SEPTEMBER 2014

PROVIDING COMFORT WITH LOUD SOUNDS

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For as long as hearing instruments have existed, users have complained about some sounds being too loud – and they still do. The complaint somewhat contrasts with the technological advances of hearing instruments. Technology is only one part, however, and its proper use is another. With respect to comfortably loud sound, technology can predict reasonable maximum power output (MPO), but user satisfaction depends on verification and individual adjustments and, if necessary, accurate measures of uncomfortable listening level (UCL). To strengthen the competency of these tasks, we aim to present background knowledge and practical guidelines for MPO verification and UCL measurement. We will also provide insight into how the Oasis fitting software guides you from average or measured UCL to MPO.

COMFORT WITH LOUD SOUNDS – AN ONGOING ISSUE

Despite the advances of digital technology, hearing aid users are still struggling with loud sounds. In a customer survey entitled "Consumer satisfaction with hearing aids is slowly increasing", Kochkin (2010) described the areas with the highest negative ratings regarding hearing aid signal processing and sound quality. Among the top five were *use in noisy situations* and *comfort with loud sounds*. How can the satisfaction in these two categories be improved?

In current hearing instruments, improving the performance in noise is the objective of various features, such as directional microphones and noise reduction systems. Both provide additional comfort, but they may divert attention from a more basic part of the fitting: maximum power output (MPO).

MPO limits the sound pressure level to which a client is subjected. It therefore has a significant effect on overall client satisfaction. When clients complain about sounds being too loud, the reason may be that the MPO is too high. In contrast to such complaints, there is also a risk of MPO being too low. In this case, speech sounds muffled and is difficult to understand (Bentler & Cooley, 2001).

Well-established procedures in the fitting software provide sensible MPO estimates for four out of five clients (Dillon, 2012). Measured values of UCL are, therefore, no longer a prerequisite for a fitting session. Whenever the MPO is too high or too low, it needs to be adjusted. For the one in five who requires it, setting MPO to a suitable value commonly begins with the uncomfortable loudness level (UCL) measurement, or its equivalent: the loudness discomfort level (LDL).

DEBATE ON THE USE OF UNCOMFORTABLE LEVELS IN THE FITTING FLOW

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As the method of fitting changed over time, so did the expert opinion on the fitting flow. In the past, experts stipulated the measurement of UCL prior to fitting, but now they favor its use for verification and validation after fitting. In fact, when Hawkins et al. (1987) discussed the LDL measurement procedure, they claimed that the LDL had to be measured for determining maximum hearing aid output. Their claim reflects the process before digital hearing instruments and fitting software were available.

By the year 2005, the opinion began to change. Mueller and Bentler evaluated the effectiveness of UCL measurements, reviewing nearly 200 articles. They concluded that the evidence "tends to support the use of clinically measured frequency-specific LDLs" (p. 470), but they refrained from making a strong recommendation.

Seven years later, Dillon (2012) reported that if "threshold-based prescription was used, individual measurements of LDL did not significantly improve fitting accuracy" (p. 328). Therefore, he concluded that the clinical time saved is better utilized for subsequent evaluation.

Despite these differing opinions of when to complete UCL measurement, it still remains an important step in the fitting process. In the light of this fact, we will discuss the measurement of UCL, its use by Oasis, and the validation and verification of MPO.

The UCL measurement is prone to inconsistent results for a number of reasons: individual behavior of clients, variety of procedures, and interpretations of instructions.

MEASUREMENT OF UNCOMFORTABLE LOUDNESS

The UCL denotes the hearing level at which a client finds sounds uncomfortably, but not painfully, loud. In contrast to the straightforward definition, the UCL measurement is prone to inconsistent results for a number of reasons: individual behavior of clients, variety of procedures, and interpretations of instructions. In an attempt to minimize these difficulties, we will recommend the Cox Contour Test (Cox et al., 1997), a "scientifically defensible procedure that is, at the same time, clinically practicable" (p. 389).

Clients' individual behavior refers to people's moods and feelings associated with certain sounds. Both impact the level of loudness that they are willing to tolerate. A good example is the level of music they enjoy during a party, but dislike it the next morning. Likewise, people enjoy the cheers in a football stadium, but dislike an equally loud sound of fingernails scratching a chalkboard (Mueller, 2009).

A similar argument applies to the pure tones used for the frequency-specific measurement of UCL. Most clients find them less pleasant than real-world sounds, which introduces a potential bias.

Compared to other measurement procedures, the Cox Contour Test (Cox et al., 1997) helps clients judge the loudness of sounds on the basis of a 7-category loudness chart, as shown in Table 1.

