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PERSONALIZED COMPRESSION WITH WIDEX MOMENT™

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A fundamental problem for people with hearing loss is that in order for sounds to be audible they need to be louder than they need to be for people without hearing loss, while the levels at which sounds become uncomfortably loud are much more similar between people with and without hearing loss. This gives the individual with hearing loss a reduced *dynamic range* within which to represent all sounds, whether soft, normal, or loud, as illustrated in Figure 1.

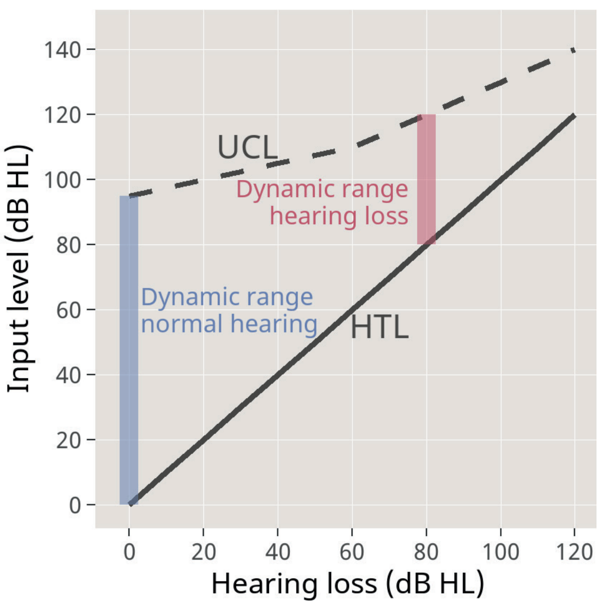

Figure 1: The relationship between hearing threshold level (HTL, solid line) and uncomfortable level (UCL, dashed line) shows the difference in dynamic range between people with (red) and without (blue) hearing loss. For the sake of simplicity, the figure does not take into account different HTLs at different frequencies. Based on Pascoe (1988).

Hearing aids solve this by non-linear amplification, using *compression* of the full range of sounds to fit into the dynamic range of the wearer: Soft sounds must be amplified relatively more and loud sounds relatively less, of course also taking into account the hearing aid user's hearing thresholds at different frequencies.

This WidexPress outlines the basics of compression and presents the pros and cons of different types of compression, before explaining how the Widex Variable-Speed Compressor works. Extensive research on different types of compression supports the idea that compression should be personalized, and we present the innovative way this is done with the updated AI engine in the Widex Moment app.

COMPRESSION

The logic of linear vs. non-linear amplification is illustrated in Figure 2. The dashed line shows linear amplification where the same amount of gain – in this example 15 dB – is applied for all input levels. This means that every 1 dB increase in output (vertical axis) represents a 1 dB increase in input (horizontal axis) – i.e., a 1:1 input/output ratio, seen in the 45-degree angle of the dashed input-output curve. Due to the limited dynamic range of a listener with hearing loss, using this approach alone means that either loud sounds get too loud or soft sounds become inaudible – or both.

Moreover, the loudest sounds are likely to be distorted and would, in a real-world case rather than in this example case, be limited at very loud output levels. By contrast, the solid line in Figure 2 shows non-linear amplification, where different input levels receive different amounts of gain. This is the input/output curve for 2 kHz input to a Widex fitting of an N3 hearing loss (Bisgaard et al., 2010).

