

Amplifying soft sounds - a personal matter

ABSTRACT

The first part of this white paper describes how amplification works in today's digital hearing aids and highlights the strength of Oticon's proprietary amplification technologies: VAC and Speech Guard. The second part is dedicated to the new features introduced with Alta 2 and Ria 2. An improvement in the feedback system allows the delivery of more soft gain without compromising sound quality - a feature that we call Soft Speech Booster, which improves soft speech understanding by up to 20%. Based on recent research results, we also introduce a new question and a new sound sample to personalise the amount of soft gain delivered to each listener - a personalisation that is visualised and fine-tuned with the new Soft Sound Perception trimmer.



Nicolas Le Goff
Ph.D.
Clinical Evidence
Oticon A/S

The importance of soft sounds

In the quietest moments of our lives, the sound level is around 50dB SPL or even lower. Those moments are filled by soft sounds and soft voices that carry particular feelings of closeness or comfort. Soft sounds are also present during everyday conversations in which the sound level is higher, typically around 60-70 dB SPL. This is because the level of speech varies quickly in time, by as much as 25 dB.

Figure 1 shows the waveform of a speech signal corresponding to the sentence “paint the sockets in the wall dull green”. The amplitude of the signal varies greatly as a function of time: plosives, such as “ck” in “socket”, can be 10-20 dB louder than vowels such as “a” in “wall” or sibilants such as “s” in “sockets”. The signal consists of a succession of “peaks” and “valleys” forming modulations. While the long-term average level of such a sentence is about 65dB SPL for a typical daily conversation, soft sounds around 40-50dB SPL are also present in the valleys, particularly at high frequencies.

The perception of soft sounds is not only important for a good hearing experience and communication in quiet environments, but it also supports speech understanding in everyday conditions. Furthermore, throughout the day, other background sounds (soft noises, distant sounds) are present in the valleys of speech signals (not shown here), which are important for a good connection with the environment.

Hearing-impaired (HI) listeners have a reduced ability to hear soft sounds. A person with a 50-dB HL threshold will most likely experience difficulty following a soft conversation if unaided. The same person will also miss

the softest parts of an average conversation, as well as distant sounds, because these sounds may be below the hearing threshold.

One solution could be to make all soft sounds easily audible by increasing the soft gain. While it is known that when speech is present in quiet, a higher soft gain is preferred, this is not the case in typical acoustical conditions with background noise and multiple sound sources (Sørensen, 2010). Bringing all soft sounds to the attention of the listener could require them to exert more effort in order to make sense of them, which is detrimental to listening comfort. Furthermore, a high amount of soft gain causes higher compression ratios, which may negatively affect sound quality.

Recent investigations [e.g., Marozeau (2007)] have shown that the perception of soft sounds is a personal matter. Some HI listeners may describe soft sounds as being actually soft, while other listeners may describe them as being moderately loud, making each individual’s ability to perceive and make sense of soft sounds markedly different.

In this white paper, we will first review how sound amplification works in hearing instruments. Then, we will explore what is special about Oticon’s solution: VAC and Speech Guard. Finally, we will focus on the new features introduced with Alta 2 and Nera 2: (a) an updated version of VAC that delivers more soft gain in a personalised and intelligent manner for up to 20% better soft speech intelligibility without compromising sound quality; (b) the new soft sound perception trimmer.

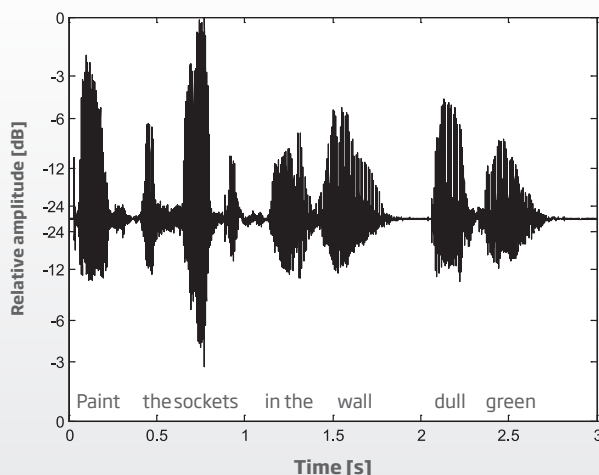


Figure 1: Three-second speech signal as recorded by a male speaker with time-aligned words

Amplification in hearing instruments

Sound amplification is the most fundamental feature of a hearing instrument. It is sometimes called “the compression”, but it relies on two components: the compression gain and a dynamic rule. The compression gain is displayed in the “Controls” panel in Genie. The dynamic behavior is indicated by the compression speed in the “Automatics Manager” in Genie.

