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NARROWING THE GAP: A COMPILATION OF **DREAM EVIDENCE**

Introduction

Since the introduction of WIDEX DREAM in 2013, substantial evidence has been published, reinforcing the numerous benefits of its sophisticated features and processing.

This article summarizes these various research studies in the context of two major end-user benefits of DREAM, namely, better sound and speech intelligibility. Overall, the evidence points to DREAM strongly outperforming other commercially available hearing aids in the same segment.

More sound

The majority of A/D converters on the market today limit input range to around 100 dB SPL. This range is sufficient for hearing aids to handle speech even if shouted, as shouted speech is generally in the range of 85-90 dB SPL – but what happens if the level of the input sound is more than 100 dB SPL?

This scenario is quite common when hearing aid users are listening to music or in the presence of loud sounds or noises, since both scenarios have peaks exceeding 100 dB SPL. Examples of such environments include live music, the cinema or a sports event. To help deal with this situation, and offer a better listening experience to hearing aid users, Widex expanded the input range of the DREAM hearing aid from 103 dB SPL to 113 dB SPL. This means that the DREAM A/D converter is able to take in sounds of up to 113 dB SPL, linearly, before the sound is compressed or clipped. Figure 1, illustrates the various sounds found in our environment.

This change, which brings in more sound in the hearing aid, has many benefits for the hearing aid user and results in improved sound quality with less chances of experiencing saturation distortion.

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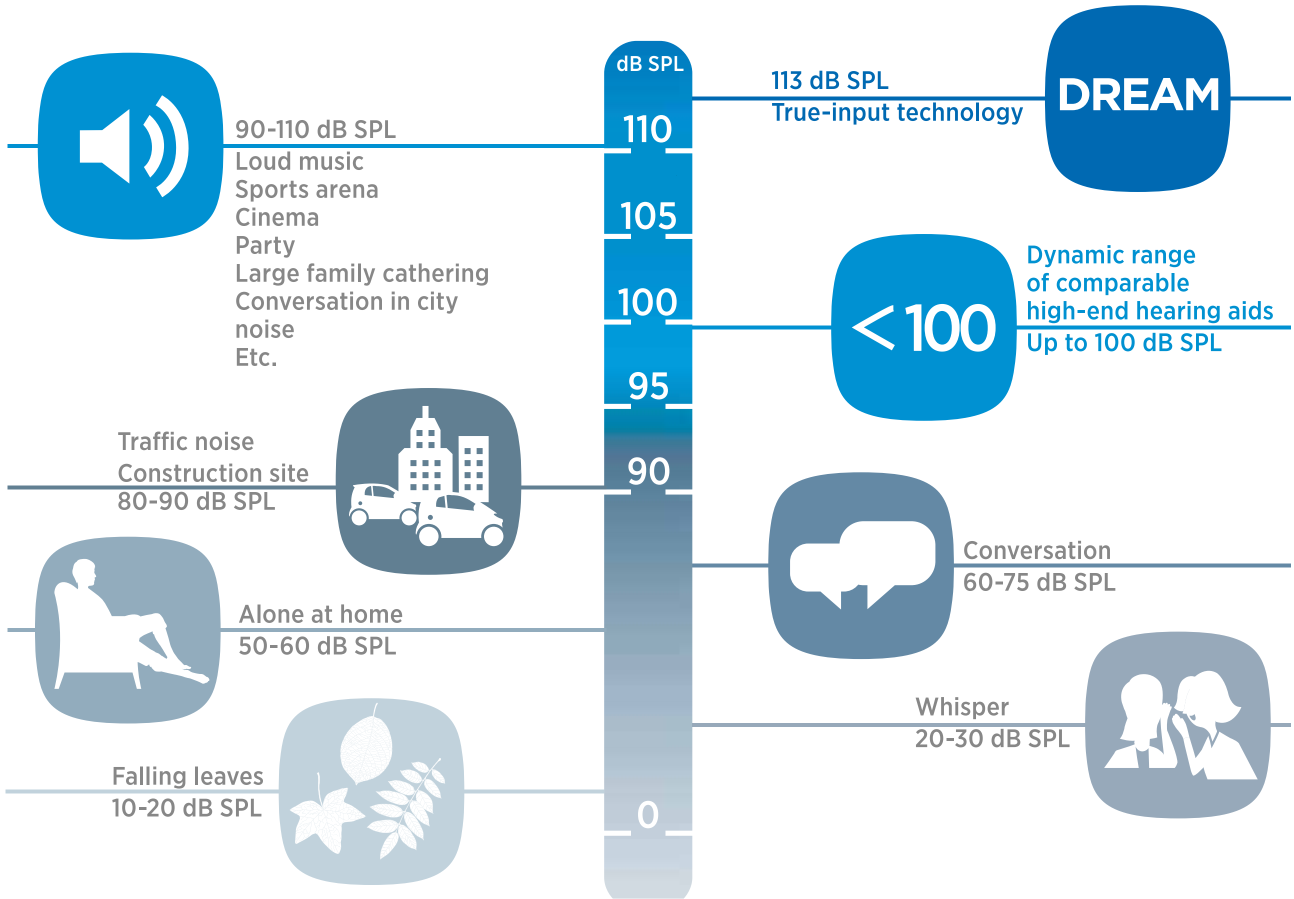