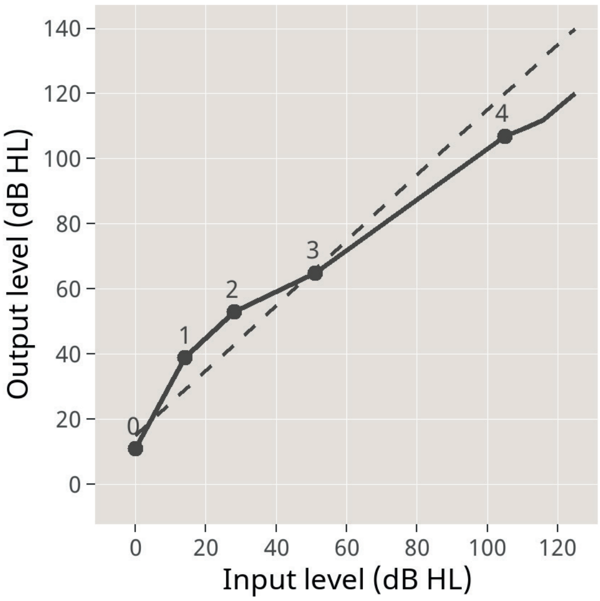

Figure 2: Linear vs. non-linear amplification. The non-linear graph is based on values for 2 kHz for an N3 hearing loss fitted with the Widex Fitting Rationale. The solid line shows the combined effect of output from the hearing aid and direct transmitted sound.

The graph shows how different ranges of input level have different compression *ratios*, which refer to the change in input level that produces a 1 dB change in output level. A compression ratio of 1 – i.e., a ratio of input to output of 1:1 – represents linear amplification as illustrated by the dotted line. Ratios above 1 represent compression, as seen for instance on the solid line between the points labelled 2 and 3, where every 1 dB increase in output represents a 1.9 dB increase in input, i.e., a compression ratio of 1.9. This means that as input sounds get louder, the output also gets louder, but the output increase is smaller than the input increase. This is indicated by a compressed input/output curve that is less steep than the 45-degree angle of linear amplification.

By contrast, *expansion* is when the compression ratio is below 1, which means that the output increases by more than the input does. This is used in the lower input ranges to decrease the audibility of the very softest sounds, including those produced by the hearing aid itself, while making sounds that are slightly louder, but still soft, audible. This is seen between points 0 and 1 in Figure 2, where every 1 dB increase in output represents 0.5 dB increase in input, i.e., a ratio of 0.5.

The numbered points are so-called compression *thresholds* or *knee points* – points at which the compression ratio changes. For Widex hearing aids, the lowest knee points are generally relatively low, but specifically defined by the hearing loss of the individual at a given frequency. This customization for the individual user is characteristic for the Widex sound and central for achieving a great sound quality that is tailor-made for the user.

The input/output curve illustrated in Figure 2 is for an N3 hearing loss (Bisgaard et al., 2010) for 2 kHz input; for other input frequencies and hearing losses, it looks different. Crucially, the input/output curves are designed to work together for all 15 bands and tailored to the individual's hearing loss.

Both compression ratios and knee points are important to the sound of any hearing aid, along with a third parameter: *compression speed*. This refers to the speed of gain changes in the hearing aid in relation to changes in input level. Such input level changes may be large sudden changes in the environment, such as a door slamming, an engine suddenly stopping, or applause after a speech, or small fluctuations such as the modulations and silent pauses of speech. Broadly speaking, fast-acting (or fast) compression means faster gain changes, which can be quite abrupt, while slow-acting (or slow) compression means slower, smoother changes. The ideal is a compression system that responds to changes in input level to ensure audibility, while preserving all relevant cues without creating artefacts.

Compression speed is determined by *attack time* and *release time*. The time within which the compressor reacts to an *increase* in input level by *reducing* gain is known as attack time, while release time is the time within which the compressor *increases* gain in response to *decreased* input levels. How quickly gain is reduced in response to sudden increases in input levels is crucial to protecting listeners against too loud input, which means that attack times must be fast: indeed, they are commonly around 5 ms (Dillon, 2012). Research and discussion about compression speeds therefore center mostly on release times, i.e., how quickly gain is increased when the input level decreases. Release times may be up to 20 seconds, with short release times typically defined as below 50 ms and long release times as above 500 ms (Kuk et al., 2018; Kuk & Hau, 2017).