Compression Gain

The key purpose for amplifying sounds in hearing instruments is to make any inaudible sounds below the hearing threshold audible. The issue is that amplifying sounds that are both below and above the hearing threshold with the same gain creates a very unnatural experience. For instance, let’s take a person with a 50-dB HL threshold. Amplifying an incoming sound that has a level of 30 dB SPL by 30 dB will increase its level to 60dB SPL and make it audible. However, amplifying normal 65 dB SPL speech with the same 30-dB gain will raise its level to 95 dB SPL, which may be perceived as too loud and unnatural.

The solution is to apply more gain on soft sounds than on louder sounds. How much gain should be applied on soft, moderate, and loud sounds is, however, a delicate matter, because amplification influences many perceptual aspects. Several strategies called “compression rationales” have been developed (NAL-NL2, DSL, VAC...). Each of them is a compromise between different perceptual and technical parameters (loudness, speech intelligibility, compression ratio...) and they each optimise a particular aspect. For instance, NAL-NL2 aims at optimising speech intelligibility without exceeding normal loudness levels. This compromise often comes at the cost of high compression ratios.

Figure 2 shows a typical compression gain applied to a moderate hearing loss. It is obtained by applying a compression rationale on the audiogram of an HI listener. Although differences between compression rationales can be significant, the gain calculated according to all rationales will show the same general pattern: high gain at low input levels that decreases as the input level increases.

Dynamic Rule

Figure 2 illustrates that a particular compression gain is applied for each input level. In a high-end instrument like Alta 2, the input level is measured 20,000 times per second. Does this mean that the compression gain should be updated 20,000 times per second? That would be like listening to music on a stereo system and adjusting the volume knob 20,000 times per second - turning it up when the level of the music goes down, and vice-versa. In effect, the level of the music would be more constant (“compressed”), but the music would be highly distorted.

To overcome this problem, the compression gain applied in hearing instruments does not change as quickly as the sound level. Instead, an estimate of the sound level is calculated over a short period of time and the gain is essentially maintained constant within this period. When the time window is shorter than 200 ms, the compression is described as “fast”. When the time window is longer than 200 ms, the compression is described as “slow”. This is the dynamic rule of amplification in a hearing instrument; it determines how fast the compression gain is updated.

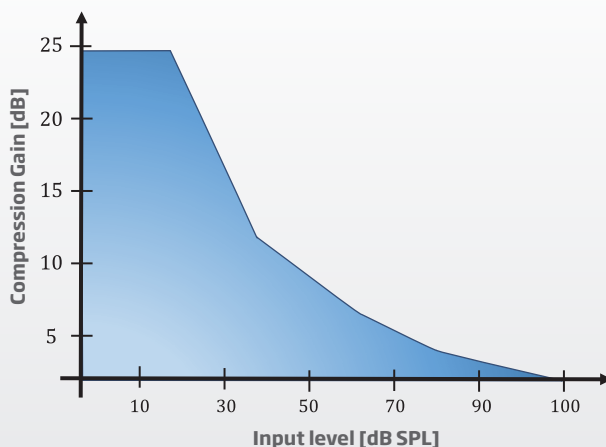


Figure 2: Compression gain as a function of the input level, i.e. “compression”. The characteristics are realistic, but have been arbitrarily chosen for the purpose of the illustration.

With fast compression, the gain is updated very frequently. When the sound level drops quickly, the amplification is quickly increased to maintain audibility. When a loud sound occurs, the amplification is quickly reduced to maintain comfort. This means that a fast compression is good at making the soft components (the valleys) of speech audible. The disadvantage is that the rapid changes in gain distort the fine details of the sound signals. In contrast, with slow compression, signals are better preserved and especially the modulations of speech signals are better maintained as a result of the more constant gain. The drawback, however, is that quick changes in sound level are not as well compensated for as with fast compression (Moore, 2008; Rudner, 2011), potentially compromising audibility and loudness comfort.

