

Sensei Pro

Using Speech Guard E to improve speech recognition

EDITORS OF THIS ISSUE

Kamilla Angelo, Ph.D., Senior Researcher, Oticon Paediatrics*

Thomas Behrens, M.Sc., Head of Clinical Evidence, Oticon A/S

ABSTRACT

One defining component of a hearing instrument is the compression system. The speed at which the compressor acts affects the dynamics of the output. At one extreme, very fast acting compression distorts intensity contrasts. At the other extreme, very slow acting compression fails on audibility and protection against loud sounds. Here, we show that the word recognition performance of children with hearing loss is in fact influenced by the amplitude compression strategy.

Oticon has recently launched its second pediatric hearing instrument family, Sensei. Here, we report data from a clinical trial run to test the efficacy of the Sensei Pro with Speech Guard E amplitude compression compared to Safari 900 with traditional wide dynamic range compression (WDRC). In a blinded repeated measures cross-over design, 21 school age children with moderate to severe hearing loss completed three laboratory test sessions interspersed by a 2-3 week field trial with each instrument. The participants repeated sentences from a primary speaker source in a challenging yet realistic listening situation, at a signal to noise ratio of +3 dB as well as reverberation. Although large individual variability was found, the average speech recognition with Sensei Pro significantly improved word recognition over both the Safari 900 instrument and traditional linear amplification.

This outcome demonstrates that the choice of compression scheme is a particularly important aspect of the hearing aid selection process. Since most of the pediatric hearing instruments on the market today are based on traditional WDRC, it is likely that the floating linear gain approach of Speech Guard E is currently the optimal strategy for providing children with a beneficial representation of the dynamic structure of speech, combined with adequate audibility.

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* For questions regarding the contents of this paper please contact, Kamilla Angelo: ang@oticon.dk

Introduction

Children with hearing loss must inevitably learn to listen to environmental sounds and speech using hearing technology with signal processed sound. There are indications that the composition and contents of sound affect how auditory information is encoded by the auditory system (Anderson et al., 2013). However, it is still not fully understood how different types of sound processing schemes affect human auditory and cognitive processing. A critical aspect of hearing technology design is matching the acoustic signal to the user's actual auditory ability. Speech constitutes the most important auditory signal for human communication, and the way in which a speech signal is processed by the hearing instrument is likely to affect auditory processing and neuronal encoding in the child's brain. An obvious prerequisite for obtaining high speech understanding in children with hearing loss is the provision of a clearly audible signal which matches the child's limited dynamic range across as high a range of input levels and environmental conditions as possible. The goal is to compress the amplified sound, striking a balance between optimizing audibility while minimizing distortion and still delivering a comfortable level. In other words, providing each child with optimally compressed acoustic stimuli via their amplification enables not only audibility, but extraction of acoustic information for proficient sub-cortical encoding and cortical representation. This should give the child the most favorable circumstances for recognizing speech, not only in quiet situations but also under noisy conditions.

Sensei is the latest pediatric hearing instrument range developed by Oticon. With Sensei Pro, Speech Guard E is now available for pediatric fittings. The Sensei instrument has several important features, many of which are uniquely pediatric: these include SmartFit Trainer (Fuglholt and Pedersen, 2013), EasyRECD (Angelo et al., 2013) and VoicePriority *i* (Johansson, 2014). In this paper, we address yet another fundamental feature of a pediatric hearing instrument: the amplitude compression strategy. The vast majority of hearing instruments fitted on children today deploy some variety of WDRC. WDRC was originally designed to substitute for the volume wheel (Fortune and Scheller, 2000). With linear hearing instruments, the sound would often become uncomfortably loud and frequent volume adjustments would be required. In particular, children are likely to benefit from WDRC technology as many of them are too young to efficiently control loudness levels themselves (Souza, 2002) and because their everyday listening environments are unpredictable with highly fluctuating noise levels (Cruckley et al., 2011) as well as high variations in talker-to-microphone position and distance (Stelmachowicz et al., 1993, Ricketts et

al., 2010). In WDRC hearing instruments, the relationship between input and output - i.e. the gain or compression ratio - is automatically set by the compressor. Compressor characteristics, such as speed at which it acts, the compression kneepoint, the number of compression channels and the output limiting parameter, differ between hearing instrument types and brands. Even though steady state amplification levels are commonly prescribed according to the generic rational target, variations across types of WDRC will differ in how both speech and environmental sounds are dynamically processed and eventually passed to the child's ear and brain.

