [Adaptive Phonak Digital Contrast[1]].

MPO	71	84	92	98	102	103	103	103	104	105	106	108	109	107	104	103	100	95	85	75
All	170	340	520	690	860	1k	1k2	1k4	1k6	1k7	2k	2k3	2k7	3k	3k4	4k	4k8	5k9	7k5	9k6
G80	0	5	16	24	28	29	30	31	33	35	39	43	44	43	40	37	34	30	21	13
G65	0	5	16	24	28	29	30	31	33	35	39	43	44	43	40	37	34	30	21	13
G50	0	5	16	24	28	29	30	31	33	35	39	43	44	43	40	37	34	30	21	13
CR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 1 The gain table as displayed in Phonak Target when linear is selected. An equal value is shown for all input levels and the compression ratio is shown as 1.

Methodology

To measure the temporal envelope of speech, resulting when linear gain, fast or slow compression is selected in a Naída B SP BTE, the hearing aid was first programmed for a severe to profound audiogram shown in Figure 3. The input signals used were loud (80dBSPL) and medium level (65dBSPL) ISTS speech and finally a sample of female speech presented in multi-talker background noise. To ensure adequate speech signal remained unmasked, a positive signal to noise ratio of +15dB was used for the speech in noise sound file.

The output of the hearing instruments was recorded using a KEMAR/manikin and the recordings analyzed in 1/3 octave resolution to calculate the RMS-level and lastly percentile spectra were calculated. The difference between the 99th percentile and the 30th percentile, were calculated to infer how well envelope cues are represented in the output. A larger difference was taken to indicate more preservation of envelope cues.

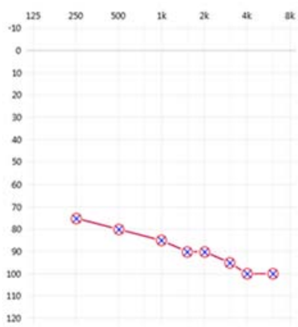


Figure 3. Air conduction audiogram used for all measurements (Hz vs dBHL). The audiogram is a standard severe to profound audiogram as described in Bisgaard, Vlaming, & Dahlquist, (2010).

[1] This implementation of slow compression also includes minor changes to the gain prescription.

	Naída B SP BTE
Audiogram	Severe to profound hearing loss
Conditions	Linear gain, Fast (APD), Slow (APD Contrast)
Stimuli	ISTS speech at 65 and 80 dBSPL , female speaker in noise
Analysis	RMS-level, percentile values (1/3 octave)

Table 2. The settings used to perform measurements of the temporal envelope of speech in a Naída B hearing aid

Results

The results for the input of average level speech-in-quiet indicate that the dynamic of the signal was increased by up to 9 dB for the linear gain setting and up to 5 dB for the slow compression setting when compared to fast compression as seen in Figure 4.

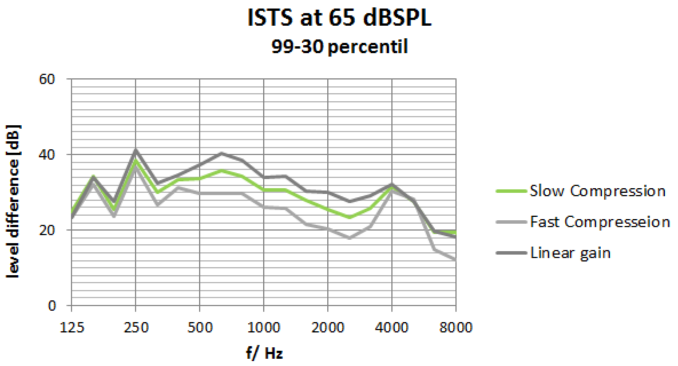


Figure 4. Measurement of the dynamic of the signal. Input 65dBSPL ISTS speech and processing condition linear gain, slow and fast compression.

In Figure 5a and 5b below, the results for loud level speech-in-quiet can be seen. They indicate that the dynamic of the signal was increased for the slow compression setting when compared to fast compression or linear gain.

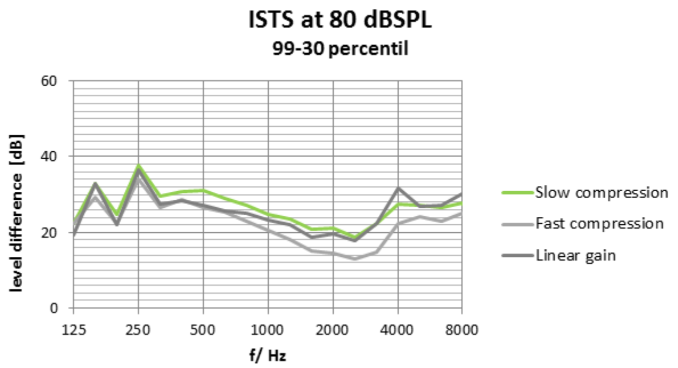


Figure 5a. Measurement of the dynamic of the signal. Input 80dBSPL ISTS speech and processing condition linear gain, slow and fast compression.