PROS AND CONS OF FAST AND SLOW COMPRESSION

Both fast and slow compression come with advantages and disadvantages, which also depend on compression ratios and knee points. The full system is complex, with many interdependencies, and the research on the effects of different choices is not always clear-cut. Nevertheless, some broad trends emerge and are discussed in the following.

The primary advantage of fast compression is that it quickly adapts to the input level and thus more quickly represents changes in the listening environment. This, for instance, makes soft sounds following loud sounds more audible. It also allows softer speech sounds, typically unvoiced consonants, to be amplified relatively more than louder speech sounds, typically vowels. By altering the intensity differences between loud vowels and soft consonants, the soft consonants may become more audible.

However, these advantages come at a cost: Fast changes in gain alter the temporal envelope of the signal, which is problematic in several ways. First, and most generally, it is detrimental to sound quality (Boike & Souza, 2000; Hansen, 2002; Neuman et al., 1995; Souza, Arehart, Shen, et al., 2015). Second, for listeners with poorer working memory, a degraded temporal envelope is likely to be problematic for speech intelligibility (Cox & Xu, 2010; Kuk & Hau, 2017; Souza, Arehart, & Neher, 2015; Souza, Arehart, Shen, et al., 2015; Souza & Sirow, 2014). Third, altering the intensity differences between speech sounds may make them harder to identify and understand (Dillon, 2012). And, finally, fast compression makes ambient noise more perceptible in quiet surroundings, while silent pauses in speech may be perceived as a pumping noise (Kuk & Hau, 2017).

Slow compression, on the other hand, preserves the temporal envelope and the identity of speech sounds better than a fast-acting system. This allows higher naturalness and better sound quality (Boike & Souza, 2000; Hansen, 2002; Neuman et al., 1995; Souza, Arehart, Shen, et al., 2015), as well as increased listening comfort (Moore, 2008). In addition, slow compression better preserves inter-aural level differences, which are crucial for sound localization (Kuk & Hau, 2017). And for hearing aid wearers with poor working memory (Cox & Xu, 2010; Kuk & Hau, 2017; Souza, Arehart, Shen, et al., 2015) and more severe hearing losses (Davies-Venn et al., 2009; Souza et al., 2005), the preservation of the temporal envelope of speech using slow compression seems particularly beneficial.

The effect of different release times is illustrated in Figure 3 for a speech signal in moderate background noise. The upper waveform shows the signal recorded through a hearing aid with a long (slow) release time of above 1 second, while the lower waveform shows the same signal recorded with a short (fast) release time of 30 milliseconds. The peaks and valleys of the signal intensity are clearly better preserved with the slower release time in the upper waveform. In the lower waveform, the faster compression reduces the intensity differences, resulting in the background noise getting amplified during pauses in the speech. The temporal envelope is better preserved with the slower compression, resulting in a better sound quality experience for all and better speech intelligibility for hearing aid wearers with worse working memory or more severe hearing losses.