Traditional WDRC systems generally operate with fixed attack and release times. The Oticon floating linear gain strategy is fundamentally different (Simonsen and Behrens, 2009). In essence, the Oticon Speech Guard approach to the compression of sound is to apply different time constants based on the degree to which the input changes. If this input change is small, a very slow time constant is applied and the signal will be processed in an almost linear manner (Nilsson, 2013). If the change in input is large and abrupt, the time constants of the compression will be very fast, to enable loudness protection and audibility of soft sounds (Simonsen and Behrens, 2009, Schum and Sockalingam, 2010).

In this study, we evaluated the impact of Speech Guard E compression, as implemented in Sensei on the Inium platform, on the speech recognition performance of school age children with hearing loss. We compared the speech recognition scores from listening with Sensei Pro directly to those obtained under conditions with syllabic WDRC (Safari 900) as well as linear amplification (i.e. Sensei instrument with fixed gain) in an ecologically valid listening test. It was found that Speech Guard E in the Sensei Pro device gives, on average, a significant speech in noise and reverb advantage of approx. 6.6% above the Safari 900 instrument and above linear amplification. We hypothesize that the Speech Guard E compression scheme, with its combination of both linear and non-linear WDRC characteristics, strikes an optimal balance between providing audibility while ensuring minimal alterations of speech cues.

Method

Participants and hearing aids

Twenty-two children aged 8 years 1 month to 14 years 11 months (average 11 years, 2 months) with moderate to severe sensorineural hearing loss participated in the study (Table 1). Each subject was compensated for participation, based on normal protocol at Vanderbilt University Medical Center. They received \$5/hour. The

children were bilaterally fitted with Oticon BTE hearing aids: the newly released Pediatric Sensei Pro 13 instrument and the Safari 900 instrument. Prior to each child's arrival, the hearing instruments were programmed to DSL v5.0a targets using age-appropriate real-ear to coupler differences (RECDs) (Scollie et al., 2005). Individually measured RECDs were obtained when the child was in the lab and necessary changes were made to the programming in the Audioscan Verifit test box. Verification of hearing aids was performed using the test box running the speech passage at 55 and 65 dB SPL. MPO was verified using an 85 dB SPL sweep tone stimulus. The proximity of the fitting to prescribed targets was evaluated by calculating the root-mean-square (RMS) of the difference between the target and the measured values. The average RMS was calculated for the individual fitting across the following frequencies: 0.25, 5, 1, 2, 3, 4 and 6 kHz, at 3 levels (55, 65 and 85 dB) for both ears. For the Sensei instrument set to linear amplification, only targets at the level of 65 dB were matched. No fitting exceeded the value of 4.5 dB RMS (McCreery et al., 2013). During lab testing, the settings of the Sensei devices were the following: adaptation manager always at level 3, binaural broadband OFF, noise reduction disabled and the acoustic setting was Omni with a closed earmold. During the acclimatization period, these features were again enabled. Because all advanced features were dis-

abled in the instruments during the lab test, the major factor differentiating Sensei from Safari was the amplitude compression scheme of the instruments. Linear floating gain (Speech Guard E) is Sensei's compression system whereas Safari used traditional WDRC.

Procedures

A blinded repeated measures cross-over design was used. Speech recognition behavioral testing using the hearing in noise sentence material, specially developed for use with children, (Hint-C) (Nilsson et al., 1994) was completed three times: 1) pre-acclimatization; 2) After first acclimatization period with hearing aid set 1; 3) after second acclimatization period with hearing aid set 2. During the acclimatization periods (2 weeks), users were required to wear the hearing instruments for a minimum of two hours during the week and eight hours over the weekend. If children used an FM system in school, they were provided with an Oticon Amigo FM system with Oticon's R12 receivers. Alternatively, the individual child's own FM system was used with a universal FM9 adaptor audio shoe. Each laboratory test was conducted under the same conditions. The subjects were required to repeat sentences in the presence of both noise and moderate reverberation (RT60 = 650 ms). The HINT-C results were scored by words, not by sentences, and were reported as a percentage