Oticon amplification

The amplification in high-end instruments like Alta 2 relies on our own compression rationale, "Voice Aligned Compression" (VAC), and our own dynamic rule, "Speech Guard".

VAC was introduced in 2004. It was based on new scientific findings on the lack of perception of soft sounds by HI listeners (Buss, 2001). It has been empirically optimised over the years to achieve an optimal combination of speech understanding and sound quality for our platform. One of the techniques used to optimise sound quality is the careful application of gain to adjacent channels - gain differences between adjacent channels cannot be too different in order to maintain continuity in speech cues across frequencies.

Speech Guard, introduced in 2010, is an adaptive dynamic rule, which combines the advantages of both slow and fast compression. It reacts very slowly (linear amplification) when the sound level remains within a 12-dB range - this is to preserve the temporal

modulations of speech - and it reacts very quickly when a sudden change in sound level occurs to maintain listening comfort and maximise audibility. Speech Guard is an advanced proprietary system and it effectively provides speech intelligibility that is superior to both fast and slow compression (Pittman, 2014).

VAC is celebrating its 10th anniversary with the release of Alta 2 and Nera 2. In celebration of the occasion, it has received two new features and a new name: VAC+.

New in Alta 2 and Nera 2

VAC+: Soft Speech Booster

Over the last ten years, the platform on which VAC runs has evolved considerably. The new version, Inium Sense, comes with a more robust anti-feedback system (Inium feedback shield). VAC+ capitalises on this improved robustness and can provide more soft gain without creating howling. Compared to VAC, VAC+ provides an increase of 3 dBs of soft gain to critical speech frequencies above 1.5 kHz. We call this increase in soft gain the "Soft Speech Booster".

Preliminary clinical testing has shown that VAC+ maintains the speech intelligibility achieved with VAC for listening conditions at moderate levels (65dB SPL), with some improvement, possibly due to the better amplification of the "valleys" of speech - further clinical trials are ongoing to confirm this. Results also show that VAC+ and Soft Speech Booster provide a clear and large increase in soft speech (50 dB SPL) intelligibility: 9% in average, with some users showing a benefit as high as 20%.

Differences in loudness perception of soft sounds

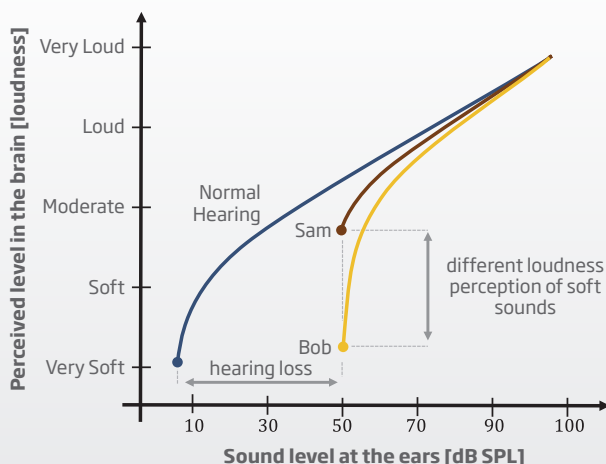
Such a benefit in speech intelligibility is a great achievement, and one may wonder what would happen if VAC+ provided even more soft gain.

Would speech intelligibility further increase? Would it come at the cost of sound quality or listening comfort? Is this a personal preference? While the research community continues to investigate these questions, recent publications suggest an important fact: the perception of soft sounds is a personal matter.

Reported data shows that the perception of soft sounds varies greatly among HI listeners (Marozeau, 2007). Some HI listeners may describe soft sounds as being actually soft, while others may describe them as being moderately loud. Such a difference can even occur in HI listeners with the same audiogram.

Figure 3 shows how the perception of sound level in the brain (loudness) varies as a function of the sound level at the ears. This loudness growth function is shown for a normal-hearing (NH) listener (blue), and two HI listeners, Bob and Sam. Bob and Sam are two extreme, illustrative cases. They both have the same hearing threshold (in this case, 50 dB HL), but their hearing experiences are very different.