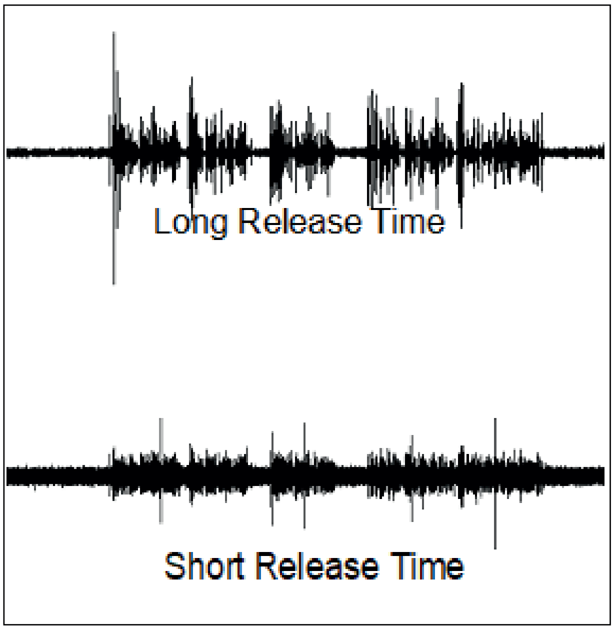

Figure 3: Waveforms for a speech signal recorded through a hearing aid using compression, with a long (slow) release time of above 1 second in the top panel and a short (fast) release time of 30 msec in the lower panel. The temporal envelope and the intensity differences between different speech sounds are clearly better preserved for the longer release time in the upper waveform.

A major disadvantage of using a slow-acting compressor by itself is that soft sounds immediately following loud sounds may be inaudible, because the gain does not rise fast enough. Additionally, individuals with high working-memory capacity may get better speech intelligibility with a fast compressor, because they benefit from the increased audibility of certain sounds but are less affected by the distorted temporal envelope than people with lower working-memory capacity (Kuk & Hau, 2017). The pros and cons of fast and slow compression are summarised in Figure 4.

	Slow	Fast
Pros	**Temporal envelope preserved** **Superior sound quality** **Signal integrity** *Benefit for poor WM & high HL*	Audibility of soft sounds *Potential benefit for good WM*
Cons	Reduced audibility of soft sounds	Degraded envelope Artefacts Reduced sound quality

Figure 4: Summarizing the advantages and disadvantages of fast and slow compression. WM = working memory, HL = hearing loss.

VARIABLE-SPEED COMPRESSION

As demonstrated above, both slow and fast compression have their advantages. However, the disadvantages associated with fast compression are more severe than those for slow compression, with fast compression resulting in reduced sound quality for all and reduced speech intelligibility for those with more severe hearing losses or poorer working memory capacity.

This is the reasoning behind the Widex Variable-Speed Compressor (VSC), which includes both fast and slow elements but is dominated by slow compression in order to provide the most natural, faithful representation of the sound at the eardrum – a constant goal for Widex.

The basic operation of the VSC is slow compression, but faster changes are allowed in certain circumstances. These depend on the changes in input level as well as on the timing of the fluctuations in the input level; in general, faster changes are allowed with larger changes in input level. Crucially, the fast element will only be active in quiet situations or in situations with good signal-to-noise ratio (SNR). This is in order to avoid the background noise in situations with poor SNR being amplified, thus further reducing SNR.

With the dominance of the slow compressor, sound quality is prioritized, while the addition of a fast element increases the audibility of soft sounds and the intelligibility of speech in relevant situations (Kuk et al., 2018; Kuk & Hau, 2017).

PERSONALIZATION OF COMPRESSION

Although there is a strong case for a variable-speed compression system, it remains a fact that "some patients prefer and/or perform better with fast compression whereas others prefer and/or perform better with slow compression" (Dillon, 2012, p. 196). Several of the studies that showed sound quality advantages for slow compression also indicated a considerable degree of individual variation in listeners' compression speed preferences (Cox & Xu, 2010; Hansen, 2002; Neuman et al., 1995). On top of this variation in sound *preference*, Souza, Arehart, & Neher (2015) argue that differences in *performance* are likely to arise from large individual variation between listeners.

In addition to differences between individuals, preference and performance are also likely to vary between different noise types (Lunner & Sundewall-Thorén, 2007) and between different speech materials (Foo et al., 2007), i.e., as a function of the situation that the individuals find themselves in. In short, preference and performance with different compression speeds vary between both individuals and situations, making it an ideal parameter to personalize for the specific hearing aid wearer in the specific situation.

PERSONALIZATION WITH MYSOUND

Personalization with Widex hearing aids is based on the hearing aid user being provided with an optimal individualized fit that seamlessly classifies and processes the sound in a way that suits most users most of the time. However, even the best automatic processing cannot predict the listening intention and preferences of every single user in every single situation (Balling et al., 2021). Therefore, Widex hearing solutions also provide the option to personalize specific parameters in specific real-life situations.