	Age (yrs)	Vocabulary** Age (yrs)	Audiometric thresholds (dB HL)															
			Right ear (kHz)								Left ear (kHz)							
			250	500	1000	2000	3000	4000	6000	8000	250	500	1000	2000	3000	4000	6000	8000
♀	10.4	9.9	55	60	70	70	60	60	65	60	60	65	70	65	60	55	65	60
♂	12.3	8	55	60	70	55	55	60	60	60	30	40	50	50	50	55	55	45
♂	8.8	6.6	35	35	45	55	50	45	40	35	35	50	55	50	50	45	35	35
♂	13.4	9.1	35	40	60	70	70	75	75	75	35	45	55	70	70	65	70	70
♂	11.10	8.10	30	35	50	55	50	45	55	65	35	35	45	55	50	50	65	65
♂	10.10	8.10	35	45	55	60	60	55	60	55	35	40	50	60	55	60	60	60
♂	10.6	4.6	30	30	45	50	60	60	60	55	30	30	40	50	60	60	65	70
♀	9.05	9.10	40	65	65	55	30	35	10	-5	25	60	55	30	35	35	0	-10
♀*	-	-	30	35	55	55	50	45	60	60	30	30	50	50	50	55	55	55
♂	13.5	9.7	25	30	40	40	55	50	55	55	25	30	40	40	60	60	65	75
♂	8.10	7.5	45	55	60	60	65	60	65	60	45	60	70	70	70	65	65	60
♀	13.4	13.10	35	40	60	60	60	55	60	50	35	50	60	60	60	65	55	55
♂	14.11	16.5	25	25	35	45	70	75	75	70	25	25	30	40	75	75	75	70
♀	9.11	7.2	70	75	70	65	60	50	5	5	50	65	65	60	55	40	0	0
♂	8.5	6.1	50	45	55	65	65	65	65	65	65	55	55	75	70	75	75	80
♀	11.7	10.9	20	30	30	40	40	40	40	15	30	30	35	40	40	40	55	45
♀	10.07	7.8	20	40	55	55	50	55	55	45	20	40	50	50	55	50	45	45
♂	9.8	7.10	10	30	50	60	50	55	50	45	20	40	50	55	55	50	50	45
♂	12.9	11	30	25	45	45	35	25	20	25	30	35	45	50	45	35	25	30
♀	11.9	5.8	30	30	45	40	45	40	45	45	30	30	40	45	40	40	45	45
♂	12.4	6.11	20	25	35	45	50	40	15	5	20	25	40	45	45	45	30	0
♀	14.01	11.2	15	20	45	45	50	55	30	15	15	20	55	50	50	50	45	15
Mean	11.2	8.7	34	40	52	54	54	52	48	44	33	40	50	53	55	53	51	46
S.D.	1.9	2.7	14	15	12	9	10	12	20	23	13	13	10	11	11	11	21	25

*The participant wore the study hearing instruments for less than a week and withdrew. The participant is currently wearing Phonak Valeo's and could not tolerate the new technology.

** Based on PPTV test.

Table 1: Gender, age, vocabulary age and hearing thresholds of participants

of correct words out of the total words in a list. The HINT-C sentences were randomized for order of presentation. Two lists were run for each condition. A total of 18 lists plus 3 training lists were therefore needed. Since the HINT-C material includes only 13 lists, some lists were reused. Reuse of lists twice is valid as long as they are always separated and randomized (Nilsson et al., 1994). The competing masker noise was the HINT-C noise with single-talker modulation, presented uncorrelated from speakers at 45, 135, 225 and 315 degrees (Fig. 1). Speech was presented at 0 degrees at a level of 65 dB SPL. All levels were calibrated with A weighting at a fixed intensity of +3 SNR for all conditions. During each visit, three gain conditions were run in a counter-balanced design: 1) the Sensei Pro instrument with floating linear gain (Speech Guard E); 2) the Safari 900 instrument with fast syllabic WDRC; 3) a condition where the Sensei instrument was set up to provide linear amplification (i.e. fixed gain according to the gain setting at moderate speech, 65 dB SPL). The “linear” hearing instrument had the same gain-frequency response for all input levels and did not hold the distortion of a compressed signal.

Results

A total of 21 children completed both trial periods (2-3 weeks each) and all three lab testing sessions. On average, children exhibited mild sloping to moderate hearing loss (Table 1). Word recognition performance was analysed using a repeated measures Analysis of Variance (ANOVA) with gain processing (Speech Guard E [Sensei], syllabic compression [Safari] and linear [Sensei, fixed gain]) and trial (pre-trial, post-trial 1,

post-trial 2) as the “within subjects” variables. Any significant main effects and/or interactions were explored post hoc using linear contrast with Bonferonni correction. Mean word recognition performance for all participants is shown as an average (left) across all lab tests and for each trial in figure 2 (right). The ANOVA results revealed a significant main effect of gain processing ($F_{2,40} = 8.450, p < 0.001, \text{partial } \eta^2 = 0.297$) and a significant trial effect ($F_{2,40} = 5.084, p < 0.011, \text{partial } \eta^2 = 0.203$). There was no significant interaction. Follow-up analysis of the main effect of gain processing revealed significantly better performance for listeners when they were fitted with Sensei than when they were fitted with Safari ($p < 0.009$) or linear processing ($p < 0.011$) (Fig. 2). There was no significant difference between performance for individuals when fitted with Safari vs. Linear processing. Overall, these results show that, on average, children demonstrated significantly better word recognition (approx. 5 percentage points) when fitted with Sensei instruments using Speech Guard E compression than the other two types of gain processing.