Figure 1. The DREAM TRUE-INPUT technology, illustrating how many sounds around us are within the 90-110 dB SPL range (top left) and how the DREAM input range can handle sounds of up to 113 dB SPL.

One of the main problems with some A/D converter designs is what is called input saturation distortion. Simply put, this means that if the incoming sound is limited or clipped even before it is digitized, due to limitations of the A/D converter. This will cause distortion – and this distortion will be carried through all the way to the output, potentially heard by the hearing aid user (as a “crackling” or “raspy” sound). See figure 2 for an illustration of clipping.

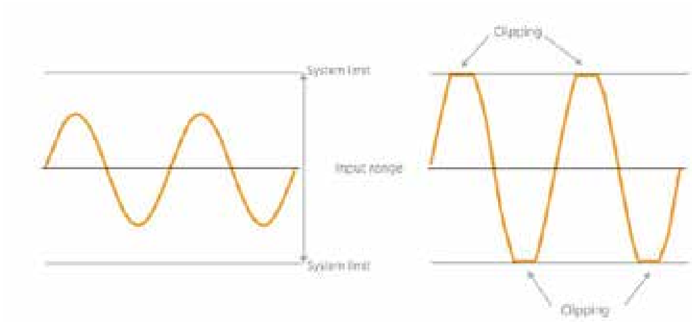

Figure 2. From Baekgaard, L., Knudsen, N. O., Arshad, T., & Andersen, H. P. (2013). If the original signal (left) exceeds the maximum level that the A/D converter is capable of handling, a part of the original signal will be missing when the signal is digitized (right).

If a signal is distorted even before it is digitized, regardless if it is speech, music or noise, it will be inaccurately represented during digital signal processing. This can lead to inaccurate classification of the signal. This distortion, if present, cannot be “undone”; once it is there, it stays there.

WIDEX DREAM is able to reduce this type of distortion, leading to a more faithful reproduction of the original signal and therefore a better classification of the sounds during digital signal processing. Ultimately, this gives the hearing aid user a better hearing experience - in particular when they are playing or listening to music, or are in an environment where there are high level inputs such as a restaurant or party.

In 2013, Krose conducted a study in which he looked at the output signal of DREAM compared to a hearing aid with a conventional A/D converter, using the same stimuli. This study showed how the DREAM A/D converter caused less distortion of the output signal compared to a hearing aid with a conventional A/D converter.

The author conducted sound field recordings on KEMAR with both conventional hearing aids (with conventional A/D converter) and DREAM hearing aids (with the expanded range A/D converter). Speech noise was presented from the side and the back at 106 dB SPL. Speech (NU-6 list) was presented from the front, at two different SNRs: 0 dB and -3 dB. In one instance, the hearing aid output was recorded with noise reduction and directionality OFF; in the other, noise reduction and directionality ON. This was for both set of hearing instruments.

The study concluded that in both conditions, DREAM had a cleaner output compared to the hearing aid with a traditional A/D converter, as seen in Figure 3.

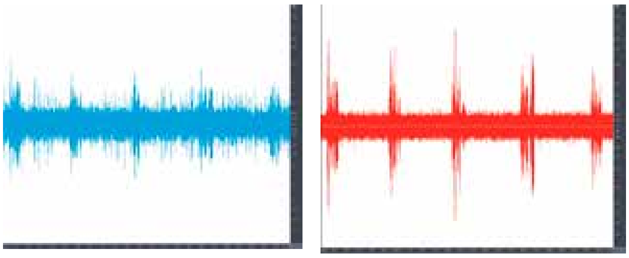

Figure 3. From Krose (2013). Difference between the recorded sound waves/output of the conventional A/D converter (blue) and the DREAM A/D converter (red), for an SNR of 0 dB, with directionality and noise reduction ON. We can see how the amplitude of the signal is preserved on the red recording, and that it is a cleaner signal.