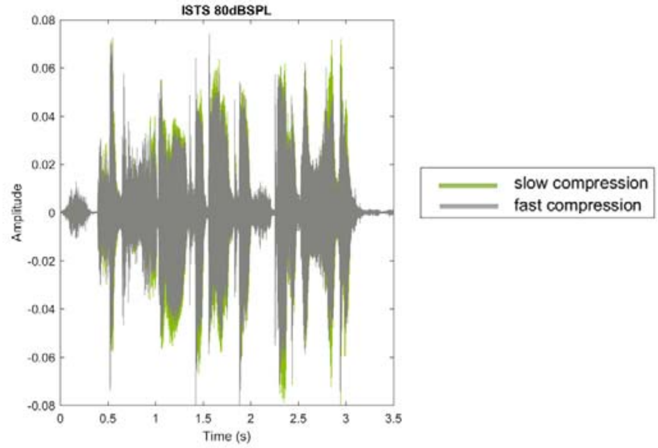


Figure 5b. Time-intensity waveform for a speech input (ISTS at 80dBSPL) measured in a Naída B. Slow compression is shown in green and fast compression in grey.

MPO and compression speed

For speech in noise, slow compression results in the highest increase in the temporal speech envelope, shown in Figure 6a and 6b. The results indicate that each of the signal processing strategies, linear gain, slow and fast compression, result in different output and therefore more or less likelihood of activating the MPO limiting.

With linear processing the limiting system will be reached earlier than with a fast compression signal processing system. This is an important observation for hearing care professionals who may wish to use linear gain or slow compression, for clients with loudness recruitment who have very restricted dynamic range and require a lower MPO to avoid loudness discomfort. In this case fast compression may be indicated.

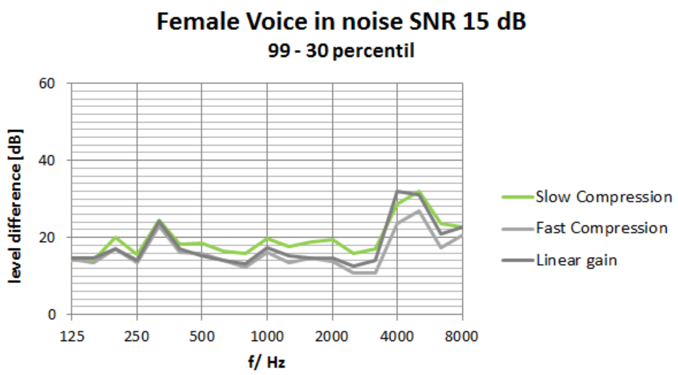
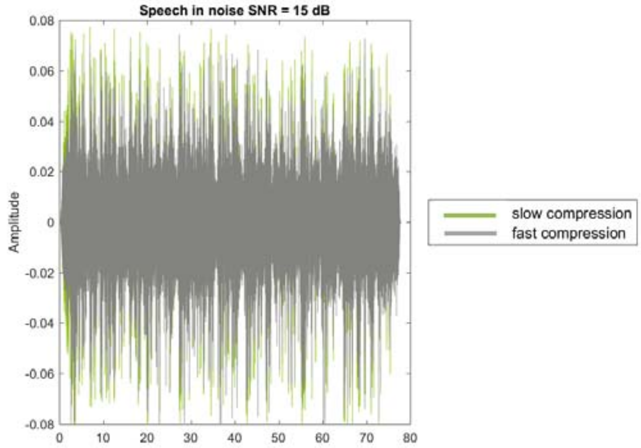


Figure 6a. Measurement of the dynamic of the signal. Input female speech in background noise of speech babble and processing condition linear gain, slow and fast compression.



6b Lower panel: Time-intensity waveform for a speech input (female voice at 65dBHL) in multitalker babble with a SNR of +15. Slow compression is shown in green and fast compression in grey.

In Naida B there is a new MPO limiting calculation which may help when more linear processing causes the limiting system to be reached earlier than with fast compression. This means that in Naída B, the MPO limiting calculation is the perfect complement to the new slow compression setting.