Follow-up analysis of the significant main trial effect revealed that participants scored significantly higher overall after the first ($p < 0.025$) and second trials ($p < 0.040$) than in pre-trial testing. This means that irrespective of the instrument in use, the children benefited from using the instrument over time. Interestingly, further examination of individual data revealed a strong order effect in some participants. That is, participants were more likely to have a high score with Safari after completing the trial with that instrument. Conversely, these same participants were more likely to have a high

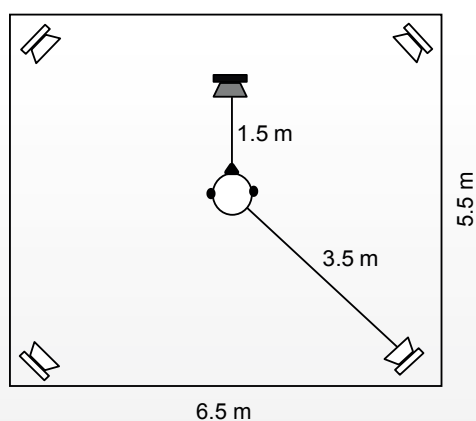


Figure 1: Listening test setup. Speech recognition performance of the participants was tested at an SNR of +3 in reverberation of 650 ms. Target speech was presented at 0 degrees at 65 dBA. Uncorrelated samples of single talker modulated HINT-C noise were presented at 62 dBA from all four corners of the room.

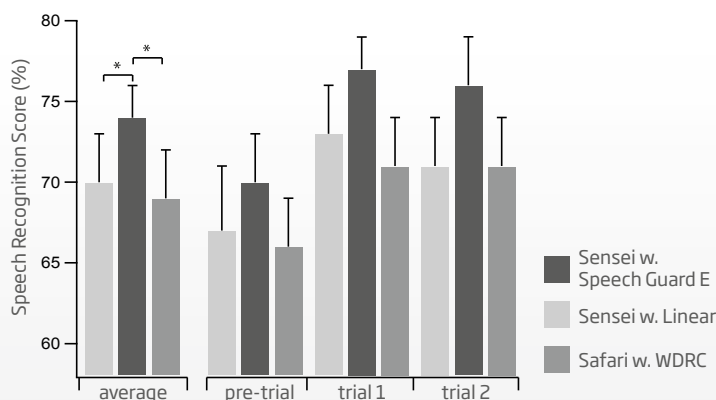


Figure 2: Effect of Sensei, Safari 900 and linear amplification on speech recognition performance. The mean scores \pm error of mean (S.E.M) of all participants are shown as the average across all trials (far left) and for each individual visit: pre-trial, trial 1 and trial 2.

score with Sensei after completing the trial with that device. For example, one participant's performance with Sensei increased 30 percentage points after the trial with the instrument, while the same child's performance when using Safari increased by 16 percentage points after the trial with that instrument. These findings, combined with the lack of significant interaction as a function of trial, support the use of an average of the three tests as the most stable and accurate measure of benefit for each individual child (Fig. 2, left).

While there was an average benefit of approximately 6 percentage points for Speech Guard E compression over syllabic fast compression processing, considerable variability existed within the data. Specifically, the magnitude of the average advantage ranged from -6 to +16 percentage points. To examine individual differences, the average (across all trials) performance advantage for Sensei over Safari in individual listeners was compared to their receptive vocabulary ability as measured by the PPVT. The average age-equivalent receptive vocabulary is plotted against Sensei's advantage over Safari in figure 3. Partial correlation analysis controlling for participant age revealed a significant negative correlation ($r = -0.470$, $p < 0.036$). These findings suggest that the listeners with the poorest recep-