This personalization works by using AI in the Widex Moment app, through the functionality Widex MySound™ (see Figure 5). The original MySound allows the user to adjust gain in three frequency bands in two different ways: MySound 'Made for you' and MySound 'Create your own'. In both cases, the starting point is the user indicating their current listening activity and intent (Figure 5a). They are then presented with MySound 'Made for you' (Figure 5b) – two recommendations based on the preferences of other MySound users in similar situations, using AI algorithms as described by Balling et al. (2021). These crowd-sourced situational recommendations are chosen in most situations, but more specific personalization is also available with MySound 'Create your own' (lower half of Figure 5b).

MySound 'Create your own' is based on a series of A-B comparisons of different sound settings. At each step, the user listens to two different sound settings and indicates their degree of preference in a simple interface (Figure 5c). Based on these preference ratings, the underlying AI engine calculates settings that are optimized to the user's preferences. This allows the user to adjust the sound in the moment without having to understand complex controls – and without having to translate their sound experiences into language that their hearing care professional may or may not be able to translate back into hearing aid settings at a later stage.

Previously, MySound worked by adjusting gain in bass, middle, and treble frequency bands, which has positive effects on ratings of sound quality (Jensen et al., 2019; Jensen & Townend, 2019; Townend et al., 2018, see Figure 6) and listening comfort (Townend

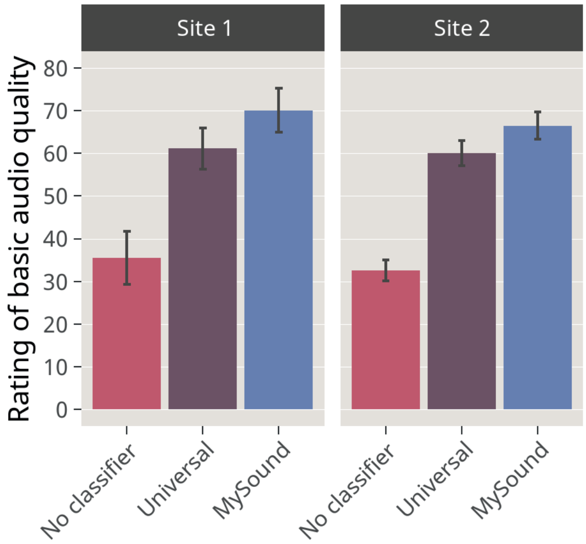

Figure 6: Ratings of sound quality from two studies of the MySound AI engine, with n = 19 for Site 1 and n = 20 for Site 2. The ratings improve drastically from the condition with no classifier to the automatic classification in the Universal program, with significant additional improvements for the personal programs created with the AI engine behind MySound. Figure adapted from Jensen & Townend (2019).