Sound quality evaluations

Several studies have assessed subjective sound quality by comparing DREAM to hearing aids that have narrower A/D converter input ranges. (Jessen, A. H., Baekgaard, L., & Andersen, H. P. (2013); Keenan (2013); Chasin (2014); Kuk, F., Lau, C.-C., Korhonen, P., & Krose, B. (2014); Rawls, S., Weiner, J., Nunes, R., & MacDonald, O. (2014).

For example, Jessen et al. (2013) conducted a benchmarking study to assess the DREAM sound quality. The comparison was between the DREAM440 hearing aid to two other commercially available high-end hearing aids. The participants assessed the sound quality of each of these hearing aids, according to a set of 6 sound quality attributes:

- Fullness
- Sharpness
- Naturalness
- "Tube sound"
- Distortion
- Loudness

This study was a double-blinded, therefore neither the testers nor the participants knew which hearing aids were being tested.

As shown in Figure 4, results showed that Widex DREAM440 was perceived as "well-balanced, very natural and full", with less perceived distortion compared to the two other high-end hearing aids tested. The other manufacturers' hearing aids were perceived as having high distortion and sharpness; which are not necessarily considered to be desirable sound quality attributes. These blinded test results were very encouraging as they showed that the participants seemed to prefer the "Widex Sound".

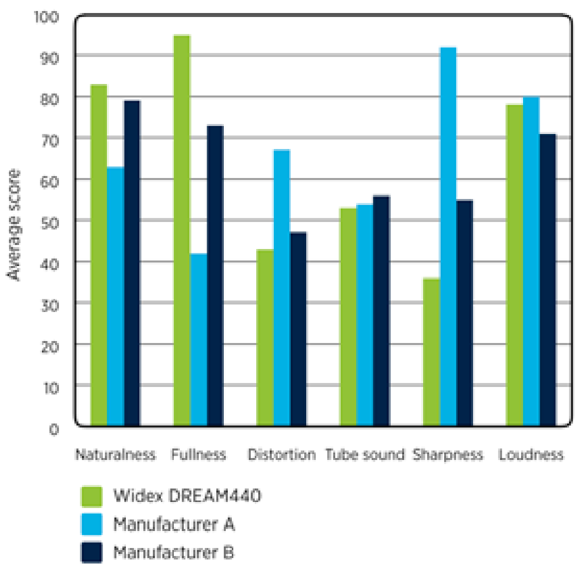

Figure 4. From Jessen et al. (2014). Evaluation of the Widex DREAM and two competing wireless premium products from leading manufacturers by a panel of hearing-impaired listeners

In 2013, Keenan evaluated, amongst other things, subjective preference of DREAM vs CLEAR. CLEAR was chosen as the comparison hearing aid, as it has a similar chipset and features as DREAM – but one of the main differences is the A/D converter input range. (103 dB SPL for CLEAR and 113 dB SPL for DREAM). The subjective evaluation part of the study revealed that DREAM was chosen between 82-86% of the time over CLEAR. While there were no subjective preferences between CLEAR and DREAM when the stimuli was soft inputs, there was a clear preference for DREAM for loud inputs. This is shown in Figure 5.

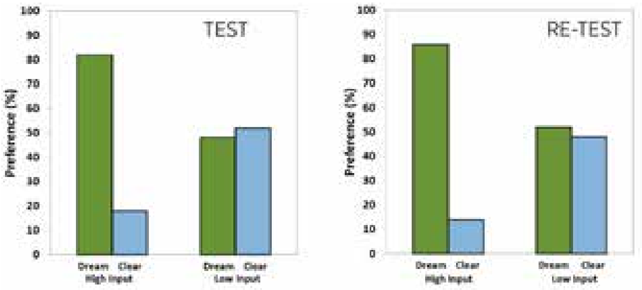

Figure 5. From Keenan (2013). Test and re-test results, showing a clear preference for the DREAM hearing aids with high input stimuli.

Continuing along these lines, Rawls et al. (2014) wanted to determine if the design of the DREAM A/D converter would help improve the overall sound quality experience in real-world situations, which included challenging or difficult listening situations.

For this trial, 26 participants were recruited. They were all fitted with DREAM440 hearing aids. The trial lasted four weeks and participants were asked to go through a variety of questionnaires before, during, and after the trial.

The questionnaires used for the trial were:

1. The Speech, Spatial and Qualities of Hearing Scales A and C (SSQ, Gatehouse & Noble, 2004). This questionnaire aims to measure "auditory disability across a wide variety of domains, reflecting the reality of hearing in the everyday world".