Table 1. Loudness descriptors from the Contour Test (Cox et al., 1997) for use when measuring LDLs

Loudness Categories

7.	Uncomfortably loud
6.	Loud, but o.k.
5.	Comfortable, but slightly loud
4.	Comfortable
3.	Comfortable, but slightly soft
2.	Soft
1.	Very soft

According to Table 1, category 1 refers to very soft sounds, whereas category 7 refers to uncomfortably loud. The authors recommend reviewing the chart with clients and keeping it in their sight during the test. In order to avoid biased interpretations, the authors also recommend reading the following instructions to the client:

> The purpose of this test is to find your judgments of the loudness of different sounds. You will hear sounds that increase and decrease in volume. You must make a judgment about how loud these sounds are. Pretend you are listening to the radio at that volume. How loud would it be? After each sound, tell me which of these categories best describes the loudness. Keep in mind that an uncomfortably loud sound is louder than you would ever choose on your radio no matter what mood you are in. (Cox et al., 1997)

Such an established test protocol offers the best conditions for achieving meaningful and reproducible results.

Oasis does not impose a particular method but supports all options by providing the appropriate tools.

WITH OASIS FROM UNCOMFORTABLE LOUDNESS TO MAXIMUM POWER OUTPUT

Now that you have completed the UCL measurement, what should you do with it? As previously described, the role of UCL in determining MPO has changed with the technology. The fluctuating expert opinions certainly complicate the decision of whether you should incorporate UCL into the MPO calculation. Ultimately, there is not one specific technique of selecting an MPO setting; rather different methods and practices co-exist. In response, Oasis does not impose a particular method but supports all options by providing the appropriate tools. To let you see how Oasis fulfills its task, we will address the following questions:

- How does Oasis transform UCL values into MPO settings?
- How does Oasis proceed when you don't provide measured UCL values?
- Why may MPO settings seem too low?
- What options does Oasis offer you to adjust MPO?

Transformation of UCL Values into MPO Settings

The transformation of UCL values into MPO settings requires three steps: Reference Equivalent Threshold Sound Pressure Level (RETSPL), Real Ear to Coupler Difference (RECD), and narrow band to broadband (NBBB) conversion. These steps are shown in Fig. 1.

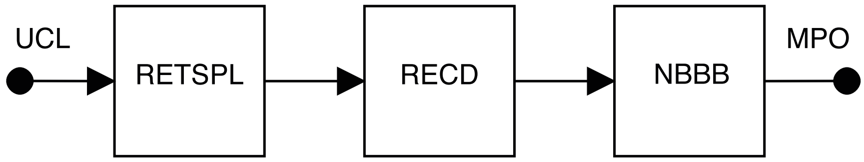

Figure 1. Block diagram of transformation from UCL to MPO

When you measure UCL, you normally use pure tones through insert or supra-aural earphones with the results expressed in dB HL. First, Oasis converts these dB HL values into 2cc coupler values. This is accomplished by adding the RETSPL to the HL. The RETSPL is the average hearing threshold in a coupler for a particular transducer. The ISO 389-1 (1998) standard provides the transducer specific RETSPL values.

The next step is to convert the 2cc coupler values to ear canal SPL by adding the RECD. For this purpose, Oasis uses age-specific average RECD values, or individually measured values if available. For children or those with abnormal ear physiology, it is always recommended to measure the RECD.

The final step requires a slight reduction of the SPL in order to balance the change from a narrowband to a broadband or complex signal. Pure tones are narrowband signals, and, speech, for example, is a complex signal. Complex signals produce a greater overall output than any of their single components or pure tones. Broadband signals also result in a greater perceived loudness by the listener.

When Oasis has performed these three steps, the value that you end up with is the MPO. As a result, the formula will look like this: UCL (dB HL) + RETSPL + RECD – NBBB = MPO.

Procedure without Measured UCL Values

As mentioned before, you may provide measured UCL values right from the start. But what happens if you don't? In this case, Oasis applies well-established procedures (Storey et al., 1998) that use the measured hearing thresholds to predict sensible MPO settings. Dillon (2012) found that using this method approximately 80% of subjects were within the +/- 5 dB range of MPO levels that were found to be acceptable for the subjects. Only those subjects with an obviously small ear canal or those with a small dynamic range need further measurements.

Seemingly Low MPO Settings

Once the transformations are complete, Oasis lets you view the resulting MPO curve. The computer screen often displays MPO values around 110 or 115 dB SPL. It may appear that these values pose a risk for limiting the 80 dB input gain curve and possibly clipping speech. However, the situation is less problematic than it appears. The reason lies in the difference between the signals displayed in the software and those processed by the hearing instrument in real life. This difference is shown in Fig. 2.