- Bob (yellow line) perceives sounds just above 50dB SPL as being soft. In fact, the softest sounds Bob can hear are almost as soft as those perceived by a NH listener. Bob's line shows a loudness growth referred to as "loudness recruitment" (Moore, 1977). It is characterised by a close-to-normal loudness near the hearing threshold, and a fast growth (see the steep slope) of loudness for sound levels above the hearing threshold.
- Sam (red line) perceives sounds just above 50dB SPL as being much louder than Bob. In fact, the softest sounds he perceives are already moderately loud for him. Sam's line shows a loudness growth known as "softness imperception" (Buss, 2001). It is characterized by the fact that he cannot hear soft sounds as being actually soft.



The hearing experiences of Bob and Sam are surely very different, and further investigations are necessary to understand their respective perceptions. Based on discussions with HI listeners, we have gathered some insights: A listener like Bob can actually hear soft sounds as being soft; he likes them and wants to hear all of them. They make sense to him and enrich his hearing experience. In contrast, a listener like Sam has difficulties coping with all the soft sounds in his environment, which he tends to describe as "noise" rather than sound. He has difficulties making sense of these soft sounds.

Data has shown that the loudness growth of individual HI listeners can fall anywhere between the two extreme illustrative cases of Bob and Sam (Marozeau, 2007). Given this knowledge, we asked ourselves: if two HI listeners with the same audiogram perceive sounds just above their hearing thresholds differently, should they all have the same amplification for those sounds? We think not, and for that reason we have introduced personalisation in VAC+.

VAC+: Personalisation and the Soft Sound Perception trimmer

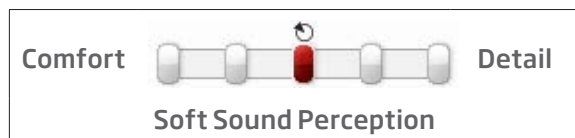
Soft Speech Booster can provide plenty of soft gain without compromising on sound quality, but research has shown that each individual HI listener perceives the presence of soft sounds differently.

Naturally, the next step was to personalise the prescription of soft gain (compression gain) of VAC+ or, in other words, to personalise the extra soft gain delivered by the Soft Speech Booster.

Figure 3: Loudness growth function for normal hearing and two hearing-impaired listeners with an arbitrary 50-dB hearing loss with different loudness growth.

Figure 4 illustrates how the soft gain delivered by Soft Speech Booster is personalised: as Bob can hear soft sounds, the lowest knee-point is moved toward lower sound levels to give him access to more soft sounds. In contrast, the knee-point is at a higher level for Sam, in order to reduce the amount of soft sounds. For both, the amplification and compression ratios for moderate and loud sounds are the same, in order to maintain speech intelligibility at moderate levels.

This personalisation is achieved by adjusting the position of the lowest knee-point of VAC+ based on a new question and a new sound demo (see the next section). The personalisation results are displayed by a new trimmer called the "Soft Sound Perception trimmer", located in the Control Panel:



The trimmer has five steps in total. The prescribed position is shown by the target sign, and it can be further fine-tuned. The extreme positions are called "comfort" and "detail". Towards "comfort", the response of VAC+ is as shown for Sam in Fig. 4 - soft sounds receive less gain, and less soft sounds are audible. Towards "detail", the response of VAC+ is as shown for Bob. Soft sounds receive more gain, and more soft sounds are made audible.

The position of the lowest knee-point of VAC+ depends on the level of the hearing loss and the position of the soft sound perception trimmer. For a moderate hearing-loss, the knee-point is close to a 45-dB SPL input level and moves towards lower levels for more severe hearing loss, without going under 26 dB SPL. This position is then further adjusted depending on the Soft Sound Perception trimmer, which can also be seen as a compression threshold trimmer: Each step corresponds to a 5-dB shift of the lowest knee-point.

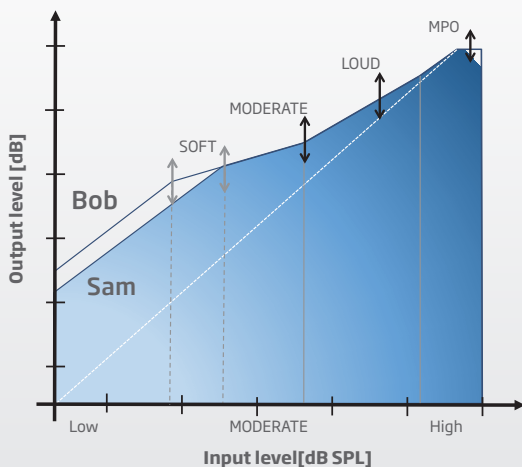


Figure 4: Input/Output function of VAC+ for the two listeners Bob and Sam. Double arrows show the effect of the current gain trimmer in the control panel/gain matrix in Genie - they affect gain and compression ratios. The new "soft sound perception" trimmer does not modify the gain and compression at medium and higher levels. Expansion/Soft Squelch not shown.