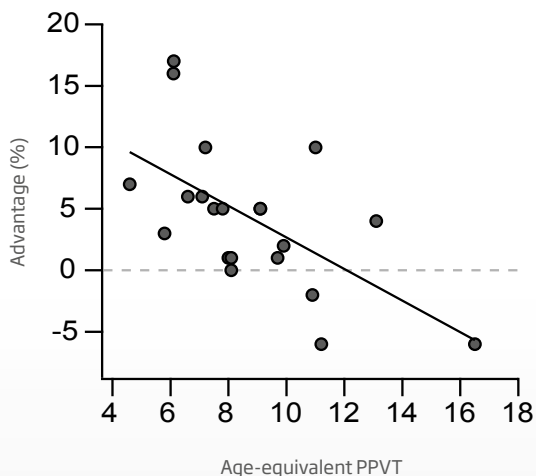


Figure 3: Advantage of Sensei over Safari. Average individual difference between speech recognition scores of Sensei over Safari as a function of the age-equivalent vocabulary scores obtained using the PPVT test. Solid line represents a linear fit to all data points, revealing a significant negative correlation between the Sensei advantage and the vocabulary age.

tive vocabulary are most likely to perform better when fitted with Sensei than when fitted with Safari, even when controlling for age.

Conclusion

The major finding of this study is the superiority in word recognition performance that children attain, on average, when wearing Sensei Pro with Speech Guard E, over Safari with fast acting compression or linear amplification. We have conducted a clinical trial comparing pediatric hearing instruments under controlled lab test setup conditions. It is important to note that the main differences found in performance are probably due to the type of amplitude compression of the hearing instruments. However, the possibility that the sound quality arising from the hardware platforms and Omni settings of the Sensei and Safari instruments could also skewer the outcome cannot be excluded. Overall, the results demonstrate that school age children are sensitive to the specific amplitude compression characteristics implemented in a hearing instrument. Even when presenting speech and noise at moderate levels only, the way in which gain can be varied to best accommodate the elevation of sound seems to have an impact on children's speech recognition. So far, very few studies have addressed the effect of WDRC and linear amplification on children (McCreery et al., 2012). In general, this evidence indicates that audibility and speech recognition are either maintained or improved with fast WDRC compared to linear amplification for pediatric users with mild/moderate-to-severe (Stelmachowicz et al., 1995, Jenstad et al., 1999, Jenstad et al., 2000) and severe-to-profound hearing loss (Boothroyd et al., 1988, Gou and Marcoux, 2002, Marriage and Moore, 2003, Marriage et al., 2005).

To our knowledge, this is the first pediatric study that explores the potential benefits of an amplification compression algorithm that deploys adaptive reaction speed, such as the Oticon Speech Guard E. We show here that, in a realistic acoustic situation (+3 SNR, RT60 = 650 ms), the participants benefited from listening to sound where the intensity modulations of the original speech signal were preserved to a higher degree than can be provided by traditional fast WDRC. Speech Guard E used in Sensei Pro is an amplitude compression system that incorporates the advantages of both linear and non-linear WDRC. This is obtained by setting gain to change slowly (i.e. approaching linear processing) as long as input only changes within a limited range (< 12 dB), but to react rapidly as soon as there is a significant

change in the input (> 12 dB). Our results indicate that this combination of fast and slow compression seems to be an optimal system, designed to maximize preservation of important auditory information while maintaining audibility of the usable information.

The two other hearing instruments with alternative compression strategies that were also tested did not reach the same level of speech recognition as the Sensei instrument. We hypothesize that Safari, with syllabic WDRC, provided the child with sufficient audibility. However, the frequent gain adjustments inherent to fast-acting compressors are more likely to have introduced temporal and spectral distortions in the speech envelope (Plomp, 1988), thus removing the intensity contrasts in the signal and reducing the number of speech cues available to the child. Conversely, with Sensei set in a linear condition (where gain was fixed at all input levels according to gain settings at 65 dB), contrasts in input signals would have been faithfully reflected in the output. Nevertheless, moderate speech has a crest factor of approximately 12 dB and this is likely to have caused some loss of audibility for the weaker components of the target signal, ultimately compromising word recognition.

The field trial indicates that, through experience, children readily adapt to new technology. Irrespective of the instrument or compression technology tested, participants benefited from familiarity with a specific sound. However, the more favorable results achieved by Sensei Pro over Safari were observed both before and after the acclimatization period.

Perspective

Here we have shown that the choice of processing strategy has an immediate effect on the pediatric population. The essential question is: how should pediatric hearing instruments perform in order to optimally support the developing auditory and cognitive system of the child? Within the field of pediatric audiology research, we are only just scratching the surface in terms of answering this question. The major obstacles are a reluctance to venture into demanding pediatric-based testing and limited access to validated pediatric testing tools, as well as recruitment practicalities. At Oticon, it is part of our pediatric mission to help build a body of evidence that will provide valuable information about how the immediate and long-term needs of children with hearing loss can best be met technologically.

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