2. The International Outcome Inventory for Hearing Aids (IOI-HA) questionnaire (Cox et al., 2000).

3. A DREAM questionnaire, developed specifically for the trial

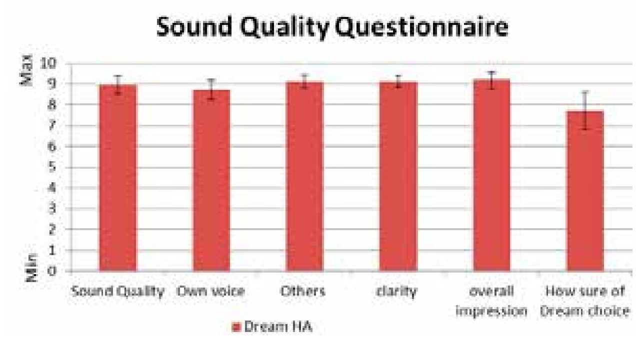

Figure 6. From Rawls (2014). Mean scores for the Widex sound quality questionnaire.

In Figure 6 we can see the mean scores for the sound quality questionnaire. The results indicated that all the participants rated the DREAM hearing aid highly on sound quality. Results from all the questionnaires showed significant improvement for both speech intelligibility and sound quality for a range of different environments, including very challenging listening situations.

As part of a study published in 2014, Kuk et al. also evaluated subjective sound quality with DREAM hearing aids, specifically when the participants were wearing hearing aids in loud or very loud environments.

To evaluate the sound quality experience, the authors created a questionnaire which specifically targeted the hearing aid users' experience in loud environments. The questionnaire contained 20 questions and participants were asked to wear DREAM hearing aids for one month, then fill out the questionnaire at the end of the trial.

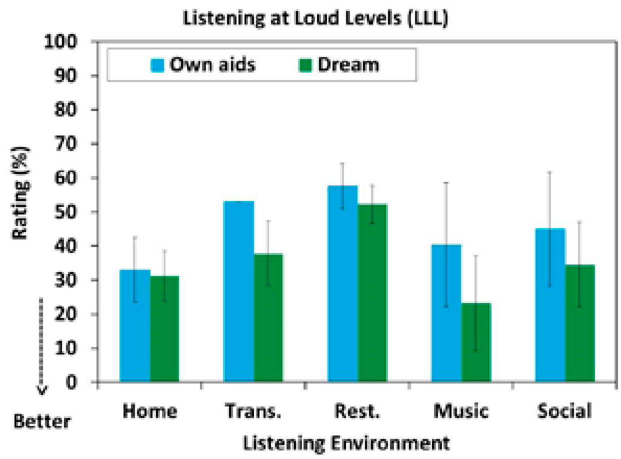

Figure 7. From Kuk et al. (2014). Mean LLL ratings for own aids and DREAM hearing aids (n = 8) grouped according to the types of listening environments.

They found that DREAM had a better rating in all the situations highlighted in the questionnaire compared to the participants' own hearing aids. The greatest improvement was in music and transportation environments, as shown in Figure 7.

As a whole, these studies revealed that under the right test conditions, the DREAM expanded input A/D converter provided benefit and significantly improved sound quality. All the participants in the studies preferred the DREAM hearing aid in difficult/loud environments, where the hearing aid inputs were loud or very loud. This is encouraging since hearing aid satisfaction has historically been rated poorly in types of environments (Kochkin, 2010).

Hearing aids and music

One particular challenge for hearing aid users is listening to music. Most hearing aids on the market today simply are not designed to be able to deal with loud music; peaks in music can reach up to 110 dB SPL (Chasin, 2007; 2014) – whereas most commercial hearing aids have a limited input range of around 100 dB SPL (Baekgaard et al., 2013a). Since the hearing aid A/D converter in DREAM can handle input sounds of up to 113 dB SPL, hearing aid users should therefore experience better sound quality when listening to music or playing musical instruments.

Chasin (2014) examined how the expanded A/D converter input range can affect listening to music. In his study, 10 experienced hearing-impaired musicians had to indicate their preference between two different Widex hearing aids: CLEAR, which does not have the improved A/D converter, and DREAM, which has the expanded range A/D converter. Each participant and tester was blinded to which hearing aid the participants received. To limit the participants' exposure to loud sounds, the stimuli were recorded through the hearing aids on KEMAR, and then presented to the hearing-impaired listeners through insert earphones.

The results indicated a strong preference for the DREAM hearing aids, with statistically significant results for soft and loud musical inputs, as well as for loud speech input. Figures 8, 9 and 10 all indicate a clear preference for the DREAM hearing aid.