Furthermore, to maintain sound quality and stability, the knee-point is automatically maintained between 20 and 50 dB SPL.

An enriched fitting flow

The new question and the new sound on the Personal Profile page were designed to prompt the client to make a decision: Do I want more details in the sound, or do I want more comfortable sound? Thirty hearing care professionals and 200 clients were interviewed to examine the question and the sound demo to verify that they help identify the patients who are more like Bob and those who are more like Sam. The new question is therefore "I prefer a more comfortable sound even if it takes away the softer details in the sound." The sound demo features a distant background noise consisting of multiple talkers and other environmental sounds.

The answer to the question, as well as the prescribed Personal Profile, sets the position of the soft sound perception trimmer as follows:

Profile/answer	Yes	No
Gentle	+5dB	0 dB
Balanced	0 dB	-5 dB
Exact	0 dB	-5 dB

Table 1: Shift in the knee point input level as a function of the personal profile and the new question. +5dB correspond to the position just left of the centre. -5dB correspond to the position just right of the centre.

Our internal survey shows that 50% of patients will be prescribed a trimmer setting in the centre (default VAC+), 35% will receive more soft gain, and 15% will receive less soft gain. Furthermore, this distribution is age-dependent, with a tendency to prescribe more details to younger patients (up to 55% for persons below 60 years old), and more comfortable sounds for older patients (up to 25% for persons above 80 years old).

Conclusion

Sound amplification is the most fundamental feature of a hearing aid. It is made up of a compression gain and a dynamic rule that are prescribed to optimise many perceptual aspects (audibility, intelligibility, loudness, quality...). With VAC+, we capitalise on the improvement of the Inium Sense platform and introduce Soft Speech Booster - a feature that allows for the delivery of more soft gain without compromising sound quality and that improves soft speech intelligibility by up to 20%.

Most rationales prescribe compression gain based on the audiogram alone. This is an approach in which only cochlear damage is taken into account. With VAC+, we not only acknowledge that the cochlea is damaged, but also that the perception in the brain (loudness) has changed. VAC+ now provides amplification based not only on the hearing loss in the cochlea, but also on how loud sounds close to the hearing threshold are perceived in the brain.

References

- Buss, M., and Florentine, M. (2001), "Growth of Loudness in Listeners with Cochlear Hearing Losses: Recruitment Reconsidered", *Journal of the Association for Research in Otolaryngology*, pages 120-139
- Marozeau, J., and Florentine, M. (2007), "Loudness growth in individual listeners with hearing losses: A review", *Journal of the Acoustical Society of America: JASA express letters*, pages EL81-EL87
- Moore, B. C. J. (1977), "An introduction to the psychology of hearing", Macmillan, London
- Moore, B. C. J. (2008), "The Choice of Compression Speed in Hearing Aids: Theoretical and Practical Considerations and the Role of Individual Differences", *Trends in Amplification*, vol. 12, pages 103-112
- Rudner, M., Ronnberg, J., and Lunner, T. (2011), "Working Memory Supports Listening in Noise for Persons with Hearing Impairment", *Journal of the American Academy of Audiology* vol. 22, pages 156-167
- Rönnberg, J., Rudner, M., and Lunner, T. (2011), "Cognitive Hearing Science: The Legacy of Stuart Gatehouse", *Trends in Amplification*, Vol. 15, pages 140-148
- Sørensen, H. C. (2010), "Hearing aid amplification at soft input levels", PhD thesis, Technical University of Denmark
- Pittman A. L., Pederson A. J., and Rash, M. A. (2014), "Effects of Fast, Slow, and Adaptive Amplitude Compression on Children's and Adult's Perception of Meaningful Acoustic Information", *Journal of the American Academy of Audiology*, pages 834-847

People First

People First is our promise to empower people to communicate freely, interact naturally and participate actively