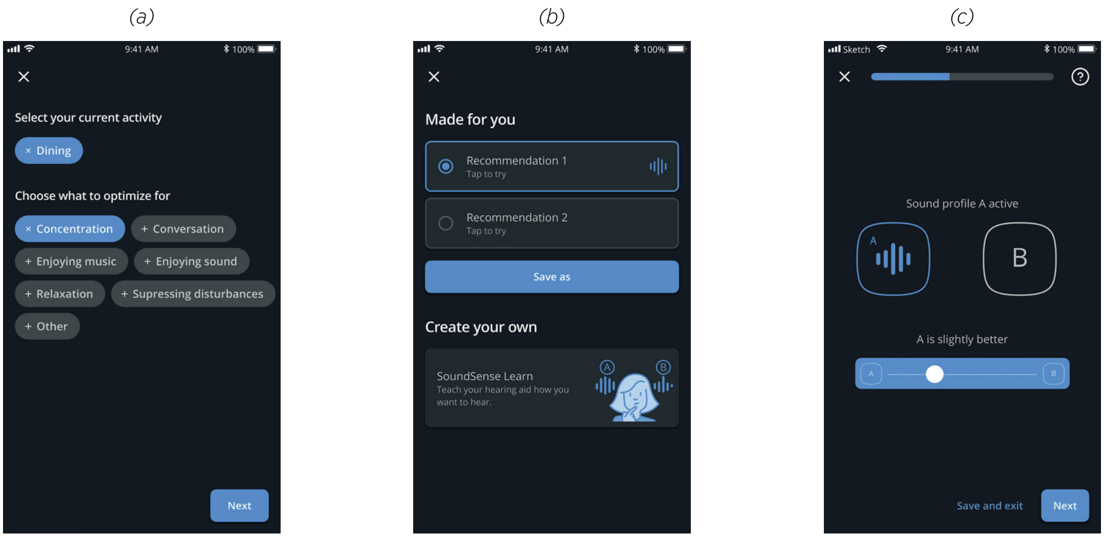

Figure 5: The process of creating a personal program using MySound: (a) Selecting activity and intention; (b) Choosing one of the two 'Made for you' options, or 'Create your own'; (c) A-B comparisons of two sound settings to create personalized settings using AI.

et al., 2018) and gives a majority of listeners the experience of being able to improve a listening situation (Balling et al., 2019). The updated MySound in the Moment app version 1.5 still adjusts gain in the three frequency bands but adds the operation of the fast compressor as an additional parameter.

COMPRESSION IN MYSOUND

The updated AI engine in MySound allows the user to manipulate how the fast compressor works around the working point of the slow compressor. This means that overall gain is still mainly determined by the slow compressor (for the reasons outlined above), but the balance between louder and softer sounds may be adjusted by the user to their specific tastes in the specific environment.

The way the fast compressor manipulations translate into sound experience for the user may be illustrated through a situation with a mixture of loud sounds coming from a source relatively close to the listener and softer sounds coming from further away. With expansion, the angle of the input-output curve is steeper (see Figure 2), giving relative emphasis to the louder sounds. With compression, the angle is less steep (see Figure 2), giving relatively more amplification to the soft sounds. This means that a more compressed sound may make it easier to hear sounds coming from a distance, giving an impression of acoustically opening up the environment. Conversely, more expansion emphasizes louder sounds in the environment and can therefore allow emphasis on nearer sounds (which tend to be louder) and reduce interference from more distant sounds, including noise in noisy situations.

Importantly, as with previous generations of MySound, the user does not manipulate the signal processing settings directly – which, indeed, very few users would likely be able to do in a meaningful way. Instead, the user simply indicates how much they prefer different settings in a series of A-B comparisons, which is a relatively simple task, but one which provides sufficient information for a powerful AI engine to create personalized settings. In the current version of the Moment app, the compression parameter is not integrated in the recommendations provided under ‘Made for you’ but is available to those users who use the ‘Create your own’ function.

PERSPECTIVES

As demonstrated above, there is a strong case for personalization of compression for the individual hearing aid user. This is something that has until now been limited to adjusting gain and compression in the fitting software – a cumbersome process of translating sound experiences to compression settings in a situation that is far removed from the environment where changes might be needed. The adjustment of fast compression in the MySound AI engine does not cover the full range of possible compression settings, but it does enable the user to personalize compression in a completely new way, and as such it represents an important first step. It also represents a substantial increase in the possibilities for personalization in MySound, coming on top of the existing adjustments of gain in different frequency bands.

More generally, it remains a central tenet of the way Widex designs hearing solutions that a great individualized fit in the clinic may be followed up with in-the-moment personalization by motivated users, who feel empowered by their ability to control their sound. Crucially, this personalization relies on an industry-leading combination of sophisticated AI, data from a large community of users, and personal input from the specific person in the specific situation. Adding compression to the list of parameters that can be personalized takes this approach an important step further.

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