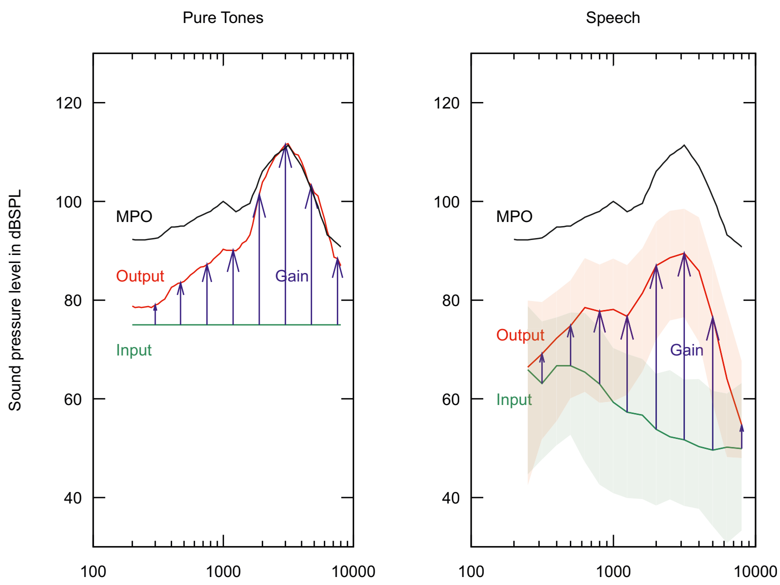

Figure 2. Significance of fixed MPO curve for narrowband pure tones vs. broadband speech

The left panel of Fig. 2 illustrates the situation for pure tones. With a gain of 35 dB at 3000 Hz, a 75 dB pure tone input reaches the MPO at 110 dB SPL. In the right panel of Fig. 2, the outcome is different even though the gain and input level are the same. The 75 dB speech input maintains a 20 dB buffer between the output and the MPO.

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The difference arises from two reasons. The first reason is that the power for a pure tone is concentrated at the specific frequency whereas for complex tones the power is spread over a range of frequencies. This results in lower spectral levels for speech. Therefore, as seen in the right graph the input of speech (green curve) is always lower than the input for pure tones. This is true as long as both signals have the same total power.

The second reason is the spectral slope of speech. The average speech spectrum falls off in the higher frequencies further reducing the output levels compared to those of pure tones. These two effects are demonstrated in the 75 dB speech signal in the right panel of Fig. 2. Both graphs use the same gain and input levels. However, due to the inherently lower input of speech and the lower levels in the high frequencies for speech, the result is a lower output compared to that of pure tones.

Options for MPO Adjustments

Whether you enter measured UCLs or rely on average UCL values in Oasis, you will occasionally need to adjust the resulting MPO. To that end, Oasis offers you three options.

The first option involves the MPO handles on the amplification screen in the Oasis software. In this case, manually raise or lower the MPO the same way that you would the gain for fine-tuning adjustments.

The second option applies when you relied on the UCL values in Oasis, but have the one out of five clients to whom the average values do not apply. For example, you may have a patient with a small dynamic range. In this case, measure and enter the UCL values into the audiogram, and start the fitting all over again. An alternative and easier approach is to use the In Situ Audiometry option in Oasis and measure the UCLs via the hearing instruments. Oasis will then re-calculate the MPO based on the measured In Situ UCLs.

The third option applies when you entered the measured UCL, but do not agree with the resulting MPO. In this case, you may expect a better result when you remove the UCL values from the audiogram and start all over again this time using the average UCL values in Oasis.

VALIDATION AND VERIFICATION OF MAXIMUM POWER OUTPUT

It is now time to verify the obtained MPO. Studies show that the verification of hearing instrument settings is crucial in order to achieve client satisfaction (Kochkin et al, 2010). Besides gain, the verification should also include MPO (Valente et al., 2007). One method of verifying MPO is to incorporate it in a real-ear measurement, using an 85 dB pure-tone sweep and checking that the maximum output does not exceed measured UCL values.

A loudness test in the aided condition will reveal potentially low MPO settings as well.

An alternative method is to perform a loudness test in the aided condition (Mueller, 2009), in particular the Cox Contour Test (Cox et al, 1997).
An advantage of this procedure is that it will reveal potentially low MPO settings as well.

Additional clinical measurements, such as self-assessment questionnaires will help to detect problems caused by a high MPO. Incorporating these questionnaires into the follow-up appointment will indicate problems with loudness that clients encounter in everyday situations.

KEEP LOUD SOUNDS LOUD, BUT OK

Fitting hearing aids is sometimes like a balancing act. Hearing instrument users need enough gain and MPO to hear speech clearly; however, exceeding the UCLs will cause discomfort and dissatisfaction.

As experience shows, MPO is an aspect of the fitting that is often overlooked but can have strong effects on satisfaction. We encourage you to give it more consideration, so that the number of satisfied clients increases.

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