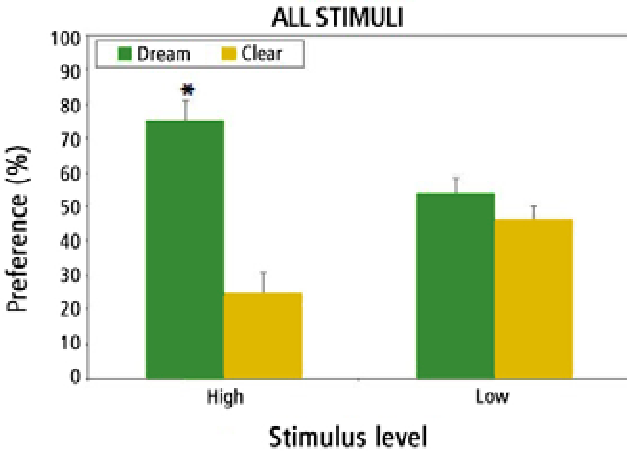

Figure 8. From Chasin (2014). The preference results in terms of clarity for the DREAM and the CLEAR hearing aids for both high presentation level and low presentation level for both music and speech combined. Statistically significant differences ($p<0.05$) are denoted with an asterisk (*)

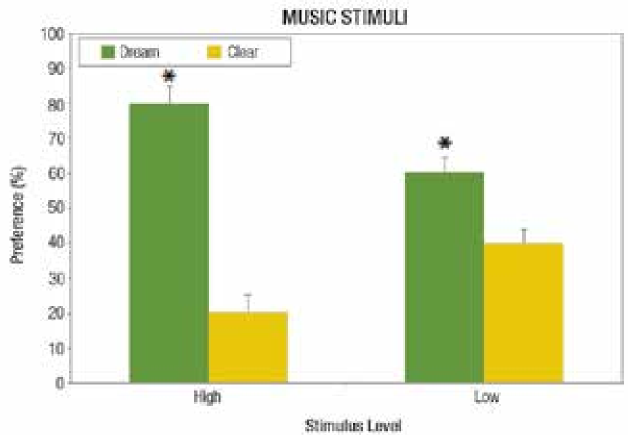

Figure 9. From Chasin (2014). The same data as shown in Figure 8 but only for the music stimuli at both low and high presentation levels. Statistically significant differences ($p<0.05$) are denoted with an asterisk (*).

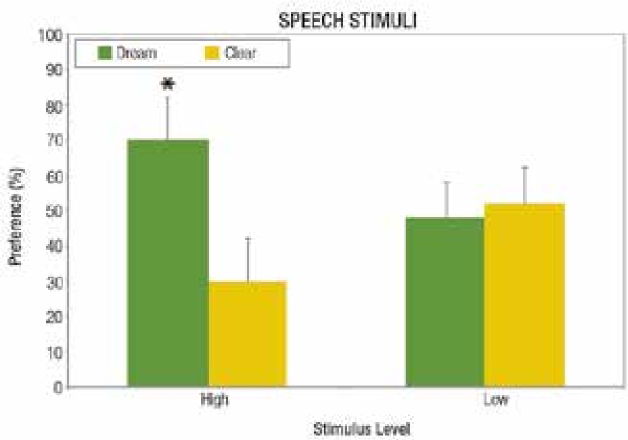

Figure 10. From Chasin (2014). The same data as shown in Figure 8 but only for the speech stimuli at both low and high presentation levels. Statistically significant differences ($p<0.05$) are denoted with an asterisk (*).

So what does this mean for music perception and musicians?

This study suggests that expanding the dynamic range of the A/D converter in the hearing aid does indeed have a beneficial effect for music perception in general and for loud speech inputs. This means that hearing aid users now have the possibility of experiencing better sound quality for music, where music can sound less distorted compared to what was has been previously available. Currently, Widex DREAM is still the only commercially available hearing instrument capable of achieving this.

More words – speech intelligibility for loud inputs

One of the benefits of the improved A/D converter in the DREAM hearing aid is the improved intelligibility and speech perception for loud speech in environments where the surrounding noise is quite loud. This is based on the fact that, because of the expanded input range, the hearing aid will have a cleaner signal to work with – resulting in a more effectively working noise reduction and directional microphone systems

Baekgaard et al. (2013b) examined speech intelligibility for loud inputs and the degree to which the expanded range of the A/D converter led to improved speech perception in loud noise. They conducted a small study of 10 participants to look at whether there was an improvement in speech perception in loud noise with DREAM, compared to another hearing aid with a conventional A/D converter. The hearing aids' adaptive features were active and set to the default. The setup of the study is illustrated in Figure 11.