An example is shown in the speech maps shown in Figure 7 . The speech maps indicate that the loud broadband speech inputs are very similar in level at the output. For the MPO curves, measured with pure tones, the output level with the new calculation (yellow), is higher than the for the old limiter (blue).

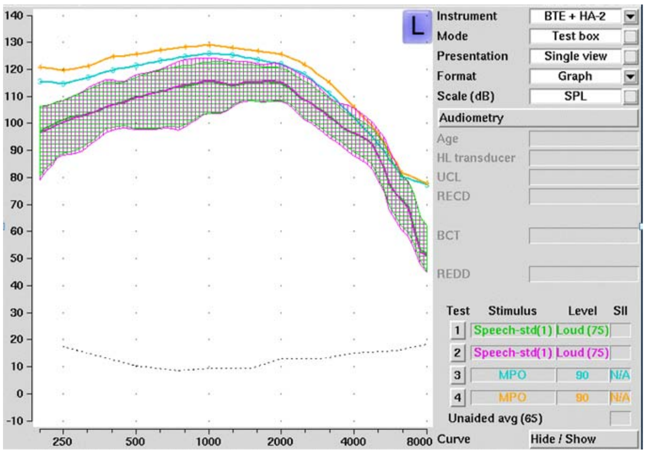


Figure 7. Speech map (Audioscan Verifit) of loud broadband output for input of male voice at 75dBSPL and MPO measured using pure tones at 90dBSPL. Fast compression is shown in green and blue and slow is shown in purple and yellow.

Conclusion and discussion

Many of our clients with severe to profound hearing loss are fitted with adequate amplification and report that speech is loud enough but continue to complain that speech sounds distorted (Souza 2015, p520) and in rare instances they outright reject digital hearing aids with fast compression. Although there are many factors which contribute to this, "problems are often attributed to a generalized problem resolving the spectral and/or temporal cues in speech."(Souza 2015, p520).

In the absence of conclusive evidence, each hearing care professional must make a case by case judgment for each client. Depending on their auditory abilities, individual clients with severe to profound hearing loss may benefit more from linear gain, fast or slow compression and some general guidelines can help.

Compression Sound Processing	Severe to profound hearing loss and assessment
Fast Compression	Recruitment resulting in restricted dynamic range requiring lower MPO.
Linear gain	Speech in quiet is the priority
Slow compression	Speech in quiet and in noise is the priority and adequate dynamic range available (≥ prescribed MPO).

Table 3 Summary of possible recommendations for severe to profound hearing loss. The recommendations assume reduced ability to resolve spectral and temporal structures in speech.

1) Fast compression

Many people with good speech understanding will enjoy the benefits of fast compression. For others with loudness recruitment which results in a very narrow amplitude dynamic range between hearing threshold and loudness discomfort and required the MPO to be set at a lower level than usual, then fast compression is the best and only option. Fast compression is designed to overcome the problem. For this group, slow or linear compression will increase the amplitude of the speech waveform compared to fast compression, which should be avoided.

2) Linear gain

Linear gain is recommended for people who do not cope well with compression when changing from analogue to digital devices. The measurements in Figures 4 to 6 above indicate that linear gain results in the greatest increase in the temporal envelope for speech in quiet but may be disappointing in noise or for louder input levels. After first listening to linear gain, slow compression might be preferred in a greater range of listening situations.

3) Slow compression

For clients with poor auditory resolution abilities and who rely on temporal envelope cues, slow compression is recommended, especially in noise. These individuals would be identified on the basis of clinical observations such as

- Speech discrimination poorer than expected for the audiogram configuration

- Amplification experience/ history with slow acting compression or linear gain
- Either or both of these in combination with a trial of the processing alternatives.

These guidelines are summarized in Table 3.

In conclusion, there is considerable scientific literature and no conclusive or easy answer about what is best when selecting slow or fast compression. As Dillon says, the only common finding is that there are individuals who prefer and perform better with fast or with slow compression. (Dillon 2012).

With Naída B, all hearing care professionals can choose linear gain and now they can also select fast or slow compression. Naída B is designed to meet the individual needs of clients with severe to profound hearing loss and provide hearing care professionals with the processing options they require. Adaptive Phonak Digital Contrast increases the envelope cues for speech compared to Adaptive Phonak Digital. Research shows that this may lead to improved vowel recognition. If slow compression is selected, it will work in perfect harmony with the new limiting system in Naída B.

For individual clients with severe to profound hearing loss, whatever their processing needs, Naída B provides every hearing care professional with the alternatives they require.

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