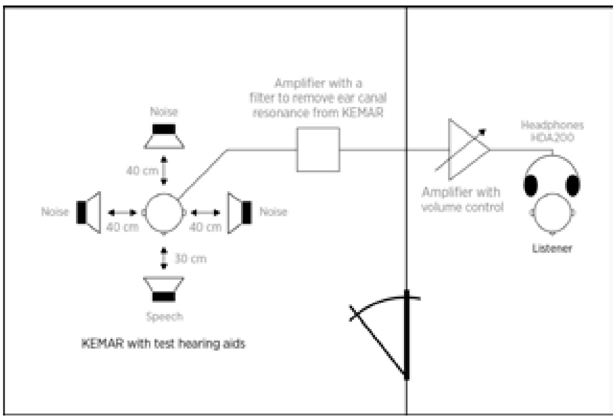

Figure 11. From Baekgaard et al. (2013). Illustration of the test setup. Speech was delivered from a loudspeaker located directly in front of a KEMAR wearing the test hearing aids, while the noise was delivered via three loudspeakers at 90°, 180°, and 270°. The participants listened to the speech stimuli from an adjoining room through headphones connected to the test hearing aids.

The results indicated that the 9 out of 10 participants had a 6.3 % improvement in word recognition scores in loud noise with DREAM compared to the reference hearing aid. This improvement in scores was statistically significant ($p<0.05$). The authors also report that there were individual improvements of up to 21.3%. Results of the word recognition test are shown in Figure 12.

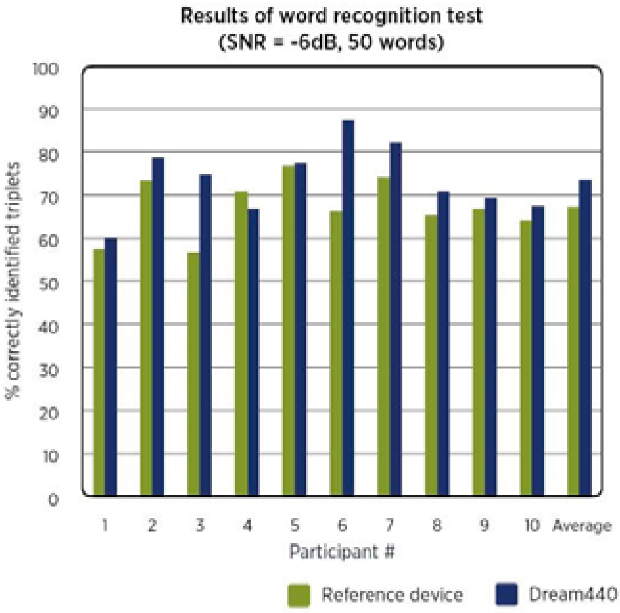

Figure 12. From Baekgaard et al. (2013). Results of the speech recognition test. The bars indicate the percentage of correctly identified triplets with the DREAM vs the reference hearing aids.

These results are very encouraging and clearly show the advantage of the expanded A/D converter and the benefit it brings to the hearing aid users. The trial indicates that in the presence of loud noise, DREAM hearing aid wearers can benefit from improved speech intelligibility, compared to a hearing aid with a conventional A/D converter.

Keenan (2013) was also able to demonstrate that speech understanding in loud environments improved for test subjects listening to DREAM.

In this double-blind study, 10 hearing impaired participants were recruited and had to compare two hearing aids: CLEAR (old A/D) and DREAM (new A/D). Both hearing aids were programmed to flat 50 dB HL loss, with settings left at default.

The hearing aids were placed on KEMAR and the participants listened through headphones connected to the hearing aids. Speech material used was the NU-6, presented at high level from the front. Speech-weighted noise was presented from the back and the side, at three different SNRs: -3 dB, 0 dB and 3 dB. The hearing instruments were tested in two conditions: omnidirectional + noise reduction OFF and directional + noise reduction ON.

Results for the speech in noise testing showed that DREAM performed much better than CLEAR for each SNR and each condition, as seen below in Figures 13, 14 and 15.

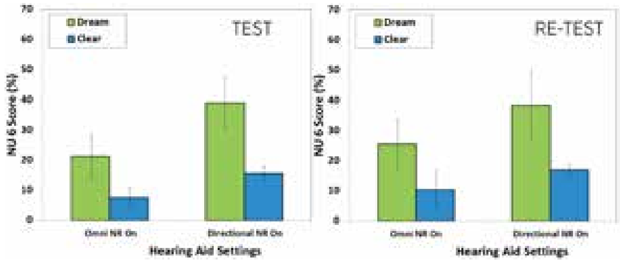

Figure 13. From Keenan (2013). Results for an SNR of -3 dB.

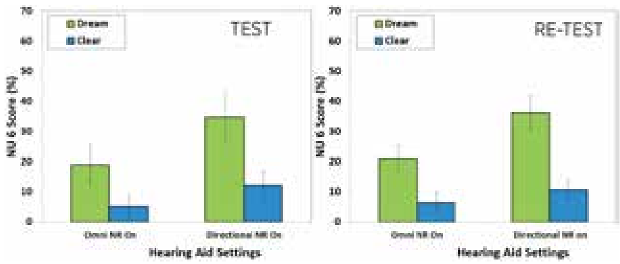

Figure 14. From Keenan (2013). Results for an SNR of 0 dB

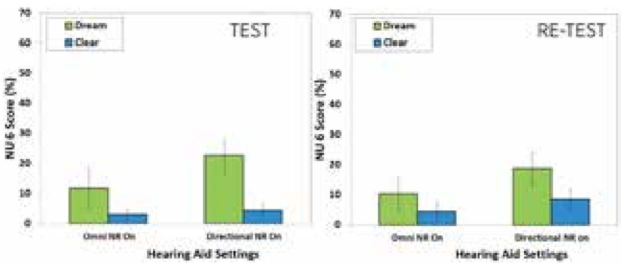

Figure 15. From Keenan (2013). Results for an SNR of +3 dB

The results for this study indicated that for loud inputs, DREAM helped participants understand speech in noise better than with CLEAR.

Kuk et al. (2014) also evaluated speech intelligibility for high and very high inputs. As stated by the author, hearing aid processing is typically evaluated at conversational level, not at high or very high levels – so they wanted to observe performance when presenting loud or very loud stimuli.

10 people participated in this study, 8 of whom were experienced hearing aid wearers. DREAM and CLEAR hearing aids were compared. As mentioned before, CLEAR has a conventional input range, DREAM the expanded input range.   The NU-6 word list was presented from the front, with noise from the side and the back. The noise had an overall level of 106 dB C and speech was presented at 103, 106 and 109 dB C (SNRs: -3 dB , 0 dB, +3 dB). The hearing aids were programmed to a flat 50 dB HL loss, in two conditions: Omnidirectional + noise reduction OFF and directional + noise reduction ON. The study was double-blinded and the stimuli was presented through headphones, which were connected to the hearing aids on KEMAR. Participants adjusted the volume of the stimuli to "loud, but OK" when listening through the headphones.

Generally, the results indicated that the performance with DREAM hearing aids was significantly better than the speech recognition scores with CLEAR. Some notable findings were:

- DREAM in omnidirectional with noise reduction OFF had a better performance than CLEAR in directional with noise reduction ON – suggesting that a cleaner input signal, even in omnidirectional mode, leads to better results than a distorted input
- The omnidirectional vs directional difference was much greater with DREAM than with CLEAR – suggesting that "the directional/noise reduction mechanism in CLEAR was compromised whereas the DREAM directional microphone was operational", due to a cleaner input into the A/D converter with DREAM
- Across the SNRs, DREAM outperformed CLEAR by about 25% in the directional + noise reduction ON and 10% in the omnidirectional + noise reduction OFF mode
- DREAM performance was always better than CLEAR

The study clearly revealed that speech recognition scores were higher with DREAM than with CLEAR. This means that DREAM should outperform competitive high-end products with much lower input dynamic ranges in their A/D converters.

Kuk et al. (2015) recently published an article in which they reported the results from evaluating speech intelligibility for various input levels with DREAM. Speech intelligibility evaluations have traditionally taken place in quiet or at conversational levels. Studies that assessed speech intelligibility for loud inputs have shown that hearing aids provided no or negative benefit at high input levels (Duquesnoy & Plomb, 1983; Cox & Alexander, 1991; Studebaker, Sherbecoe, & McDaniel, 1999). Therefore, the authors wanted to evaluate speech intelligibility performance at various input levels, for various signal-to-noise (SNR) ratios, and to see if there was still a speech intelligibility in noise benefit even for loud inputs/loud environments.

Once again, the DREAM A/D converter proved to be beneficial for speech intelligibility scores in loud noise and for music perception/sound quality assessments. DREAM out-performed hearing aids with conventional A/D converters and was also subjectively preferred by the majority of the test subjects.

The participants for the study were 10 hearing impaired adults. The authors also gathered speech intelligibility scores for 5 normal hearing adults, for comparison.

In the study, they tested:

- Speech intelligibility in quiet for inputs of 50 dB and 65 dB SPL
- Speech intelligibility in noise for 65, 85 and 100 dB SPL with signal to noise ratios of +6, +3 and -3 dB, for both the normal hearing and the hearing impaired participants
- Hearing impaired participants gave subjective preference ratings for unaided vs aided, for both speech and music, at levels of: 50, 65, 85 and 100 dB SPL in quiet

The main conclusion of this article were the following:

- They found improved speech understanding background noise, for aided compared to unaided, for various input levels, including loud and very loud inputs
- In loud environments, in the aided condition, hearing impaired listeners performed just as well as normal hearing persons (the performance for hearing impaired/aided was only a little bit worse)

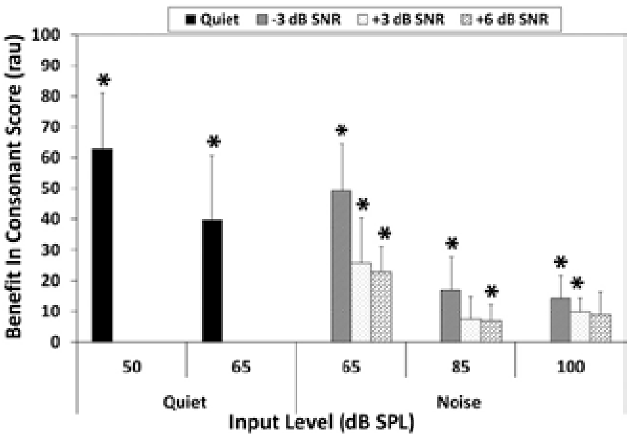

Figure 16. From Kuk et al (2015). Difference in phoneme scores (in rau) between aided and unaided performance (i.e. aided benefit) of HI participants across the different stimulus conditions. The asterisk (*) denotes a significant benefit.

The results of the study showed that for the aided conditions, it becomes more difficult to understand speech clearly as the levels of the noise around increases. This is of course an expected result. The interesting observation, however, was that even if the input was very loud (85 and 100 dB SPL), the aided speech scores were still higher than the unaided speech scores, for the hearing impaired participants (see Figure 16 for the aided vs unaided differences). This goes against what was previously shown in literature, which typically showed decreasing aided speech intelligibility scores when the input was above 80-85 dB SPL.

In addition, the aided performance of the hearing-impaired participants paralleled the performance of the normal hearing listeners. As the authors report, this is very encouraging because the aided participants had very similar scores to the much younger normal hearing subjects.

As the authors mention in the article, these results with DREAM "confirm the possibility of narrowing the speech intelligibility gap between normal hearing subjects and hearing impaired aided listeners". In other words: it seems like hearing impaired participants experience the same amount of difficulties as normal hearing people, when in difficult and loud environments. This is clinically relevant as it could help the clinician with counselling, to ensure that hearing aid users receive the appropriate help to improve their communication.

Conclusion

WIDEX DREAM is still the only commercially available hearing aid which is able to achieve an input dynamic range of 113 dB SPL. Most hearing aids on the market have an upper limit of around 100 dB SPL. The advantages of this extended input dynamic range means that there will be less saturation distortion of the input signal before it is digitized. Having a cleaner signal means that there will be a better representation of the original signal, which will maximize the effectiveness of the adaptive features of the hearing aid, such as the directional microphone and the noise reduction.

The studies mentioned in this article have shown that participants have all benefited from DREAM's A/D converter and that it can provide benefit for hearing aid users over other hearing aids which do not have an extended input dynamic range.

In summary:

- Participants prefer the DREAM sound in subjective sound quality assessments
- Participants prefer the DREAM hearing aid when listening to music
- Participants performed better at aided speech intelligibility tasks for loud inputs compared to when wearing another hearing aid which did not have an expanded input dynamic range
- In speech intelligibility tasks with inputs of above 80 dB SPL, hearing impaired users, in an aided condition, performed better than in an unaided condition. In previous studies, it was shown that aided was usually worse than unaided – so these are encouaging results
- In loud environments, in the aided condition, hearing impaired listeners performed just as well as normal hearing persons

Overall, the DREAM A/D converter yielded positive and significant results in speech intelligibility tasks as well as subjective sound quality assessments. We can therefore assume that under similar conditions as the ones in which the participants were tested, hearing aid users will experience the same real-world benefits.

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